# Thermo-Physical and Geotechnical Comparison of Fired Clay Bricks Produced from Oujda and Zayo Soils, Morocco

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**Abstract:**

The use of locally available materials as alternative construction resources represents an effective strategy for reducing building costs and improving the sustainability of construction practices. The present study aims to conduct a comparative analysis of the geotechnical, mineralogical, and thermo-physical properties of two clay soils collected from the North-East of Morocco. To characterize these materials, several geotechnical and mineralogical tests were performed. Particle size distribution analysis revealed that the clay fraction is approximately 30.2% for Oujda soil and 26.1% for Zayo soil. Plasticity tests indicated that both soils exhibit moderate plasticity. Furthermore, X-ray diffraction (XRD) analysis showed that the mineralogical compositions of the two soils are largely similar. The thermo-physical properties were determined using the Hot Disk method. The obtained results indicate that Oujda clay soil presents a lower thermal conductivity compared to Zayo soil, suggesting a better potential for thermal insulation. Consequently, Oujda soil appears more suitable for manufacturing building bricks when thermal insulation is an important requirement. To further evaluate their thermal performance in buildings, the experimental results were integrated into a dynamic thermal simulation using the EnergyPlus software. The simulation assessed the heating and cooling energy consumption of a building constructed with bricks made from the two soils. The results demonstrate that bricks produced from Oujda clay provide better thermal performance and contribute to improved energy efficiency.

**Keywords**: Energy efficiency, Plasticity, Mineralogical, Thermo-physics, Fired bricks.

## 1. Introduction

The resumption of the construction in local materials was imposed following the economic, energy and housing crises. Economic, energy and housing crises. These crises have imposed to demand for alternative solutions. In the building sector, the solution was to increase the use of local materials and decrease the use of manufactured and energy-intensive materials. The oldest material still used in building construction is soil, which is locally available in almost all regions of the world. Especially the soil, which is concentrated in clay, which is the raw material for the manufacture, fired bricks. In the North-East of Morocco, this soil is found in abundance. What makes it distinctive for the brick industry in the region is because of its low cost.

To develop efficient products with controlled properties, several studies have been reported in the literature on the influence of clay minerals and thermal treatment from different regions of Morocco on the dynamic behavior of construction materials. [1]. A study conducted by Mellaikhafi et al.[2] investigated the mineralogical and geotechnical properties of five soil samples collected from different areas in southeastern Morocco. The mineralogical analysis revealed a high presence of quartz, calcite, and calcium carbonate. The particle size distribution showed that the soils generally contain a low proportion of clay and a relatively high proportion of silt. During the design of a building, it is important to estimate the thermos-physical properties of the building materials [3,4]. A study

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conducted by El Hammouti et al. [5] on the comparison of the thermo-physical properties of two unfired clay bricks manufactured by Nador and Oujda soils. The results show that there is a 0,572W/mK difference in the thermal conductivity 0,037MJ/m$^3$K in the heat capacity of the two soils. A study was carried out by researchers to investigate the effect of firing on the thermo-physical properties of industrial clay bricks. [6]. The results indicate an increase of 17% in thermal conductivity and 14.8% in thermal diffusivity after firing.

This work presents an experimental study on the thermo-physical properties of two types of locally (North-East of Morocco) available fired clay bricks. The objective is to see the effect of these bricks on the heating and cooling consumption in buildings with a dynamic thermal simulation using the Energy Plus software.

## 2. Materials and sample preparation

### 2.1. Materials

Two soil samples were extracted from two different regions in northeastern Morocco (Soil A: Zayo) and (Soil B: Oujda), and both regions are known to have numerous brick factories. The notable presence of numerous brick kilns in the two regions highlights the crucial importance of studying the local soils. This endeavor carries significant meaning as it allows for an understanding of the specific characteristics of these two types of soils and their impact on brick production. By closely analyzing the composition, texture, and geological properties of the soils, it becomes possible to adapt manufacturing techniques, optimize available resources, and ensure the durability of the materials produced. Thus, studying these soils is of paramount importance in ensuring the sustainability of the brick kiln industry in these regions, Fig. 1 shows the extraction sites of the studied soils


*Fig. 1. Extraction sites of the studied soils.*

### 2.2. Sample preparation

To evaluate the effect of the nature of clay soils on The thermo-physical properties of bricks were investigated using cylindrical samples measuring 50 mm × 20 mm, with water contents determined from the Atterberg limits. After preparation, the samples were first air-dried for 24 hours under ambient conditions, then placed in an oven at 60 °C until a constant mass was reached. The dried specimens were subsequently fired in an electric furnace at 800 °C. The temperature was increased at a rate of 2 °C per minute and maintained at 800 °C for 1 hour.

