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Case study

Thermal properties of adobe employed in Peruvian rural areas: Experimental results and numerical simulation of a traditional bio-composite material

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ABSTRACT

The adobe is a widely used traditional material in popular constructions in rural areas of Peru and more generally in Andean countries. In order to increase comfort and energy efficiency of constructions, it is necessary to better know the thermal characteristics of the adobe, seen as a bio-composite material.

Different adobes have been studied. Effective thermal conductivity and heat capacity were measured by means of a hot parallel-plate method. Density was estimated using a pycnometer and measuring physical dimensions and mass of each sample, which allowed the calculation of thermal effusivity and diffusivity. Some numerical simulation results displayed good agreement with experimental outcomes. The work presented here has implications for future studies of this traditional building material and might potentially help solving the problem of sustainable housing.

1. Introduction

Soil as mud bricks has been used in the construction of dwellings for thousands of years [1,2], and approximately 30% of the world's current population still lives in earthen structures [3]. It is affordable, environmentally friendly and abundantly available. Mud bricks have been used as a building material around the world, especially in developing countries [4,5]. In Peru, earth is an important element in people's life as a material and symbolic resource; mud brick is known as adobe. Chan Chan is America's greatest pre-Columbian town in northern Peru built in adobe, a building technique which is still used in many parts of the Peruvian rural areas. [6,7]. It is well known that mud bricks present low thermal conductivity [8–11] and could be a good option for thermal insulation. However, adobe constructions not properly designed and strengthened might present a deficient response when subjected to seismic actions, suffering severe structural damage and often reaching collapse [12,13]. Therefore mechanical properties of abode bricks have been extensively studied in Peru [14,15]. Several efforts to raise awareness in the population have been implemented so they build earthquake resistant houses. A standard

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Nomenclature

e	Thickness (m)
m	Measured mass (kg)
T	Time (s, h)
A	Thermal diffusivity ($m^2\,s^{-1}$)
C_p	Specific heat ($J\,kg^{-1}\,K^{-1}$,$J\,kg^{-1}\,{}^{\circ}C^{-1}$)
V	Volume of composite (m^3)
T	Temperature (K,$^{\circ}C$)
q	Heat flux ($W\,m^{-2}$)
u	Uncertainty
r_c	Kapitza resistance ($m\,W^{-1}$)

Subscripts

eff	Effective thermal conductivity
m	Matrix, mass
f	Filler
c	Composite, contact
v	Volume fraction
exp	Experimental
ini	Initial
end	Final
exch	Heat exchanger
sup	Upper face
inf	Lower face

Greek symbols

λ	Effective thermal conductivity ($W\,m^{-1}\,K^{-1}$)
ρ	Density ($kg\,m^{-3}$)
ϕ	Mass fraction (%)
Δ	Difference of arbitrary parameters
Ω	Spatial domain

has been published on adobe construction, focused on the strengthening of earth buildings, like the Adobe Peruvian Standard published in 2006 [16].

Unfortunately, Peruvian adobe thermal properties have not been thoroughly studied. It is well known that the highlands, or the *Andes*, are exposed to rough weather conditions. Low temperatures, heavy rain, and strong winds combine with little or none thermal insulating techniques, poor housing design or planning and health problems, such as malnutrition, among other social issues; all together leads to a critical situation in several isolated villages. Thousands of highlanders, especially children and elderly, die every year due to chronic respiratory infections, produced by the crude temperatures to which they are exposed [17–20]. This is in clear contrast with the availability of solar radiation as is shown in Fig. 1 [21].

Lately, a number of governmental, non-governmental and academic institutions in the country have taken interest and action [22]. Specifically, the Universidad Nacional de Ingeniería (through the Faculty of Science and the Center of Renewable Energy) is strongly involved in thermal calculations and the design of houses for rural areas [23,24]. The goal is to achieve indoor healthy thermal conditions for the inhabitants, adapting local resources, pre-existing techniques and empirical knowledge. The aim of this work is to characterize the thermal conductivity of traditional un-stabilized Peruvian adobe, obtained by mixing different soils and straw. In order to contribute to the background knowledge of the physical properties of adobe, the results presented in this paper will also participate to enhance the insulation and efficiency of traditional buildings.

This work is one of the first few ones which have been done in order to improve the building performance within the Peruvian rural context [17,22]. The final aim is to allow the inhabitants of the high Andes region of Peru to overcome the harsh scene where they are settled.

The experimental used techniques and the modelling approach are based on the fact that the adobe is clearly a bio-composite material.