TÉCNICO LISBOA CERIS Civil Engineering Research and Innovation for Sustainability

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THERMAL CONDUCTIVITY OF COMPRESSED EARTH BLOCKS PRODUCED WITH RECYCLED CEMENT

M. Glória Gomes[1*], J. Alexandre Bogas[1], S. Real[1], R. Cruz[1]

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REPÚBLICA PORTUGUESA

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1. INTRODUCTION

PROJECT Eco+RCEB - ECO-EFFICIENT RECYCLED CEMENT COMPRESSED EARTH BLOCKS

This work is financed by the Portuguese Foundation for Science and Technology (FCT) , under the project **Eco+RCEB - Eco-efficient recycled cement compressed earth blocks (PTDC/ECI-CON/0704/2021)**

Fundação para a Ciência e a Tecnologia

REPÚBLICA PORTUGUESA

https://cdwvalue.eu/project-ecorceb

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OUTLINE

1. Introduction
2. Materials and methods
3. Experimental results and discussion
4. Conclusions

1. INTRODUCTION

Earth building material

has been exploited in construction for centuries due to its:

- production simplicity and high material abundance
- low embodied energy and carbon footprint
- high sound insulation
- high thermal inertia and higroscopicity and low thermal conductivity

©Francois Xavier Marit/Afp/Getty Images

https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a1627-10-stunning-examples-of-earth-architecture-around-the-world

Great Mosque of Djenné (built in 1907, Mali, Africa)

Energy efficient envelope that can ensure a good **hygrothermal comfort** of occupants with low energy demand

1. INTRODUCTION

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- high thermal inertia and higroscopicity, low thermal conductivity and good hygrothermal comfort

fell into disuse, especially after the 19th century, with the:

- development of new construction techniques
- use of alternative building materials

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A renewed interest in earth as a building material emerged with the recent:

- concerns of more sustainable construction materials
- the emergence of new construction techniques, namely mechanical and chemical stabilisation, to improve their performance

1. INTRODUCTION

Earth building material

Some examples: a. Single-family house, Beja, Portugal. Arch. Bartolomeu Costa Cabral (http://eartharchitecture.org/); b. Chapel of Reconciliation, Germany. Rudolf Reiterman and Peter Sassenrath (www.mimoa.eu); c. Nk'Mip Desert Interpretive Center, Canada. HBBH Architects (http://www.inspirationgreen.com/); d. School of Fine Arts, Oaxaca, Mexico. Arch. Maurício Rocha (http://www.world-architects.com/); e. House in Victoria, Australia. Arch. Jolson Architecture Interiors (http://www.archdaily.com/.

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1. INTRODUCTION

Earth building material

Of the various earth construction techniques, such as ancient rammed earth and molded adobes, **compressed earth blocks (CEB)** are expected to be most easily accepted by modern society since:

- the improved mechanical properties (mech. stabilization)
- greater manufacturing control

To overcome the CEB water susceptibility and poor durability, cement can be used in CEB production (chemical stabilization) as it improves:

- volume stability
- strength
- durability

A renewed interest in earth as a building material emerged with the recent:

- concerns of more sustainable construction materials
- the emergence of new construction techniques, namely mechanical and chemical stabilisation, to improve their performance (structural strength, water resistance and dimensional stability)

1. INTRODUCTION

WHAT HAPPEN TO THE HYGROTHERMAL PERFORMANCE OF CEB?

BUT

cement manufacture is **high carbon-polluting**

↓

need to adopt **more sustainable** practices in the concrete sector => **low-carbon thermoactivated recycled cement (RC)** produced from recycled construction and demolition waste materials

GOAL

This study aims to:

- analyse the **influence of the incorporation of RC** in the **thermal conductivity and hygroscopic sorption properties of compressed earth blocks** (CEB)
- **compare with** reference **CEB not stabilised or** produced **with equal Portland cement content**

2. MATERIALS AND METHODS

Designation	Soil[a] (%)	PORTLAND CEMENT PC[b] (%)	RECYCLED CEMENT RC[b] (%)	Water[b] (%)
PC10	90	10	-	15.0
RC10	90	-	10	16.5
PC5	95	5	-	15.2
RC5	95	-	5	16.5
RC2PC8	90	8	2	15.0
RC5PC5	90	5	5	15.5
UCEB	100	-	-	14.4

[a] Soil with 4% humidity; [b] By weight of solids (soil+stabiliser); [c] Total w/b, including water absorbed by soil

5-10% stabiliser with 0, 20, 50, 100% RC

reference unstabilised CEB

7 different CEB compositions:

- 2 with 5% and 4 with 10% of stabiliser (Portland cement –PC and recycled cement – RC)
- 1 reference unstabilised CEB (UCEB), for comparison purposes

2. MATERIALS AND METHODS

	CLAYEY SAND SOIL	PORTLAND CEMENT	RECYCLED CEMENT	
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The soil is composed of 20.1% gravel, 48.4% sand and 31.5% silt/clay

- organic matter content <1%
- density 2.7 g/cm^3
- optimum moisture content 16%
- liquid limit 30%
- plasticity limit 22%
- plasticity index 8%

