EXTENDED ABSTRACT

Water vapor permeability of mortars produced with lightweight and insulating aggregates

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1 Introduction

In exterior, renders fulfill several applications as waterproofing and masonry protection, hygrothermal and acoustic comfort, decorative functions and so on (Flores-Colen, 2009). In theory, a waterproofing coat should perform a low capillarity coefficient and liquid water permeability and a high water vapor permeability, that allows the evaporation of water as a result of precipitation and water from condensation produced in interior of buildings by normal habitability and machines work. The use of thermal and insulating renders aims at some benefits shared with external insulation systems just as: i) correction of thermal bridges and the reduction of internal condensation; ii) improved thermal performance in summer (using thermal inertia of exterior walls); iii) doesn't reduce interior area; iv) ease application to support (Frade *et al.*, 2010). Proportional to their thickness, these mortars should be apply with other types of insulation, in order to obtain higher thermal resistance of facades (Veiga *et al.*, 2012). That way, housing conditions and buildings' energy efficiency could be improved by thermal renders application.

According to EN 998-1 (CEN, 2010), lightweight mortars (LW) should present apparent density lower than 1200 kg/m^3, compressive strength between 0,4 and 7,5 N/mm^2 and capillarity water absorption that varies depending on the mortar composition. On the other hand, water vapor diffusion resistance factor (μ) has no declared value for lightweight mortars (LW). However, if lightweight mortars intend to be considered with thermal performance enhanced (T), the same coefficient must be equal or less than 15, according the water vapor permeability test for mortars (EN 1015-19 (CEN, 2008)). In addition, mortars with improved thermal performance (T) should have compressive strength in the range between 0,4 to 5 N/mm^2, thermal conductivity less than 0,2 W/m.K and maximum capillary water absorption of 0,4 Kg/m^2.min^{0,5}.

The use of lightweight aggregates in mortars is directly associated with thermal insulation capacities. The existence of voids promotes low thermal transmissions. Silica aerogel is a nanostructured aggregate characterized by an open pore structure with 95% air content and small dimensions (10 to 100nm). In this way, this aggregate presents low bulk densities (<500 kg/m^3), low thermal conductivity (0,01 to 0,02 W/m.K), non-reactive and incombustible and excellent acoustic properties. On the fresh state, its workability is affected due to hydrophobic nature, that difficult the connection between aggregate and water present on mixture. It should be noted, this is still an aggregate with high capillary coefficient and high initial cost where final strengths are reduced (Flores-Colen *et al.*, 2013). Cork is a natural material with interesting properties (Gil, 2007). The closed cellular porous structure with waterproofed thin walls to liquids and gases and are filled with a gas similar to air. These characteristics ensure to the material low bulk density (60 to 70 kg/m^3), thermal insulation capacities (close to 0,04 W/m.K) and significant compressive capacities in order to reduce vibrations and impacts.

Expanded clay is obtained from natural clays heating (Moravia *et al.*, 2006) with brown color, approximately 90% of total volume is closed porous network due to gas expansion on heating process, where the bulk density (300 to 700 kg/m^3) is lower than bulk density of the material that has given rise to. Chemically and not being spoiled by fungi or parasites, this product is widly used in civil construction since it has thermal conductivity in order to 0,10 W/m.K which provides a higher thermal insulation solution.

The incorporated additions on mortars, according EMO (EMO, 2001) and based on EN 998 (CEN, 2010), are organic or inorganic substances which are added to the blend, in small amounts, in order to modify the mortars properties both in fresh and hardening state. These additions can function to improve certain characteristics such as workability, water vapor permeability, capillary water absorption, compressive strength, etc (Seabra *et al.*, 2007). Surfactants added to mixture induce the formation of small air bubbles (10nm to 1mm) that improve the dispersion of the hydrophobic aerogel within the binder. That way, mortars are more workable and homogeneous decreasing their water content with some advantages like cracking resistence, waterproofing capacity, cut in cappilary water absorption, increased resistance to ice-defrost cycles, and so on.

The cellulose ether as a water retainer, promotes a complete coating hydration ensuring a good adhesion to support, more open time to driyng process, improved water transport and limiting cracking by faster driyng (Pourchez *et al.*, 2009). This addition retains water inside the mortar making the acquous phase more viscuous.