## 3. Methods

### 3.1. Particle size analysis and Plasticity

The sedimentation test enables measurement of the ratios among the various granulometric fractions that make up the soil. Materials with a diameter of less than 80μm are covered. In practice, a wet sieving process utilizing an 80μm mesh screen first separates the fraction smaller than. According to the standard NF EN ISO 17892–4 [7], the sedimentation technique Fig. 2 is used to assess particle size distribution for lower sizes.

*Fig. 2. . Sedimentation analysis*

The plasticity test, also known as the Atterberg limits, is used to characterize the behavior of materials such as liquids, plastics, semi-solids (shrinking solids), and solids. The two Atterberg limits, the liquid limit (WL) and the plastic limit (WP), were determined using the Casagrande apparatus in accordance with the NF P94-051 standard.[8]. The plasticity index (IP) is defined as the numerical difference between the liquid limit (WL) and the plastic limit (WP).. The greater this difference, the more plastic the material is, the main responsible for the plastecite of the materal is the clay [9].

### 3.2. Mineralogy

To better understand the soil, a mineralogical investigation was carried out using XRD. This technique was employed to identify clay minerals present in very fine crystalline form. The diffraction patterns were obtained using a SHMDZU XRD-

6000 diffractometer operating at 40 kV and 30 mA, with emission conditions as specified Cu Kα radiation with a range of 5-60° (2θ) radiation with a wavelength of 0,154 nm at a rate of 0,02°/min.

### 3.3. Thermo-physical

In this work have been used the "Hot Disc TPS 1500" device to measure the different parameters of thermal transport .Fig. 3 shows the different components of the Hotdisk method. This methodology, which adheres to ISO 22007-2 [10] and is based on the Transient Plane Source (TPS) technique, is used to quickly obtain thermos-physical data about the sample. The hot disk method was developed by Gustafsson [11]. By inserting a probe in between two symmetrical samples of infinite extension, the measuring concept entails enforcing a uniform heat flow in the plane separating the samples. By monitoring the temperature change of the sample while applying a constant power. The probe comprises of two sheets of Kapton or Mica insulation, depending on the temperature of operation, and a double Nickel spiral that is 10µm thick. It functions as a temperature sensor and a heat source. Its resistance rises as the temperature rises.

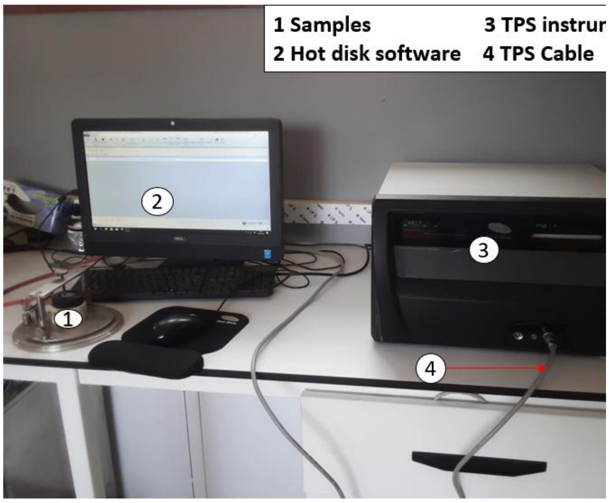


*Fig. 3. Hotdisck method*

## 4. Results

### 4.1. Particle size analysis and plasticity

Fig. 4 shows the particle size distribution of the two soils A and B. Note that there is a slight difference in the granular distribution between the samples studied. Which is characterized by a low sand content (6-9%). However, both samples contained high percentages of silt and clay (29-19%) and (28-24,3%) respectively.