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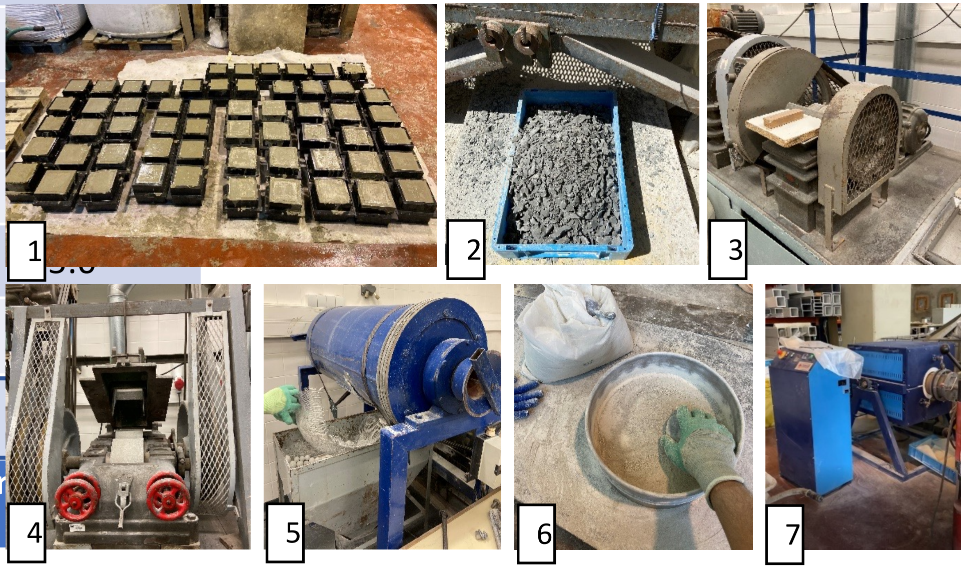
RECYCLED CEMENT PRODUCTION



1 - Production of the cement specimens; 2 - Large jaw crusher (< 7 cm); 3 - Small jaw crusher (< 3 cm); 4 - Roller mill (< 1 cm); 5 - Ball mill (< 250 µm); 6 – Sieving; 7 - Thermoactivation at 650 °C

2. MATERIALS AND METHODS

CEB PRODUCTION (220x105x60 mm) | Manual press of about 3.5MPa

Spraying | Sieving | Mixing | Compacting | Curing

- CEB were subjected to 7 days of wet curing whereas UCEB underwent dry curing (7 days covered with a plastic film).
- After this period, the CEB were air cured under laboratory conditions up to testing age.

2. MATERIALS AND METHODS

Experimental campaign

7 different CEB compositions:
6 stabilised with PC and RC (PC10; RC10; PC5; RC5; RC2PC8; RC5PC5) and **1 unstabilised** (UCEB)

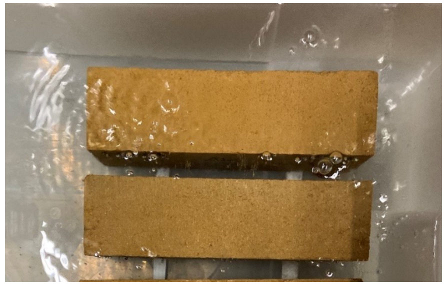
Thermophysical and hygroscopic sorption properties

- Thermal conductivity (λ)
- Density (ρ)
- Moisture content (ψ)
- Sorption and desorption curves

Dry state

Higroscopic range

Over-higroscopic range



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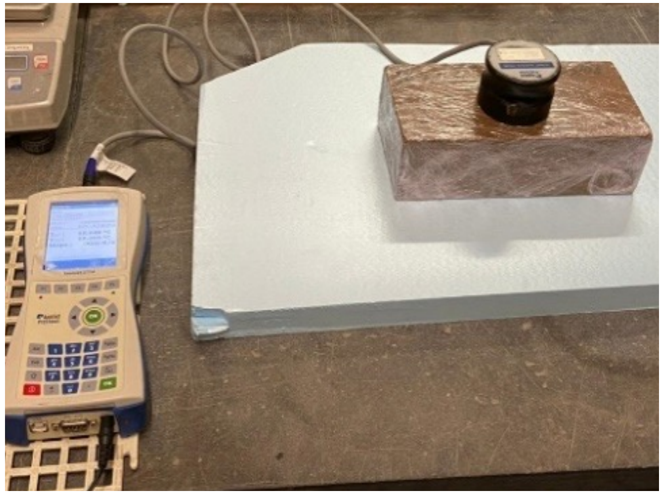
THERMAL TESTS

- **ISOMET 2114** – Modified transient pulse method (ASTM D5334:2014; ASTM D5930:2009)
- Surface probe



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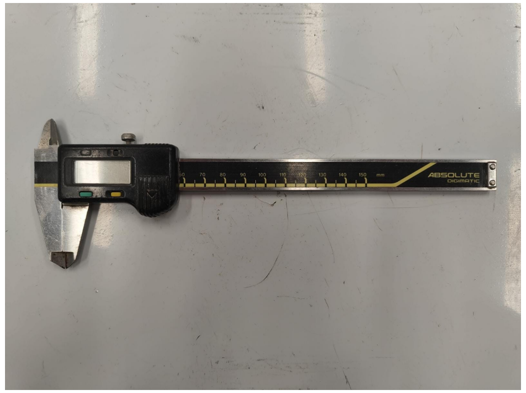
DENSITY AND MOISTURE CONTENT