On mortars and concretes, resins are used in order to uniformize the mixture and improve workability. They should be added together with aggregates and binder and after with water. As the water is consumed in cement hydratation, the polymers form a layer on non-hydrateded cement grains and surronding aggregates in order to ensuring their connection with remaining mixture. There are four groups of polymers where powder resin belongs to dispersible powder polymers.

Civil construction binders are divided in two groups: i) Inorganic binders which includes *Portland* cement, aerial lime, hydraulic lime, and gypsum; ii) Organic binders such as synthetic resins and animal or vegetable bitumen. Within the inorganic binders there are other two groups designated by air binders (aerial lime and gypsum) and hydraulic binders (*Portland* cement and hydraulic lime). Literature reports that the higher dosage of cement present in the mixture, the more compact became the mortar with lower porosity (Veiga *et al.,* 1990). The excess of water resulting of binders hydratation, allows the pores formation of mortars in the hardened state. In addition, the matrix pores and interface binder/aggregates pores are due essencialy to higher water/binder ratios. Mosquera *et al.* (2004) verified that a higher dosage of cement, in substitution of aerial lime, promotes a different porous network, with a reduced total pores volume and with no conexion (closed porosity).

The moisture phenomena transfer can occur on liquid and vapor state, simultaneously, sequentially or isolated (Freitas, 1992). On liquid state, water penetrates in the mortar and runs through its pores network by capillarity forces. This process is explained by an attraction force between liquid and solid higher than the force of liquid cohesion. On gas state, water vapor diffusion is a direct consequence of a pressure gradient between two environments, which depends of hygrothermal characteristics. The evaporation is one of the mechanisms of drying process and consists in the transformation of liquid water into vapor water through capillarity and diffusion processes. Drying is intrinsically related with water vapor permeability because renders should be permeable enough in order to expel the inside moisture to the periphery over the course of the time. According to the Fick's Law, water vapor permeability is defined as the portion of vapor flow (kg) that passes through a material, per unit of thickness (m), time (s) and surface (m^2) when a differential-pressure exists between the two specimen sides. The water vapor diffusion resistance factor (μ) is a adimensional parameter of the material, useful to compare water vapor permeability between mortars, in this case. This parameter indicate, how many times, water vapor permeability of a mortar is higher than water vapor permeability of an air layer with the same thickness under similar conditions.

2 Experimental campaign

The experimental campaign was carried out including reference mortars with silica sand and lightweight mortars of silica aerogel, perlite, expanded clay and expanded cork granules. The evaluation of mortars' behavior with lightweight aggregates had as mainly objectives:

- Quantitative evaluation of water vapor diffusion resistance factor (μ) according the EN 1015-19 (CEN, 2008) that specify water vapor permeability test, in several lightweight and silica sand mortars;
- Influence evaluation of lightweight aggregates (silica aerogel, perlite, expanded clay and cork granules), admixtures (resin, cellulose ether and surfactants) and binder (cement, fly ash and aerial lime) on water vapor diffusion resistance factor of formulated mortars;
- Correlation of water vapor diffusion resistance factor according to bulk density, shape/size of test pieces, elapsed test time, side of test piece in contact with outside environment.

As the Table 1 illustrates, the aggregates and binder, excepted in two mortars, are the same with a varied range of additions incorporated. All produced mortars contain cellulose ether (0,075% or 0,15% of the cement mass), surfactants (0,5%; 1,0%; 2,0% or 3,0% of cement mass) and only four mortars have resin included on their compositions. On Table 2, all mortars are formulated with CEM 32,5 and only one aggregate included, whereas mortar "A" is the only one that any additions are incorporated. Finally, Table 3 describe the binder variation (cement, fly ash and limestone) in two ranges of aggregates (silica sand or aerogel). On this case, aerogel mortars are the only one that additions were included. After production, mortars were placed inside a climate chamber during 28 days. In the first two days, mortars were exposed to hygrothermal conditions of 20ºC ± 2 ºC and 95 % ± 5% of relative humidity.

