DETERMINATION OF U-VALUES OF RENDER SYSTEMS SUPPOSED TO WEATHERING

BESTIMMUNG VON U-WERTEN AN BEWITTERTEN AUßEN-PUTZSYSTEMEN

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SUMMARY

The study investigates the U-value development of two different insulation render systems on two different base walls in the context of a large-scale artificial weathering laboratory test, to assess the durability of the render systems. In total four wall partitions of different composition were investigated. A particular focus is the improvement of energy efficiency, centred on the development of an aerogel-based insulation render aimed to improve building envelope performance. The material was developed and characterised in the framework of the Horizon-2020 project "Wall-ACE". U-values were calculated and measured in situ, before and after the durability test, which subjects the envelopes under investigation to extreme weathering conditions. The results show a considerable deterioration of all analysed walls after the test conclusion. However, the found values differ according to the support wall, or to the insulation applied. A change of insulation properties was observed.

ZUSAMMENFASSUNG

Die Studie untersucht die U-Wert-Entwicklung von zwei unterschiedlichen Dämmputzsystemen auf zwei unterschiedlichen Wänden im Rahmen eines groß angelegten Labortests zur künstlichen Bewitterung, um die Haltbarkeit der Putzsysteme zu beurteilen. Insgesamt wurden vier unterschiedlich zusammengesetzte Wandaufbauten untersucht. Ein besonderer Schwerpunkt liegt auf der Verbesserung der Energieeffizienz, die auf der Entwicklung eines auf Aerogel basierenden Isolierputzes zur Verbesserung der Gebäudehülle beruht. Das Material wurde im Rahmen des Horizon-2020-Projekts „Wall-ACE" entwickelt und charakterisiert. Die U-Werte wurden vor und nach dem Haltbarkeitstest in situ berechnet und gemessen, wobei die untersuchten Putze extremen Bewitterungsbedingungen ausgesetzt waren. Die Ergebnisse zeigen eine erhebliche Verschlechterung aller untersuchten Wände nach dem Versuchsende. Die gefundenen Werte unterscheiden sich jedoch je nach Wandaufbau oder aufgebrachter Dämmung. Eine Änderung der Dämmeigenschaften wurde beobachtet.

KEYWORDS: U-value, aerogel, insulation render system, artifical weathering

1. INTRODUCTION

High-energy demand concerning the building stock and its envelope's efficiency are a recurrent research theme. In this sense, an improvement of 27% regarding the buildings energy efficiency is required in the European Union (EU) by 2030 [1], which pushes the minimum required performance levels of the building envelope, and consequently encourages the development of innovative technologies to reach climate objectives at a wide scale.

For instance, the thermal transmittance (U-value) of the exterior walls from residential buildings in Germany showed a reduction over the years. Until 1978, one could find a U-value of 1.15 W/(m²·K), which decreased to 0.64 W/(m²·K) from 1979 to 1994, had an average 0.28 W/(m²·K) from 1995 [2], and the Passive House suggests that the U-value should range between 0.1 and 0.15 W/(m²·K). The U-value is one of the most significant properties to define the energy behaviour of a building envelope. Both theoretical and experimental methods can be used to assess this property. The theoretical U-value is regulated by ISO 6946:2007 [3], based on an electrical analogy and a steady-state condition. Generally, the U-value is widely accessed by means of the heat flow meter method also known as the average method, regulated by ISO 9869-1:2014 [4].

In the framework of the Horizon 2020-project "Wall-ACE" [5] an aerogel-based insulating external render was developed aimed at reducing energy losses through a highly efficient insulation system. The product is as a response to stricter specifications of the building envelope, result of the EU bolder targets. The thermal conductivity of the developed material was measured in steady-state conditions at lab scale using the hot plate method according to EN 12667 [6] ($\lambda = 0.035$ W/mK). However, the product performance may or may not be similar to that measured at small-scale (experiment) conditions because of various reasons associated with design, construction and operation aspects. The inhomogeneity of the materials due to on-site mixing and set-up, besides the effects of air infiltration, moisture migration and temperature differences influence and deteriorates the material properties, which directly affect the energy performance of the building.