- High precision weighting scale
- Micrometer
- The **density** was determined by the geometric method (EN 1015-10)
- **Moisture content** volume by volume



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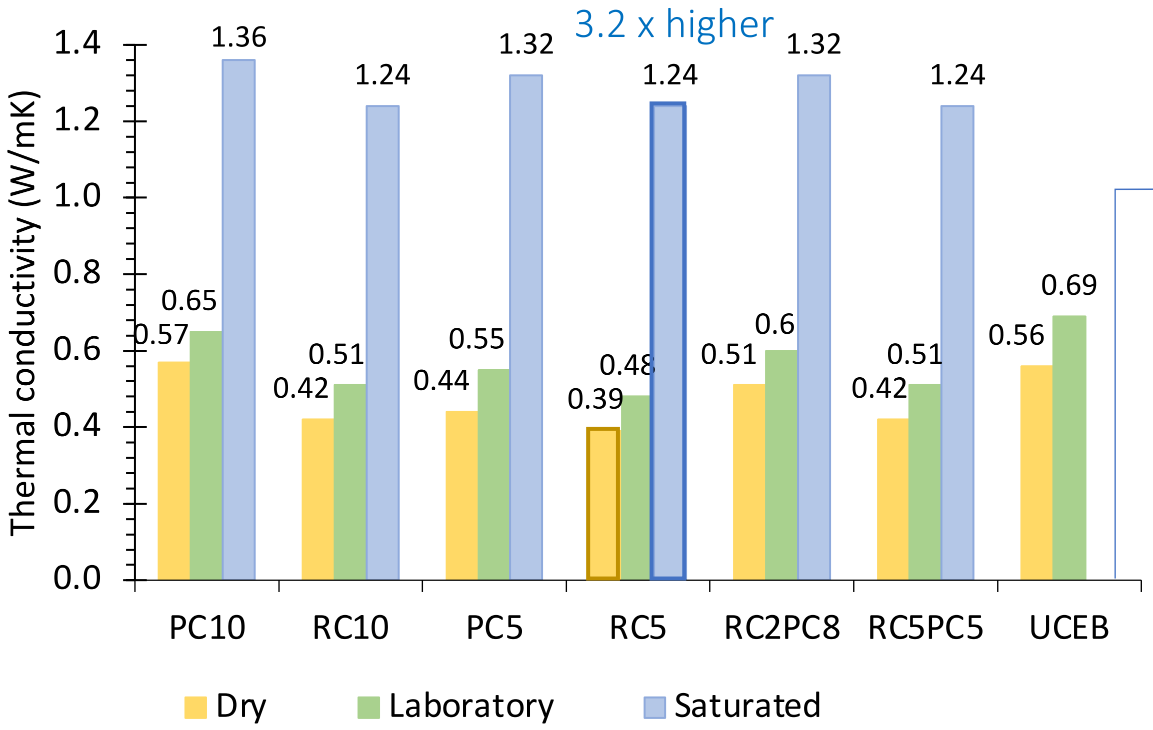
SORPTION AND DESORPTION CURVES

- CLIMATIC CHAMBER METHOD (EN ISO 12571)
- 35%, 65%, 80% and 95% relative humidity (RH), at constant temperature (T=23 ± 0.5ºC)
- 0% RH - oven drying the samples at 60ºC±5ºC until constant mass