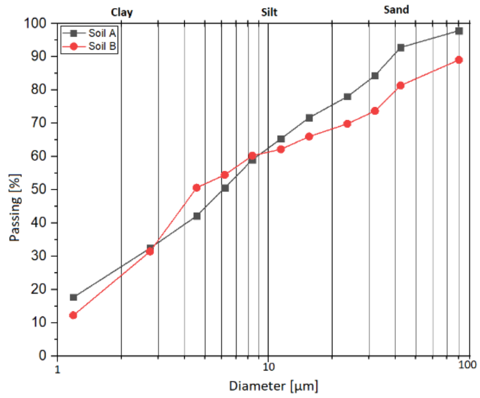


*Fig. 4. Particle size distribution of soils*

By determining the two Atterberg limits plasticity limit WP and liquidity limit WL, it is therefore possible to study the behavior of soil in the presence of water. Indeed, Table 1 shows in detail the Atterberg limits for and the plasticity index of the two soil samples A and B. The results show that the plasticity of soil A is 52 is greater compared to soil B which has 48. This can be explained by the fact that soil A contains more clay, which makes its plasticity index greater [9].

*Table 1. Geotechnical characteristics of the studied soils*

| Properties | | Soil A | Soil B |
|---|---|---|---|
| Particle size distribution | Clay (d<2µm) | 28% | 24,3% |
| | Silt (2µm<d<50µm) | 29% | 19% |
| | Sand (50µm<d<80µm) | 6% | 9% |
| Atterberg limits | Liquid limit | 52 | 48 |
| | Plastic limit | 26 | 25 |
| | Plasticity index | 26 | 23 |

### 4.2. Mineralogy

Fig. 5 shows the results of the mineralogical study by X-ray diffraction analysis. It was noticed that the two soil samples have almost the same mineralogical composition. The peaks showed that both samples contain several minerals, they contain large amounts of quartz, and close amounts of goethite, calcite and ilite. With a slight difference in soil B, which contains a small amount of kaolinite.

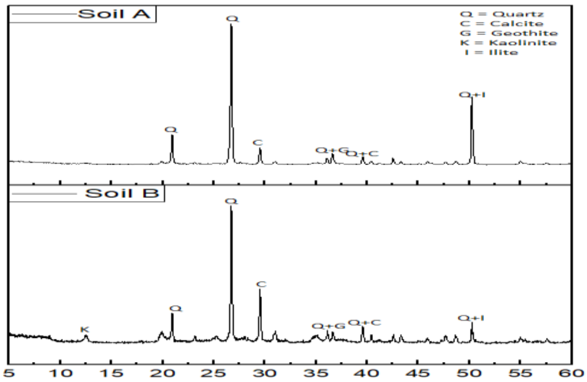


*Fig. 5. XRD analysis of soils*

### 4.3. Thermo-physical

The thermo-physical properties of the two soil samples, A and B, are presented inTable 2. Were noticed that the thermal conductivity of sample B (0,592 W/mK) is low compared to sample A (0,677 W/mK). This means that sample B gives 12,5% more thermal resistance than sample A. This can be explained by the fact that sample B contains a higher percentage of sand than sample B, because the crystallization of the sand granules offered the possibility to improve the porosity of the samples. these port is filled with air which has a low thermal conductivity [12]. In contrast, sample A exhibits a higher density and a more compact structure due to its elevated clay content, which contributes to an increase in the material's thermal conductivity [13].

*Table 2. Thermo-physical properties*

| Sample | Th. conductivit v [W/mK] | Th. diffusivity [mm²/s] | Vol. specific heat | Specific heat | Density [kg/m³] |
|---|---|---|---|---|---|
| A | 0,677 | 0,534 | 1,286 | 663 | 1940 |
| B | 0,592 | 0,520 | 1,140 | 597 | 1910 |

### 4.4. Dynamic thermal simulation

To evaluate the impact of the thermal performance of the materials studied in this article on building energy consumption, a dynamic thermal simulation was carried out using EnergyPlus . Three simulations were carried out on a building located in Nador with a surface area of 80m². The first with the reference materials described in Table 3. The other two simulations with the same materials, only the bricks used in the exterior and interior walls are replaced by bricks A and B in each simulation. The building under study contains two bedrooms, a toilet, a kitchen and a living room as shown in Fig. 6. The geographic coordinates of the building are: Latitude 34.10 °N, Longitude -2.8 °E and elevation 16m.