Nevertheless, to enter the market and endure in the construction sector, the product must also be evaluated regarding its technical performance under real weather conditions. This includes an assessment of product durability and serviceability, which covers hygrothermal behaviour through large-scale tests. Therefore, this paper concentrates on a large-scale laboratory test (EOTA-wall test) according to DIN EN 16383:2017 [7] to assess the thermal performance of the aerogel-based external render on different substrates. The test is normaly used to assess ETICS[1] systems and serves as a test with harsh conditions. The aim was to determining the development of the U-value because of such harsh conditions, as well to compare the differences between theoretical and onsite U-values measurements. As the EOTA-wall test provides an excellent accelerated exam for durability, assessing the thermal properties of the walls before and after this large-scale test will help to verify the effects on the U-value for the different materials and compositions.

2. METHODS

2.1 LARGE SCALE DURABILITY TEST

a) Investigated walls – construction

A large-scale laboratory test (EOTA-wall test) was performed according to DIN EN 16383:2017 [7] to assess the durability of the two external insulation render developed by partner quick-mix. The test chamber consists of two opposing walls spaced one meter apart, with the plaster systems facing each other.

On one side, the Quick-mix external render was applied, while on the other side another high-tech perlite-based render (Tri-O-Therm) was used as reference material. Each wall is half made up of bricks (LB1 and LB2) and half with concrete blocks (CB1 and CB2), measuring in total 4.0 x 2.1 (length x high), see Fig. 1. Therefore, it can be considered that four walls are under investigation, here named from A to D.

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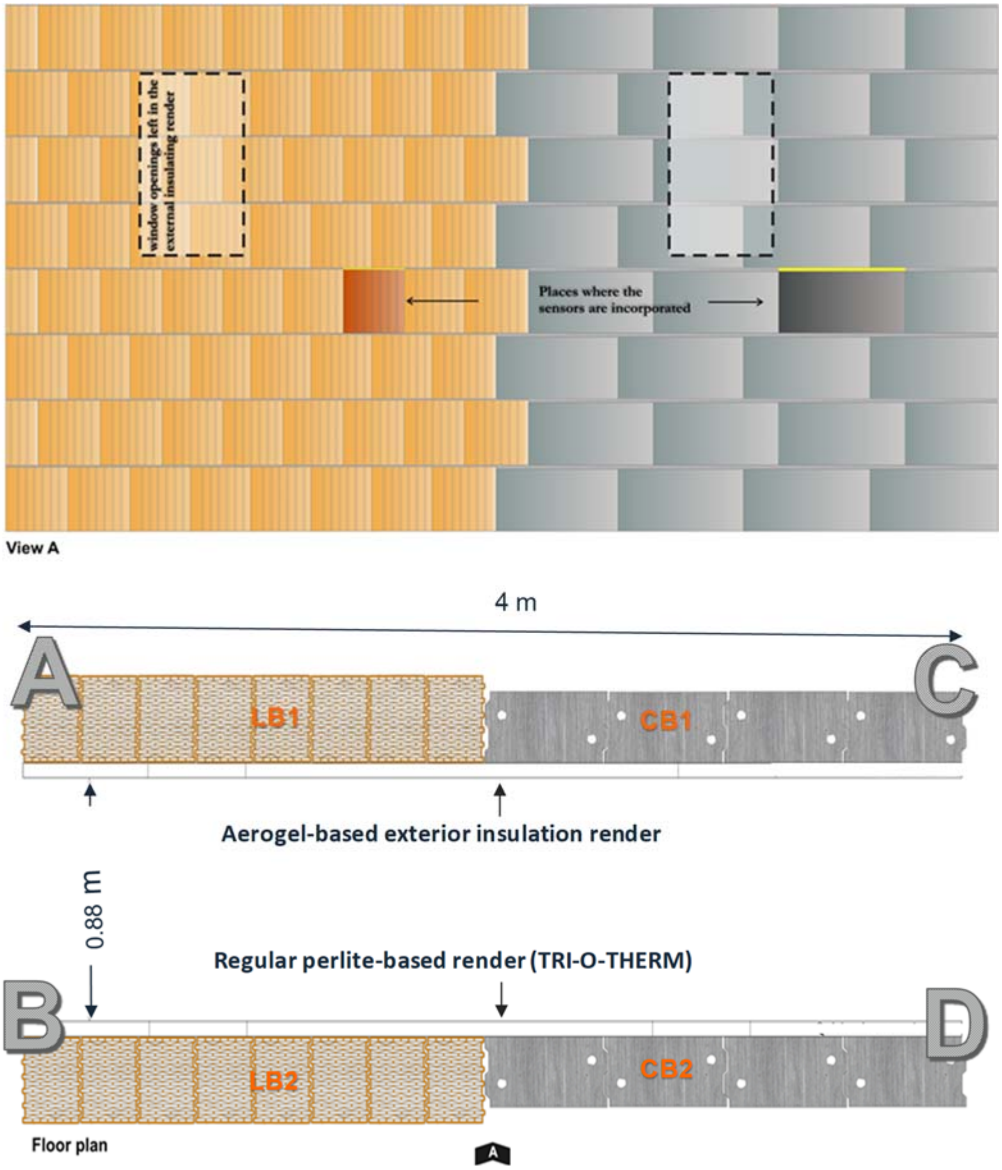
[1] External thermal insulation composite systems (ETICS)