3. RESULTS AND DISCUSSION

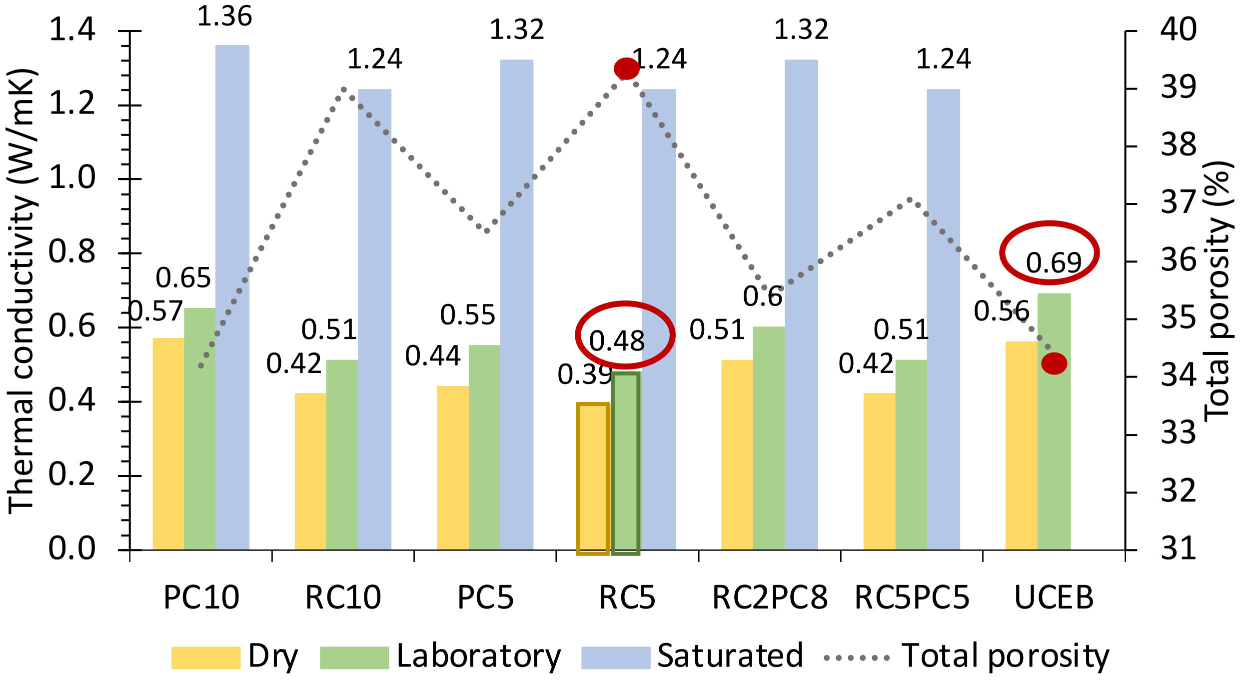


Unstabilised CEB disintegrated after a few hours submerged in water.

Not tested in the saturated state

- Thermal conductivity tended to increase with the moisture content
- Thermal conductivity of the CEB in the saturated state was more than twice as high as those in the dry state, with this difference being maximized in the blocks with RC incorporation
- The effect of the moisture content was more relevant to the thermal conductivity than other parameters, such as the type and amount of stabiliser

3. RESULTS AND DISCUSSION

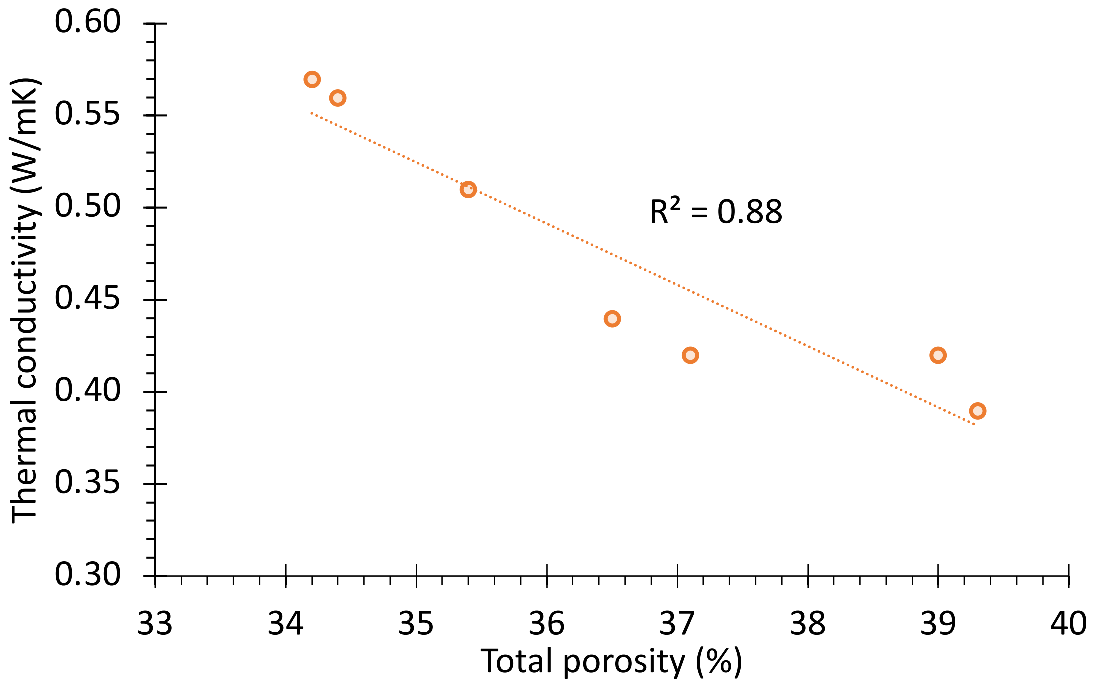


U-value ≈ 2.3 W/m^2K

$U_{CEB} \approx U_{hollow\ brick}$ (11 cm)