Table 1 – Render compositions to evaluation of additions influence

Binder (mass %)	Aggregate (volume %)	Additions (% of CEM mass)			ID.
		EC	TA	R	
50%CEM(42,5)+40% C+10%CV	60%AG+20%GC+15%AE +5%P	0,075	2,000		$I^{P0,075EC2TA}$
	60%AG+20%GC+20%AE	0,075	2,000	2,000	$I^{0,075EC2TA}$
		0,150	2,000		$I^{0,15EC2TA}$
		0,075	3,000		$I^{0,075EC3TA}$
		0,150	3,000		$I^{0,15EC3TA}$
		0,075	0,500		$I^{0,075EC3TA}$
		0,075	0,500	2,000	$I^{0,075EC0,5TA2R}$
	60%AG+20%GC+15%AE +5%P	0,075	0,500	2,000	$I^{P0,075EC0,5TA2R}$
	60%AG+20%GC+20%AE	0,150	0,500		$I^{0,15EC0,5TA}$
		0,075	1,000		$I^{0,075EC1TA}$
		0,150	1,000		$I^{0,15EC1TA}$
		0,075	0,500	4,000	$I^{0,075EC0,5TA4R}$

According this, mortars were produced with quadrangular specimens (40 x 40mm) with 10mm of thickness and circular specimens (D = 160mm) with 20mm of thickness. The evaluation of aggregates and binder influence was carried out with two specimens of each type while the evaluation of additions was carried out with one specimen of quadrangular type. Each acronym present in the following formulations is given by the following products:

- ***CEM (32,5 or 42,5)*** *– Cement CEM II B/L class 32,5N or 42.5N;* ***C*** *– Aerial lime;* ***A*** *– Silica sand "mesquita type 1";* ***CV*** *– Fly ash; AG – Silica aerogel;* ***GC*** *– Cork expanded granules;* ***AE*** *– Expanded clay;* ***P*** *– Perlite;* ***EC*** *– Cellulose ether;* ***TA*** *– Surfactants;* ***R*** *– Resin powder.*

Table 2 - Render compositions to evaluation of aggregates influence

Binder (mass %)	Aggregate (volume %)	Additions (% CEM mass)	Additions (% AG mass)	ID.
		EC	TA	
100%CEM (32,5)	100%A			**A**
	100%GC	0,075	0,05	**GC**
	100%AE	0,075	0,05	**AE**
	100%AG	0,075	0,5	**AG**

After this, until reach the 28 days of cure, mortars were exposed to 20 ºC ± 2 ºC and 50 % ± 5% of relative humidity. Subsequently, the test was prepared through dry cup method. The analysis considers two environments with relative humidity and controlled temperatures which cause a vapor flow through the test specimens due to pressure gradient installed, from the higher RH to lower RH created by silica gel (Figure 1a) inside the cup. The results obtained by water vapor transfer are quantified by gained weight as function of time (kg/s). The set (specimen + solution + cup) daily recording is carried out until the flow stabilizes. On the first week, the recording is twice a day and then, once daily until flow stabilizes.

Table 3 - Render compositions to evaluation of binder influence

Binder (mass %)	Aggregate (volume %)	Additions (% CEM mass)	Additions (% AG mass)	ID.
		EC	TA	
80%CEM(32,5)+20%CV	100%A	-		**A**^{80CEM20CV}
50%CEM(32,5)+50%CV				**A**^{50CEM50CV}
50%CEM(32,5)+40%C+10%CV				**A**^{50CEM40C10CV}
80%CEM(32,5)+20%CV	100%AG	0,075	0,5	**AG**^{80CEM20CV}
50%CEM(32,5)+50%CV		0,075	0,5	**AG**^{50CEM50CV}
50%CEM(32,5)+40%C+10%CV		0,075	0,5	**AG**^{50CEM40C10CV}

The quadrangular specimens test was realized inside a sealed box with hygrothermal conditions recreated by a saline solution (approx. 71,5%) at the bottom of the box (Figure 1d) while the circular specimens were tested inside a climate chamber of IST Construction Laboratory, under similar conditions. The quadrangular specimens test was carried out with two testing-set specimens – “glass test” and “cover test” to evaluate the proper function of the mastic sealer that wrap specimens and the covers capacity to seal the small boxes, respectively (Figure 1b and 1c). The results, through graphical analysis, are obtained by the slope value of the linear regression for each mortar, that represents the increasing of mass per unit of time (kg/s):

$$\Lambda = \frac{m}{A \times \Delta p}$$

Where:

- Λ – Water vapor permeance [kg/(s.m^2.Pa)]

- m – Slope value of linear regression which reflect the water vapor flow (Kg/s)
- A – surface area (m^2)
- Δp – Differential pressure between environments (Pa)

With water vapor permeance (Λ), water vapor permeability (W_{vp}) could be calculated through:

$$W_{vp} = \Lambda . t$$

Where:

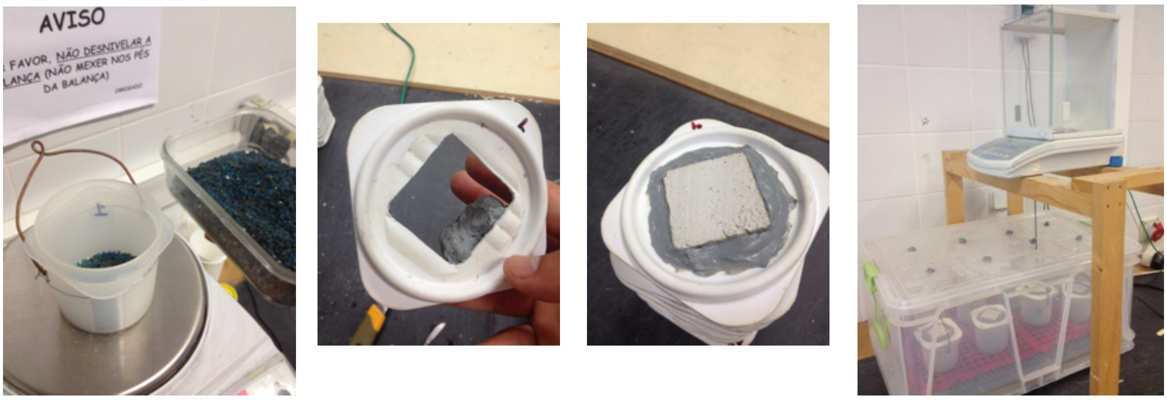
- t – specimen thickness (m)
- W_{vp} – water vapor permeability [kg/(s.m.Pa)]

Finally, water vapor permeability (W_{vp}) enables to obtain the water vapor diffusion resistance factor (μ), which are the adimensional parameter for each mortar, used to compare the water vapor permeability:

$$\mu = \frac{Wvp_{ar}}{W_{vp}}$$

Where:

- Wvp_{ar} – diffusion coefficient for water vapor in air at atmospheric pressure (approx. $1{,}95\times10^{-10}$) [Kg/(s.m.Pa)].



a) **b**) **c**) **d**)

Figure 1 – a) silica aerogel; b) mastic and cover; c) specimen with mastic applied; d) test set

3 Results

The water vapor permeability results were evaluated according standards and mixture components presented in mortars. Due to specificity of the present dissertation, factors that influencing the experimental method were also analyzed as elapsed test time, bulk density of mortars, shape of test specimens, hygrothermal conditions and specimen face in contact with external environment. The water vapor permeability values obtained for silica sand mortars and other lightweight aggregates (perlite, cork granules and expanded clay) served as a comparative basis to aerogel mortars, which were the aim of this dissertation.

3.1 Test method

The elapsed time on water vapor permeability test is one of the main factors to be considered on calculation of water vapor diffusion resistance factor (μ) of mortars. The increasing test time leads to a superior μ value, since the slope value of linear regression is lower, and water vapor permeability decreases. The increased mass of the set is more significant on the first days of the test than in the last ones. The hygrothermal conditions present by boundary environments of the test specimen are quite different and tends to approach rapidly at the beginning. Once conditions tend to equalize this velocity decreases. Taking into account that mortars specimens weren't tested simultaneously, and the test time should be adjusted according to a comparison analysis between mortars, in this study, the test time is given considering the interval between 140 to 168h.

It was found that, all mortars with quadrangular shapes have higher bulk density than circular shapes of the same mortars (Figure 2). The Silica sand mortars on quadrangular specimens presented an increased bulk density (between 5 and 12%) compared to circular specimens. In comparison, this relation presented a further increase to aerogel specimens (between 21 and 23%). The same compact method on both shapes easily densify a smaller volume (quadrangular specimens), which brings into less porosity, and therefore, a minor water vapor permeability and a superior μ value for mortars (Figure 3).