a) Floor plan of the two walls and exterior view from the right side

b) EOTA Wall Test - perspective sketch
The red marks represent the blocks that were equipped with sensors (h = 1,0m)

c) EOTA Wall test rig

Fig. 1: EOTA test rig

Table 1 lists the materials of the tested wall and their thermal conductivity, as well as their R-value and U-value calculated using the theoretical approach from the ISO 6946:2007 [3]. Technical data sheet and design documents provided the information on the building materials and surface resistances. The calculated U-value can be determined as follows:

$$U_D = \frac{1}{R_{si}+\sum_i \frac{t_i}{\lambda_i}+R_{se}}, \tag{1}$$

where U_D represents the calculated U-value evaluated by the theoretical method (W/m².K); t_i is the thickness of the i -th layer (m); λ_i is the thermal conductivity (W/m.K); and R_{si} and are the interior and exterior surface resistances (m².K/W), respectively.

Table 1: Stratigraphies and thermophysical properties of the test wall

Material Layer	Walls	t	λ	ρ	μ	R	U_D	
Internal surface	A-D					0.13		
Brick/	A-B	300	0.1	650	14	3	0.198	A
Concrete Block	C-D	240	0.34	800	8.9	0.7		
Adhesion layer	C-D	2	0.283	1089	11.7	0.007		
Tri-O-Therm/	B-D	60	0.055	268	7.1	1.09	0.232	B
Wall-ACE	A-C	60	0.033	150	2	1.81		
Adhesion layer	A-D	7	0.283	1089	11.7	0.025	0.377	C
Glass fiber mesh	A-D	1.5	0.045	140	700000	0.03		
Finishing layer	A-D	3	0.619	1520	51	0.0048	0.508	D
External surface	A-D					0.04		

t: Thickness (mm); λ: Thermal conductivity (W/m.K); ρ: Density (kg/m³); μ: Water vapour resistance; R: Thermal resistance (m².K/W); U_D: Theoretical thermal resistance (W/m².K)

b) Weathering cycles (Fig. 2)

The large-scale test consists of weathering cycles, where the wall is exposed to the following heat-rain and heat-cold cycles according to paragraph DIN EN 16383: 2017 [7]:

Heat-rain cycles:

The rig is subjected to a series of 80 cycles, comprising the following phases:

1) Heating to 70°C (rise for 1 hour) and maintaining at (70 ± 5)°C and 10 to 30% RH for 2 hours (total of 3 hours),

2) Spraying for 1 hour (water temperature (+ 15 ± 5)°C, amount of water 1.5 l/m² min),

3) Leave for 2 hours (drainage)