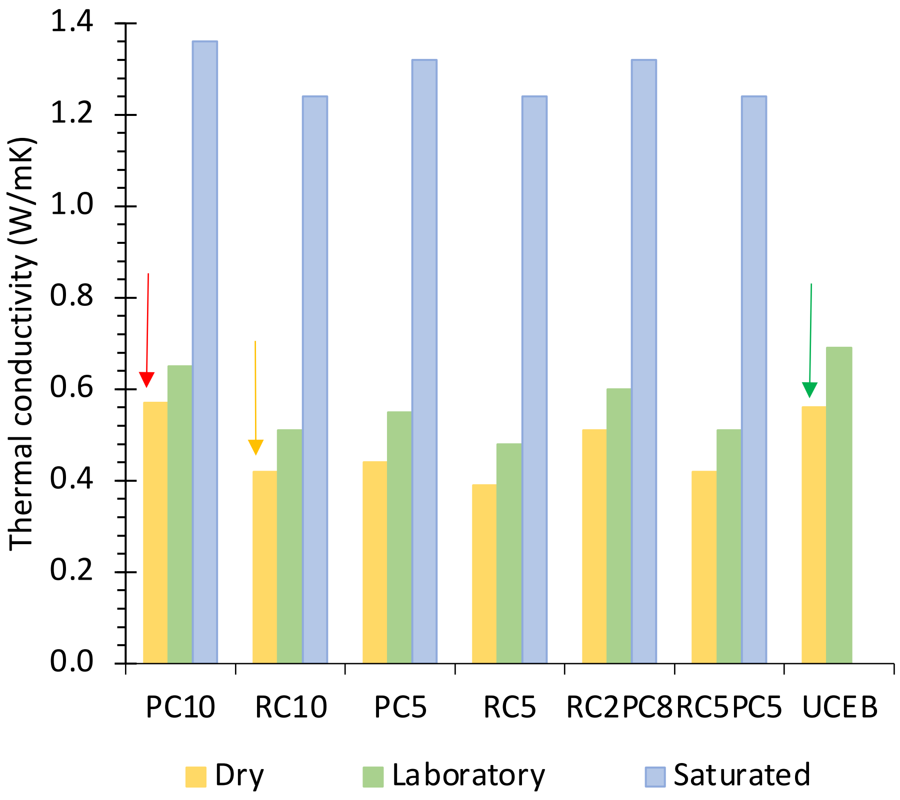
- Oven-dried CEB showed 12% to 20% lower thermal conductivity than air-curing CEB (water eliminated during air-curing)
- The incorporation of RC in CEB decreases the thermal conductivity up to 30% (higher porosity associated to the CEB with RC, produced with a higher amount of water to account for the higher water demand and porosity of this stabiliser)

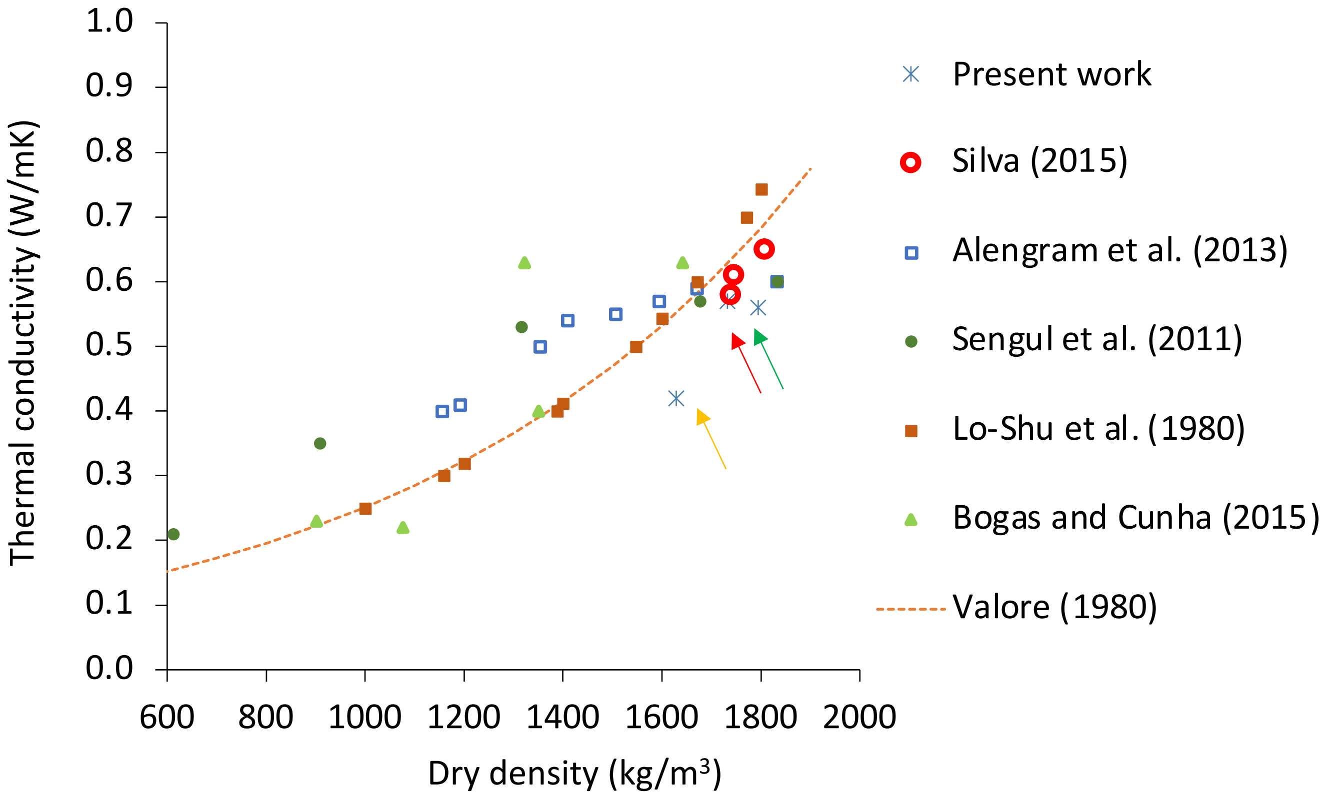
3. RESULTS AND DISCUSSION



- A high correlation between the thermal conductivity in the dry state with the total porosity of CEB