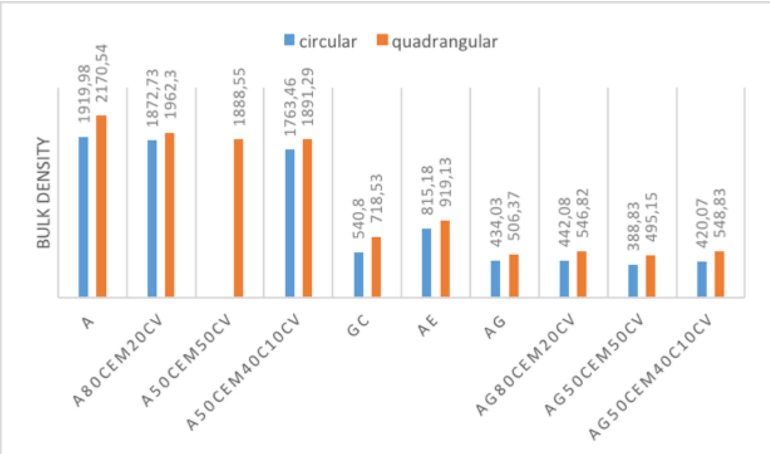


Figure 2 – Mortars Bulk density

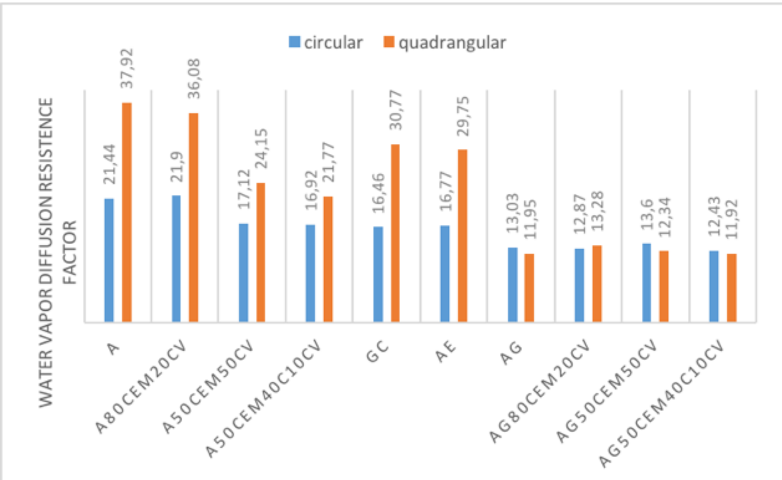


Figure 3 – Mortars water vapor diffusion resistance factor (μ)

For silica sand mortars on quadrangular specimens, the water vapor diffusion resistance factor increased between 22 and 47% compared to the circular ones. On the other hand, for aerogel mortars the μ value was practically the same, since mortars present a lighter and fragile structure.

Regarding the test conditions, it was found that temperature and relative humidity were more stable on quadrangular specimens, carried out on watertight seal boxes, than in circular test specimens, carried out inside a climate chamber of the civil construction laboratory, which is non-exclusive access. However, due to the higher volume of circular specimens, this point is attenuated since the water vapor permeability results are closer to values obtained by other authors.

3.2 Comparison analysis

On this chapter, mortars are analyzed considering the influence of additions, aggregates and binders presented on formulated mixtures. The water vapor permeability test results are shown on Table 4, considering a large combination of additions included on mortars.

Table 4 – Additions influence - μ values; elasticity modulus and thermal conductivity

ID	Quadrangular specimens (40x40x10mm)			
	μ	Elapsed test time (h)	Elasticity modulus (MPa)	Thermal conductivity (W/m.K)
$I^{0,15EC1TA}$	**15,10**	167,42	420,08	0,09
$I^{0,075EC0,5TA4R}$	**18,04**		666,32	0,10
$I^{0,15EC0,5TA}$	**15,29**		377,98	0,10
$I^{0,075EC1TA}$	**15,14**		403,10	0,09
$I^{0,075EC0,5TA2R}$	**14,87**		368,62	0,09
$I^{0,075EC0,5TA}$	**16,09**		604,43	0,10
$I^{0,075EC2TA2R}$	**14,85**	167,37	240,58	0,13
$I^{P0,075EC0,5TA2R}$	**16,77**		401,09	0,09
$I^{P0,075EC2TA}$	**13,26**		73,46	0,12
$I^{0,15EC2TA}$	**12,71**		173,55	0,12
$I^{0,075EC3TA}$	**14,98**		95,43	0,14
$I^{0,15EC3TA}$	**13,40**		63,81	0,12