Heat-cold cycles:

The rig is exposed to 5 heat/cold cycles of 24 hours comprising the following phases:

1) Exposure to (50 ± 5)°C (rise for 1 hour) and a maximum 30% RH for 7 hours (total of 8 hours),

2) Exposure to (- 20 ± 5)°C (fall for 2 hours) for 14 hours (total of 16 hours)

Rain-heat-cold cycles:

1) Spraying for 8 hours (water temperature (+ 15 ± 5)°C, amount of water 1.5 l/m² min)

2) Exposure to (- 20 ± 5)°C (fall for 2 hours) for 4 hours (total of 6 hours)

3) Heating to (20 ± 5)°C (rise for 1 hour)

4) Spraying for 1 hour (water temperature (+ 15 ± 5)°C, amount of water 1.5 l/m² min)

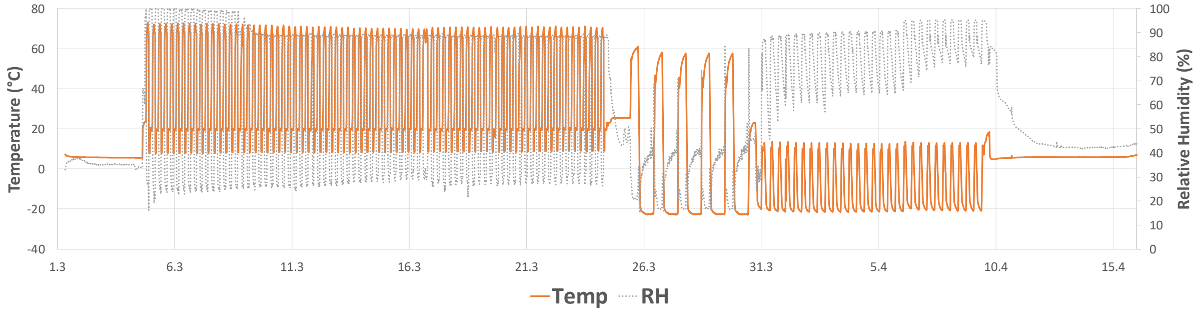
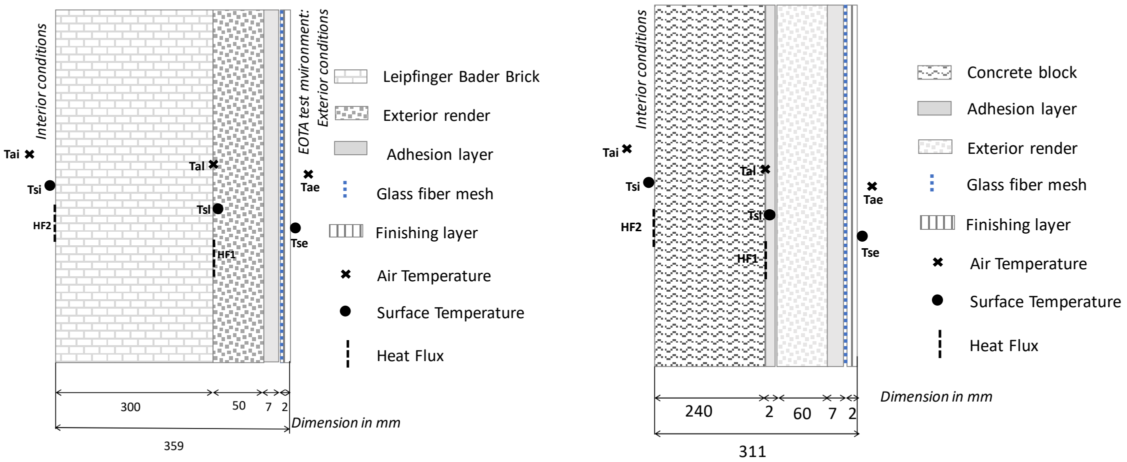