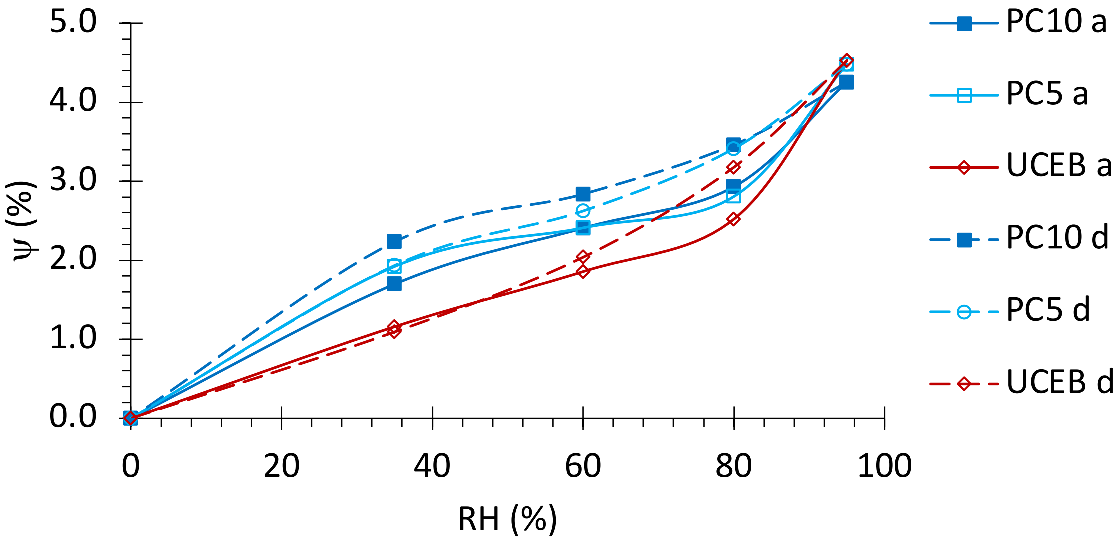
3. RESULTS AND DISCUSSION



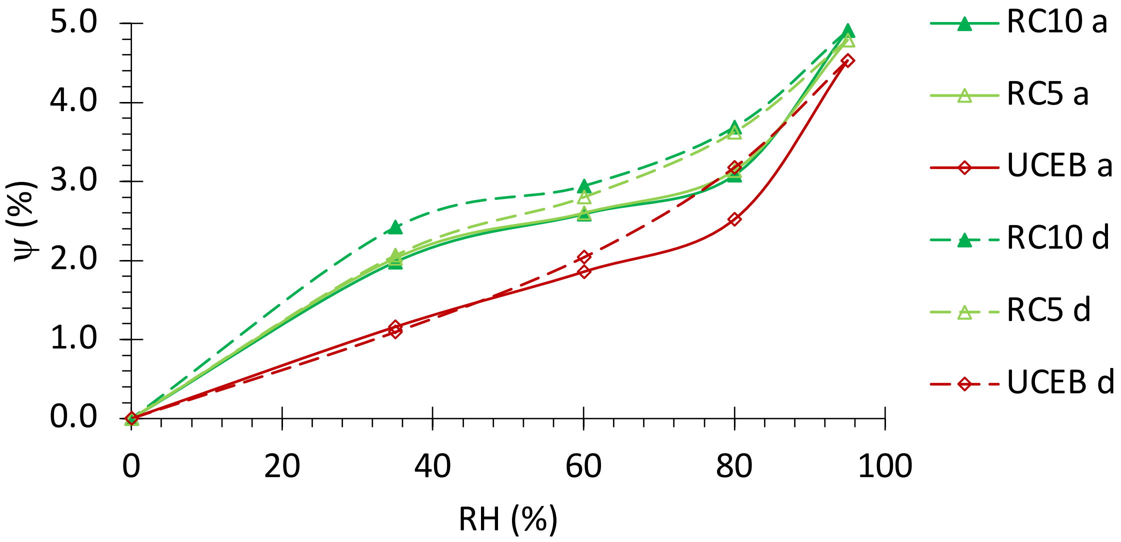


- Thermal conductivity of CEBs is also directly related to their density

3. RESULTS AND DISCUSSION



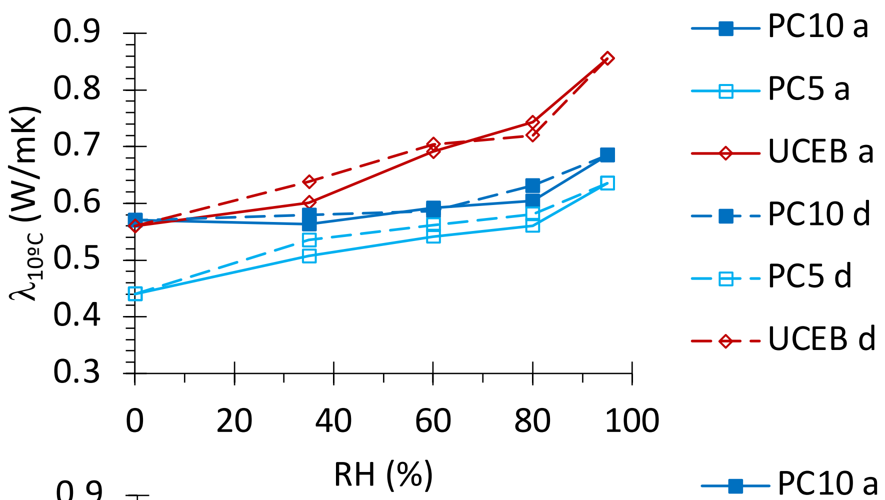
PC 0%, 5%, 10% vs. UCEB (a- sorption; d-desorption)

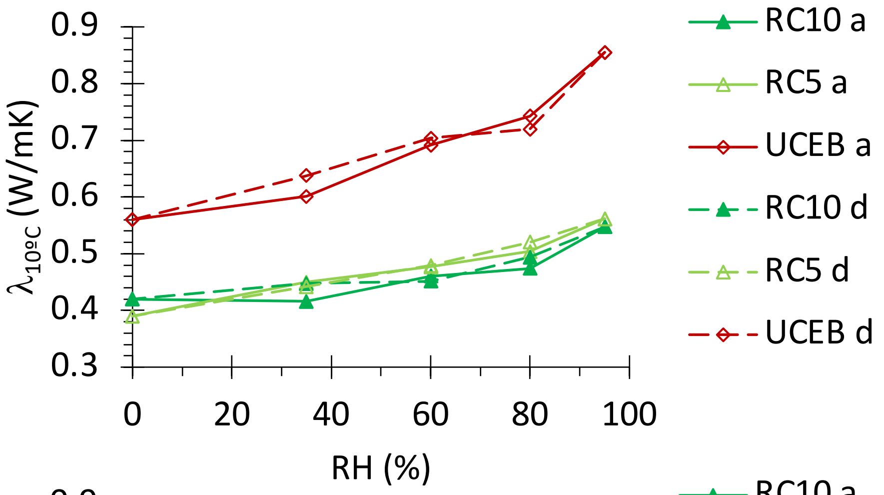