*Table 3. Characteristics of building materials*

| Element | Material | Thickness [mm] | Th. Conductivi [W/mK] | Density [kg/m³] |
|---|---|---|---|---|
| Exterior wall | Mortar | 20 | 0.80 | 1600 |
| | Fired clay | 200 | 0.972 | 2130 |
| | Mortar | 20 | 0.97 | 1525 |
| Ground floor | Tile | 20 | 1.3 | 2300 |
| | Mortar | 50 | 0.80 | 1525 |
| | Reinforced concrete | 200 | 2.3 | 2240 |
| Roof | Plaster | 20 | 0.46 | 1280 |
| | Concrete slab | 160 | 1.3 | 1920 |
| | Mortar | 20 | 0.80 | 1525 |
| Internal walls | Mortar | 20 | 0.80 | 1525 |
| | Fired clay | 200 | 0.972 | 2130 |
| | Mortar | 20 | 0.97 | 1600 |
| Glazing | Double-glazing U-va = 1.39 W /m²·K | | | |

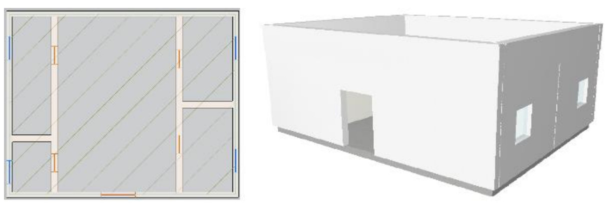

*Fig. 6. 2D and 3D model of the building studied*

Fig. 7 illustrates the annual energy consumption for heating and cooling of the studied building, based on the set-point temperatures of the investigated geographical area, namely 20 °C and 26 °C [14]. It can be seen that the annual energy consumption for heating is 107,59 kWh/m² for the building constructed with B brick walls, which means that there is a difference of 11,64% and 2,92% in heating consumption compared to A and Ref bricks, which consume 121,77 kWh/m$^2$ and 110,83 kWh/m$^2$ respectively. On the other hand, the annual cooling energy demand is 70.01 kWh/m² when using B bricks, compared with 74.37 kWh/m² and 72.34 kWh/m² for the reference (Ref) and B bricks, respectively, corresponding to increases of 5.8% and 3.2%. It can be concluded that the construction with B bricks is more efficient in terms of energy consumption in both cases of heating and cooling.

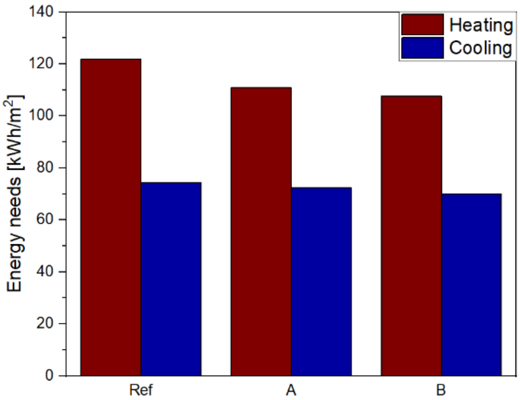


*Fig. 7. Annual energy consumption*

## 5. Conclusion

This paper presents the results of an experimental study on the mineralogical and thermo-physical geotechnical properties of soil samples collected from Oujda and Zayo. The results obtained are as follows:

- The geotechnical results show that the particle size distribution of the two samples is almost identical and a difference of 4% between the plasticity index of the two samples.
- A small change was observed between the mineralogical distribution of soil A and B.
- In terms of thermal conductivity, the clay samples from Zayo (soil A) and Oujda (soil B) exhibit values of 0.677 W/m·K and 0.592 W/m·K, respectively. This difference is attributed to the higher sand content in soil B compared to soil A, which directly affects the porosity and subsequently the thermo-physical properties.
- In terms of energy performance, the simulations showed that buildings constructed with B clay bricks are more efficient than those built with A clay bricks.

The addition of local vegetable additives to the soil and the search for better firing programs to improve the thermal transport properties of the bricks are underway.

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