Fig. 2: EOTA Wall weathering cycles and periods when the U-value was estimated (Period 1 and 2)

c) Temperature and heat transfer monitoring

Each of the tested walls was equipped with hygrothermal and heat flow sensors incorporated at the brick and concrete blocks, joints and exterior render layers. The hygrothermal sensor measures temperature and relative humidity. The type used was the Sensirion STH25 [8], which has a small size (3 x 3 x 1.1 mm^3) and a resolution of ± 0.2 K and ± 1.8% RH. As for the heat flow plates the type used was the FQA018C [9]. Each sensor is assigned a calibration value, which corresponds to the heat flow density in W/m² when the plate provides an output of 1mV. The sensors are square with 120 x 120 x 3 mm^3 dimensions and 90 x 90 mm^2 meander size having an accuracy of the calibrated value of 5% at 23°C.

A cross-section of the walls with their corresponding materials and thicknesses as well as the positioning of the different sensors is shown in Fig. 3.



a) Brick walls (A and B)

b) Concrete walls (C and D)

Fig. 3: EOTA test - walls sections (A-D)

The signal of the hygrothermal sensors was measured with sensor nodes developed by Smartmote [10] within the SMooHS project [11]. Data were recorded every 15 minutes, and the nodes sent the measured signals wireless to a base station, which is connected via a LAN to a database. Smartmote further developed a database with a graphical user interface and sensor network within the CETIEB project [12]. In contrast, the measurements from the heat flow sensors were read and recorded by the ALMEMO 5690-2M data acquisition system, and later gathered with the other collected data.

2.2 DATA ANALYSIS: U-VALUE

To have an overview of the walls thermal performance both before, and after the EOTA test (Periods 1 and 2 - Fig. 2), the thermal resistance was analyzed using the average method regulated by ISO 9869-1:2014 [4]. The average method assumes that the U-value can be obtained by dividing the mean density of the heat flow rate through the internal face of the component by the mean temperature (air or surface) difference across the envelope, as shown in Eq. (2).

$$\boldsymbol{U_{AM}} = \frac{\sum_{j=1}^{n} \boldsymbol{q_j}}{\sum_{j=1}^{n} (\boldsymbol{T_{i,j}} - \boldsymbol{T_{e,j}})}, \tag{2}$$

where U_{AM} represents the *U*-value evaluated by the average method (W/m².K); *q* is the density of the heat flow rate (W/m²); T_i and T_e are the interior and exterior air temperatures (°C), respectively; *j* represents the individual measurements and *n* the number of measured data points.

As the outdoor climate is intrinsically dynamic, a long period of averages acquisition is usually required to obtain a reasonable estimation of the equivalent steady-state thermal behaviour of the wall. However, the temperatures inside the EOTA chamber in both periods of the U-value assessment were kept constant to ensure a significant temperature difference (above 12°C) between the wall sides. Thus, as the average method was conducted in quasi-stationary boundary conditions, the test met the convergence conditions soon after attending the first requirement, which should exceed 72 h. The conditions to satisfy the accuracy and the applicability of this method are detailed in ISO 9869-1:2014 [4].

3. RESULTS

The temperature difference across the test walls (ΔT=°C), as well the heat flux (W/m²) measured during the two periods: before and after the EOTA durability test, named as Periods 1 and 2, are presented in Fig. 4.