In this way, results shown that higher dosages of surfactants (TA) and cellulose ether (EC) added on mortars promotes an increase of water vapor permeability (lower μ value). On the other hand, mixtures with higher dosages of resin (R) promotes a lower water vapor permeability on mortars (higher μ value). The EC addition leads to an agglomeration of voids on fresh state. When the paste is hardening, these grouped voids forms larger voids promoting the water vapor diffusion through the mortar (Pourchez *et al.*, 2009). According to TA addition, with respect to the stable bonding of binder paste and hydrophobic aggregates (aerogel), was verified an air bubbles formation between aggregate and binder interface. These voids leads to an increased number of macropores on harden mortars (Júlio *et al*, 2016). The included R on mixtures leads to a decreasing water vapor permeability of mortars as expected, since this addition acts like a bond aggent between the non hydrated aggregates and cement particles and the remaining binder paste. It should be mentioned that, this analysis was carried out considering the simultanious use of additions amounts which, promotes an open porous structure and, consequently, improve the water vapor permeability on mortars. All produced mortars shown thermal conductivity values lower than 0,2 (W.m.K) and almost half of them set water vapor diffusion resistance factor (μ) lower than 15. According to EN 998-1 (CEN, 2010), all mortars perform improved thermal behavior and almost half are thermal mortars (T).

On Table 5, water vapor permeability results are presented considering the aggregates influence on mortars mixtures. Results exhibit an increasing water vapor permeability on mortars with lightweight aggregates. Comparing to the reference mortar ("A"), "GC", "AE" and "AG" mortars shown 22%, 23% and 39% more water vapor permeability since they are lightweight mortars and, such as, more porous. Some authors found that, incorporation of lightweight aggregates by sand substitution enhanced mortars thermal behavior, since open porosity increase (Kearsley *and al.*, 2001; Flores-Colen, 2009), which leads to a reduced μ value of mortars. According to EN 998-1 (CEN, 2010), only aerogel mortar is presented as thermal (T) since μ value is under 15.

Table 5 – Water vapor permeability test results – aggregates influence

ID	Circular specimens (160mm diameter and 20mm thickness)			
	μ	S_d	μ (average)	Elapsed test time (h)
A	22,21	0,444	**21,44**	166,12
	20,67	0,413		
AE	17,31	0,355	**16,46**	
	15,60	0,318		
GC	17,00	0,354	**16,77**	
	16,53	0,336		
AG	13,23	0,265	**13,03**	140,68
	12,82	0,263		

Finally, the results of water vapor permeability, according to binder paste included on mortars, are shown on Table 6. Comparing sand mortars to the reference mortar "A", it was found that increasing fly ash dosages promotes a decreasing on μ value (around 20%). However, the same wasn´t verified for "$A^{80CEM20CV}$", despite of Júlio *et al.* (2016) had verified a upper total pores volume for these mortars. Considering aerogel mortars, the inclusion of fly ash produced a minor improvement (1 to 5%) of water vapor permeability, except to "$AG^{50CEM50CV}$" since the result wasn't expected too. The contradictory values could be related to water/cement ratio and the scale factor that is enough smaller to compare (μ values of 12.43 and 13.60). According some authors, the increased porosity and therefore, higher water vapor permeability, on sand mortars with fly ash inclusion by cement substitution arise from the higher water/binder ratio to obtain the necessary paste workability instead of fly ash own inclusion (Fernandes, 2005).

For aerial lime inclusion by cement substitution, water vapor permeability on mortars increase (Mosquera *et al.*, 2004). These improvements were verified to sand mortars as well to aerogel mortars where water vapor permeability shown an increase of 21% and 5%, respectively. The water vapor permeability to sand mortars with fly ash and aerial lime presented closer results to lightweight aggregates, which could be a good way to improve mortars thermal behavior. Considering thermal mortars (T), once again, only aerogel mortars shown these results.

Table 6 – Water vapor permeability test results – binder paste influence

ID	Circular specimens (160mm diameter and 20mm thickness)			
	μ	S_d	μ (average)	Elapsed test time (h)
$AG^{80CEM20CV}$	12,96	0,268	**12,87**	140,68
	12,77	0,262		
$AG^{50CEM50CV}$	13,98	0,292	**13,60**	
	13,22	0,275		
$AG^{50CEM40C10CV}$	12,93	0,257	**12,43**	
	11,93	0,241		
$A^{80CEM20CV}$	22,50	0,463	**21,90**	166,12
	21,30	0,447		
$A^{50CEM50CV}$	17,61	0,361	**17,12**	
	16,62	0,337		
$A^{50CEM40C10CV}$	16,59	0,347	**16,92**	140,68
	17,24	0,362		