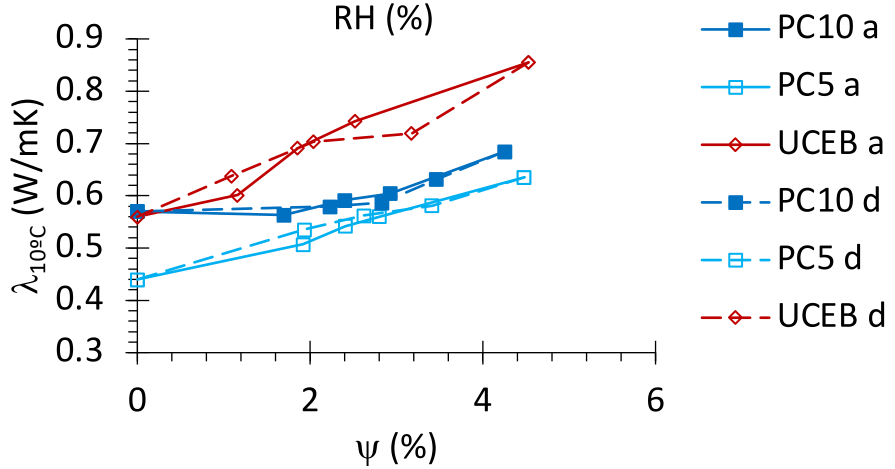
RC 0%, 5%, 10% vs. UCEB (a- sorption; d-desorption)

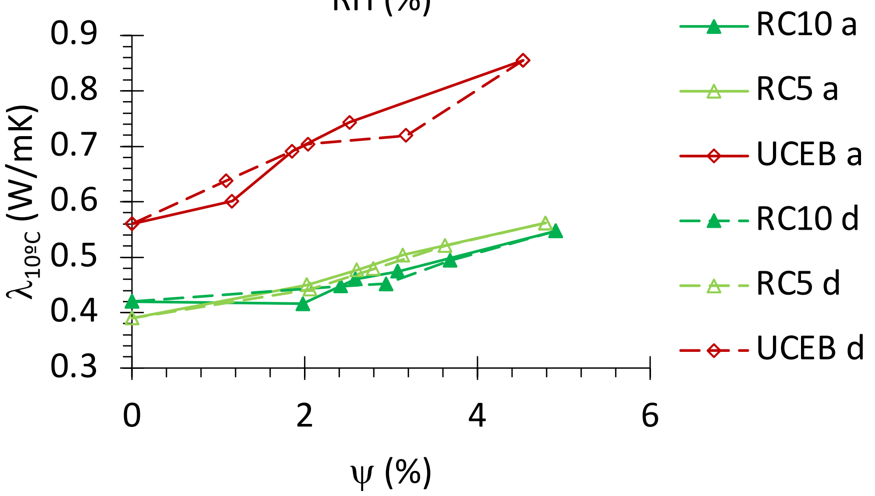
- Stabilised CEBs present a higher adsorption of water vapour compared to the UCEB
- There is sorption hysteresis, with desorption giving higher equilibrium moisture contents than sorption at equal ambient climate conditions