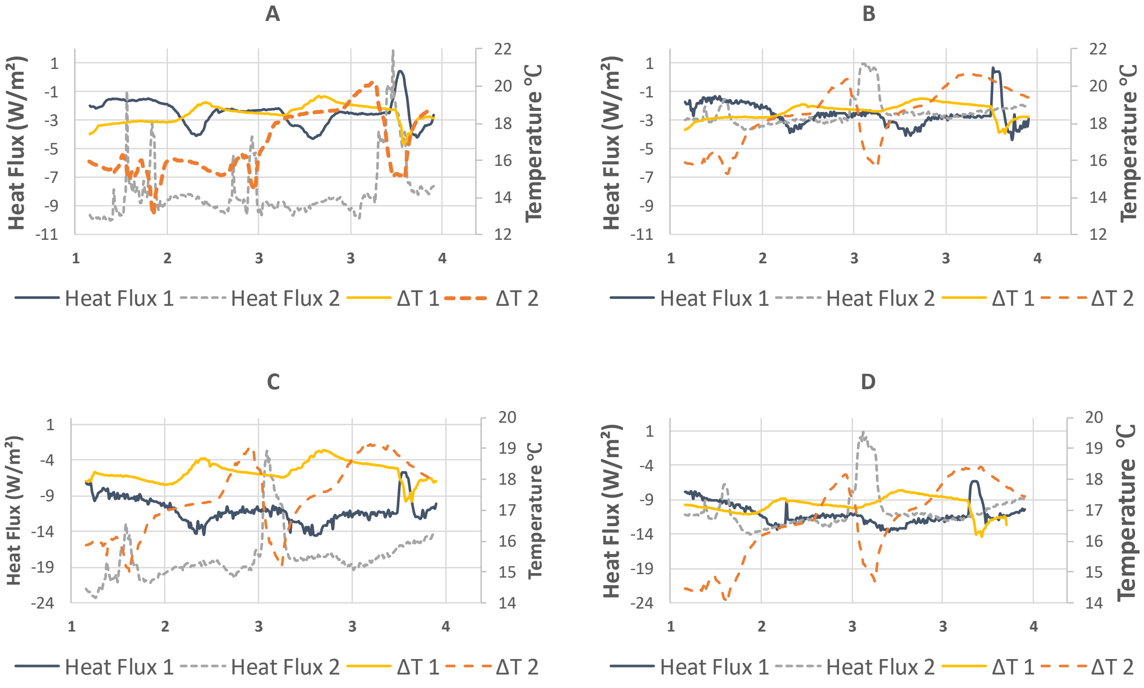


Fig. 4: Temperature difference (°C) and heat flux (W/m²) obtained at the two monitoring periods: (a) Wall A; (b) Wall B; (c) Wall C; (d) Wall D

The graph scales were adjusted in order to correlate the walls with the same substrate (Brick: A and B; Concrete Block: C and D) since to adopt a single scale for the four walls would make it difficult to read the data. As can be seen, the temperature difference between the sides of the analysed walls in the two investigated periods is higher than 15°C. However, a more stable behaviour is observed in the first period (continue yellow/light line), when compared to the second one (dashed orange/dark line); although the environment within the EOTA test chamber was kept in a controlled state in both U-value assessment phases.

As expected, heat flux measurements were higher in concrete walls (C and D) than in brick walls (A and B), due to thermal properties of these materials. The measured values range from -2.4 to -8.5 W/m² on brick walls, while they range from -11.3 to -18.2 on the ones made of concrete blocks.

Comparing the wall with the aerogel-based insulating external render data (Walls A and C), and the reference perlite-based render Tri-O-Therm (Walls B and D), one can note a more significant difference between the first and second period measurements on walls A and C, which have more spaced lines. Differently, walls B and D have more grouped lines, showing consistent behaviour between the two measurements periods, which directly affects the measured U-values.

In this sense, Fig. 5 shows the evolution of the U-value on the investigated walls over the total test duration (>72 hours) regarding the two periods analysed.