4 Conclusions

This work allows to understand the influence of mixture components considering mortars thermal behavior and water vapor diffusion through mortars. In this way, water vapor permeability tests were produced in several mortars established that:

- Elapsed time should be adjusted considering a comparative analysis and results are obtained in the range of 140 and 168 hours;
- A linear relationship was obtained between water vapor diffusion resistance factor and bulk density of mortars;
- Hygrothermal conditions should be as stable as possible but didn't affect mortars specimens with higher volumes;
- Surfactants and cellulose ether incorporation improved mortars thermal behavior since more voids are present on mixture leading to mortars with higher water vapor permeability;
- Aerial lime and fly ash inclusion by cement substitution allows to reach μ values of sand mortars quite similar to μ values of mortars with lightweight aggregates;
- Lightweight mortars shown an improved thermal behavior compared to reference mortars since, there was an increment of water vapor permeability (lower μ values);
- Aerogel mortars presented the best results which allows to consider half of them as thermal mortars, considering μ values lower than 15.

5 References

CEN. (2008). *"Methods of test for mortar for mansory - Part 19: Determination of water vapour permeability of hardened rendering and plastering mortars". EN 1015 - 19.* Brussels: Comité Européen de Normalisation.

CEN. (2010). "Specification for mortar for masory - Part 1: Rendering and plastering mortar". EN 998-1.

EMO. (2001). *"EMOdico - dicionário Técnico".* European Mortar Industry Organization. 3ª edição.

Fernandes, V., Silva, L., Ferreira, V. M., & Labrincha, J. (2005, Abril). "Influence of the kneading water content in the behaviour of single-coat mortars". *Cement and Concrete Research*, pp. 1900 – 1908.

Flores-Colen. (2009). *"Metodologia de Avaliação do desempenho em serviço de fachadas rebocadas na óptica da manutenção predictiva".* Dissertação para a obtenção do Grau de Doutor em Engenharia Civil, Instituto Superior Técnico, Lisboa.

Flores-Colen, I., de Brito, J., & Soares, A. (2013). *"A Nanotecnologia Aplicada às Argamassas de Revestimento".* Construlink 34, vol 11.

Frade, D., Gonçalves, P., Nascimento, R., & Sequeira, A. (2010). "Argamassas de reboco com características térmicas". *3º Congresso Português de Argamassas de Construção.* Lisboa.

Freitas, V. (1992). *"Transferência de Humidade em Paredes de Edifícios - Análise do Fenómeno de Interface".* Dissertação para obtenção do grau de Doutor em Engenharia Civil, Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Civil, Porto.

Gil, L. (2007). "Manual Técnico: Cortiça Como Material De Construção".

Júlio, M. D., Soares, A., Ilharco, L. M., Flores-Colen, I., & Brito, J. D. (2016, Julho 30). "Aerogel-based renders with lightweight aggregates: Correlation between molecular/pore structure and performance". *Construction and Building Materials, Vol. 124*, pp. 485-495.

Júlio, M. D., Soares, A., Ilharco, L. M., Flores-Colen, I., & Brito, J. D. (2016, Junho 21). "Silica-based aerogels as aggregates for cement-based thermal renders". *Cement and Concrete Composites, Vol. 72*, pp. 309-318.

Kearsley, E., & Wainwright, P. (2001). "Porosity and permeability of foamed concrete". In *Cement and Concrete Research* (Vol. 31, pp. 805-812). Elsevier.

Mosquera, M. J., Silva, B., Prieto, B., & Ruiz-Herrera, E. (2004, Outubro 13). "Addition of cement to lime-based mortars: Effect on pore structure and vapor transport". *Cement and Concrete research, Vol. 36*, pp. 1635 - 1642.

Pourchez, J., Ruot, B., Debayle, J., Pourchez, E., & Grosseau, P. (2009). "Some aspects of cellulose ethers influence on water transport and porous structure of cement-based materials". In *"Cement and Concrete Research"* (Vol. 40, pp. 242-252). France: Elsevier.

Veiga, M., & Faria, P. (1990). "Revestimentos de Ligantes Minerais e Mistos com base em Cimento, Cal e Resina Sintética". Lisboa: LNEC.

Veiga, M., & Malanho, S. (2012). "ETICS e argamassas térmicas: novos desafios de desempenho e sustentabilidade". *Seminário TEKTÓNICA.* Lisboa: LNEC.