3. RESULTS AND DISCUSSION



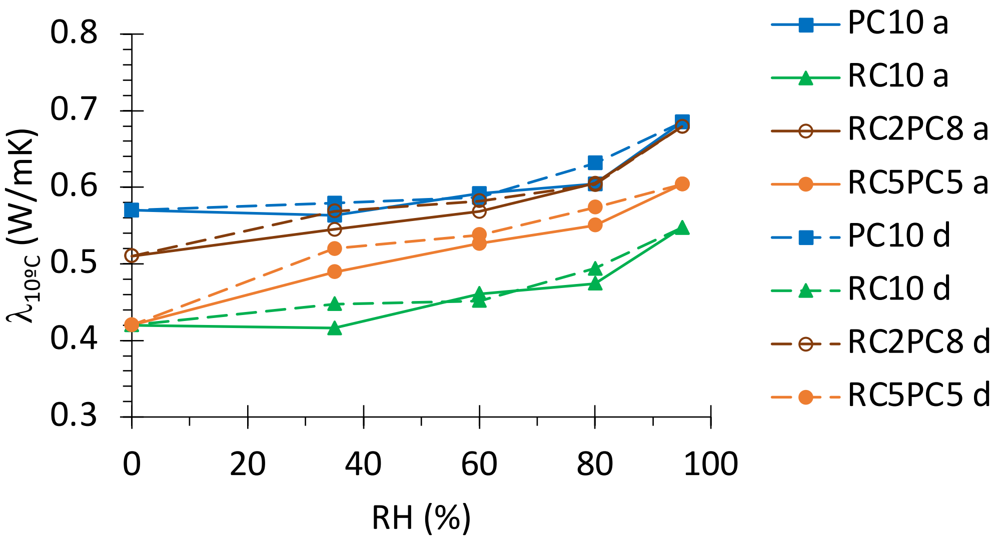


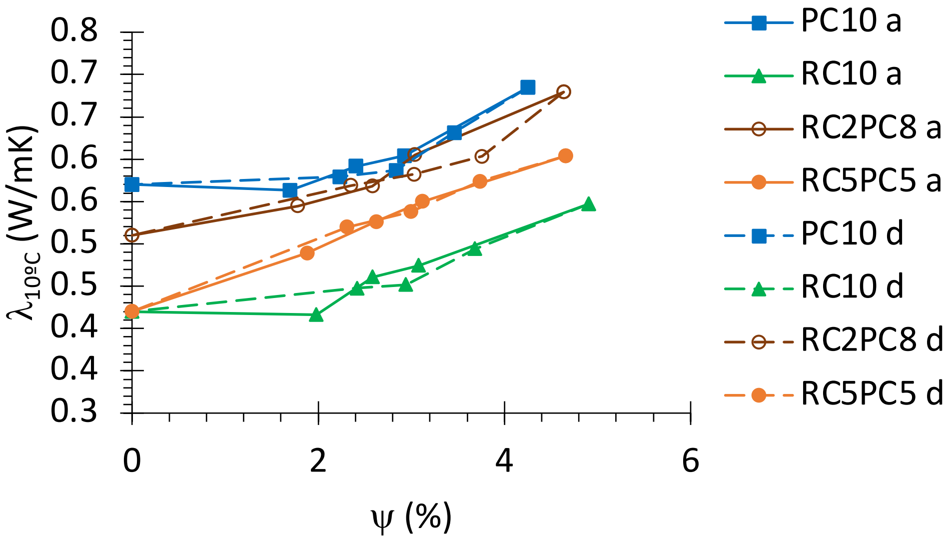




- The higher moisture content and relative humidity, the greater the thermal conductivity of CEB, showing the importance of assessing the moisture content in service conditions

3. RESULTS AND DISCUSSION





10% of stabiliser (RC, PC or RC+PC)

- Thermal conductivity of stabilised CEBs with RC is lower than with PC but tend to be more affected by the moisture content, because air in a higher volume of voids is replaced by the more conductive water
- The more significant increase of thermal conductivity occurs for relative humidity higher than 80% (micro capillary pores filled with water)

7. CONCLUSIONS

- An experimental campaign was performed to assess the thermophysical and hygroscopic sorption properties of 7 different compressed earth blocks (6 stabilised with PC and RC and 1 unstabilised), for dry, hygroscopic and over-hygroscopic ranges
- Thermal conductivity, density, moisture content and sorption and desorption curves were determined
- Thermal conductivity of CEBs increases with both density and moisture content
- Stabilised CEBs present, in general, a higher adsorption of water vapour compared to the UCEB
- The CEB stabilised with RC displayed lower thermal conductivities (up to 30%) than UCEB or CEB stabilised with PC but is more affected by the moisture content (higher porosity)
- RC is a more eco-efficient alternative to PC that can be successfully incorporated in CEBs showing additional benefits in the thermal performance of the CEBs.

THANK YOU FOR YOUR ATTENTION

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