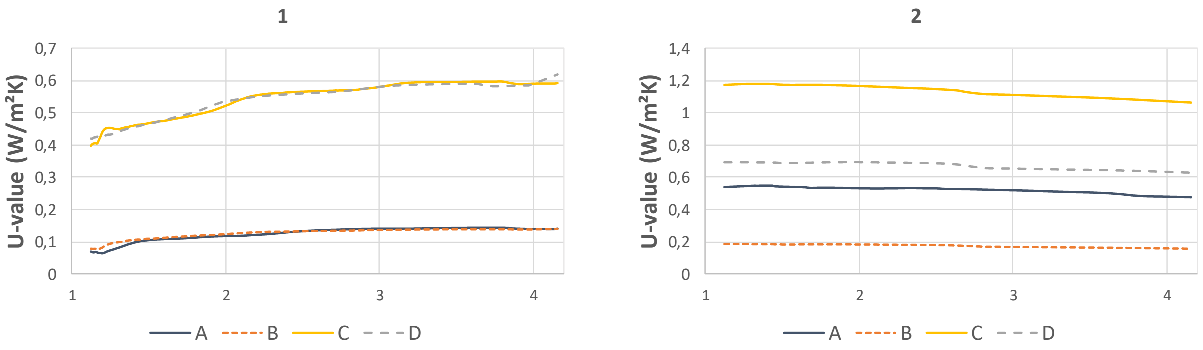


Fig. 5: Evolution of in situ U-value: (a) Period 1; (b) Period 2

The in situ U-value tended to stabilize after the 48th hours of the test, and like the heat flux measurements, while in the first period (Fig. 5a), before the durability test, the walls with the same substrate appear to have a similar behaviour; the same does not repeat in the second moment of the U-value evaluation (Fig. 5b). At the end of Period 1 the walls with aerogel present a subtle better U-value performance. Nevertheless, the difference between the U-values obtained is small, being 0.01 and 0.03 W/(m²·K) for the brick (A-B) and concrete walls (C-D), respectively. At the end of the second period, the aerogel walls do not show a better result, and the difference rises for the brick and concrete walls to 0.34 and 0.46 W/(m²·K) respectively, as shown in Fig. 6.

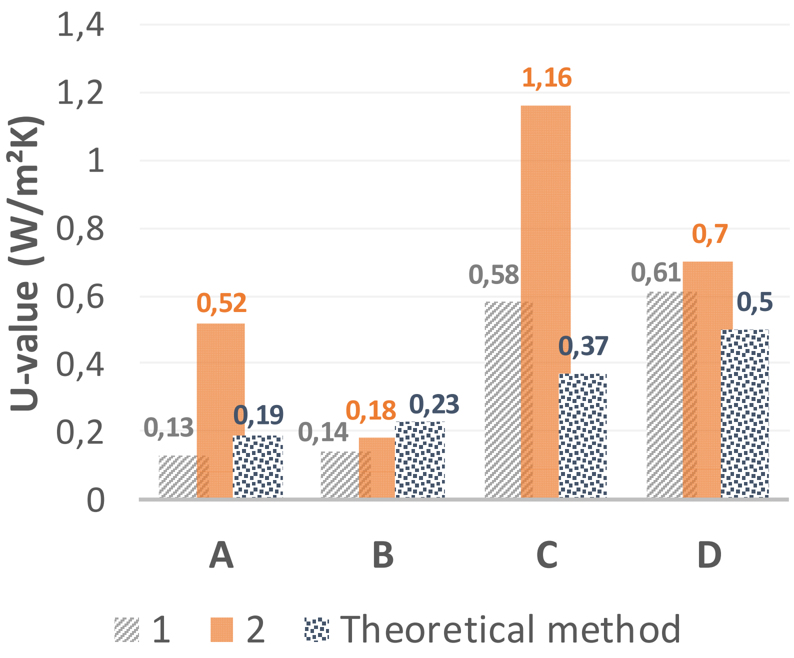


Fig. 6: Calculated/measured U-values of the investigated walls

These results show that the thermal performance of the investigated walls deteriorated considerably after the EOTA test, a result that reflects the effect of external/climatic conditions on the building envelope efficiency. At the same time, there is a greater effect of the harsh test conditions on the walls with aerogel exterior insulation render. While walls B and D, which are the reference walls with the perlite-based render Tri-O-Therm, worsened by an average of 20%, wall C had its U-value almost doubled, and wall A, more than tripled. This is due to the suction of water of the insulating renders adopted in the experiment. The aerogel render has a higher water uptake compared to the perlite render. However, this characteristic may lead to the degradation of the constructive component thermal performance; the supporting surface render system should provide a stronger support. Further development is needed.

Furthermore, some differences can also be noted between the in situ U-values and the theoretical U-values calculated according to the ISO 6946 standard. The values found are between those estimated in the first and the second evaluation period, before and after the EOTA test, showing that these values not accurately represent the in situ ones.

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