Morocco’s housing challenge: Effect of current marketed building materials on the energy performance of residential buildings

M Charai1,2*, H Sghiouri1, A Mezrhab1, M Karkri2 and L Moga3

1 Mohammed First University, Mechanics and Energy Laboratory, Morocco
2 Paris-Est University, Certes, France
3 Civil Engineering and Management Department, Technical University of Cluj-Napoca, Romania

* mouatassim.charai@u-pec.fr

Abstract. The paper provides a research on the energy performance of current marketed building materials used for household construction in eastern Morocco. Firstly, the characterization of the thermophysical properties of commonly used building materials (cement, plaster, hollow bricks and insulation boards) was carried out using the Hot Disk method. A local building material database of eastern Morocco region was developed. It was found that the thermal conductivity of the most affordable insulation boards was of 0.03 W/mK, while the thermal conductivity of cement-based products ranged from 0.65 to 0.7 W/mK. The experimental results show that the Moroccan market of building materials cannot participate in promoting eco-construction and designing efficient lightweight building envelopes at local level. Therefore, a strong focus on the development of local low-cost insulation materials for building applications are needed. The numerical building performance analysis shows that available building practices are only efficient for passive heating. Further studied on passive cooling techniques are greatly required for designing low energy buildings in Morocco.

1. Introduction
Over the past decade, Morocco has deployed straightforward strategies to reduce the building energy consumption by implementing radical reforms in favor of sustainable constructions. A thermal regulation standard for buildings, an energy efficiency law (i.e. law 47-09), new energy institutions (i.e. IRESEN - Research Institute for Solar Energy and New Energies, AMEE- Moroccan Agency for Energy Efficiency, MASEN- Moroccan Agency for Sustainable Energy) have been put in place to reach a new target aimed at saving 20% of the energy consumption by 2030, including building sector [1].

In fact, the Kingdom of Morocco put a strong focus on building energy efficiency by updating status quo/go reports on this field and promoting R&D co-operation be-tween Moroccan universities and industrial units for developing green low-cost building materials. For example, the Research Institute for Solar Energy and Renewable Energies (IRESEN) has funded several projects related to construction issues and has enabled the creation of several research laboratories throughout Morocco (figure 1), notably the Green and Smart Building Park (GSBP), which will be interested in green
building research. Also recently, the National Centre for Scientific and Technical Research (CNRST) signed a partnership agreement with the Holding AL OMRANE (HAO), which represents the leader-housing operator in Morocco, for the development and promotion of housing and urban planning, through launching the first “Omraninnov” research & development call for projects [2].

Such actions are implemented owing to the fact that the national construction market cannot keep pace with current challenges. Several research studies have been conducted to improve the thermal comfort of Moroccan buildings. Sghiouri et al. [3] investigated different passive cooling strategies for reducing overheating for building located in semi-arid climate. A Ketouane et al. [4] studied the potential use of phase change material in hollow brick walls for improving the thermal performance of building envelopes, since almost Moroccan houses are constructed of hollow bricks.

However, this work will characterize the thermophysical properties of current building materials marketed in eastern Morocco to investigate the thermal performance of local residential buildings. Recommendations for the design of thermally compliant houses will be developed.

2. Materials and methods

2.1. Building material specimens

Given the purpose of the paper, we focused on the products most used for the construction of typical Moroccan houses. Figure 1 illustrates the main ingredients of Morocco building envelopes. According to the only supplier of insulating materials located in Oujda, the XPS insulation boards was chosen due to their quality-price ratio. All products are collected from local manufacturers and suppliers to evaluate the energy performance of houses at local level.

Since cement and plaster are sold as powder, the samples were prepared by hand mixing the matrices with water and molded in aluminum mold. A plaster/cement-to-water ratio of 0.7% was used. The final samples were left to dry at room temperature. The thermal characterization was performed when the samples reach a constant weight.

![Figure 1. Studied products: (a) insulation boards (b) cement and plaster (c) hourdis and bricks.](image)

2.2. Thermophysical characterization

The Hot Disk (TPS 2200, Sweden) apparatus was used to determine simultaneously the thermal conductivity, the thermal diffusivity and the heat capacity of the studied products. The experimental setup is shown in figure 2. The method is based on a Transient Plan Source (TPS) technique [5]. The measurement consists to sandwich the TPS sensor between to identical samples, as indicated in figure 2b. Direct electrical power is injected through the TPS sensor to heat samples. After the heating phase, the TPS sensor monitors the time-dependent response. Then, the thermal properties of samples are deduced using parameter estimation algorithms based on the recorded experimental temperature data.

The thermal characterization was carried out in accordance with ISO 22007-2 standard.
Figure 2. Setup of thermal tests (a) Hot disk apparatus (b) TPS sensor.

Figure 3. Hollow brick (a) real view (b) sketch view (c) brick-element (d) electrical analogy.

For hollow bricks, we firstly characterized the fired clay constituting the brick because the used method did not take into account the air pores. We then estimated the thermal conductivity of a 12-hole brick using the Electrical Analogy of Heat Conduction, as presented in figure 3. Basing on the thermal circuit shown in figure 3d, the thermal resistance of the hollow brick can be written as follows:

$$R_{\text{hollow}} = 2R_1 + \left( 2 + \frac{1}{R_3} + 4\frac{1}{3R_2} \right)^{-1}$$  \hspace{1cm} (1)

Where $R_1 = \frac{e_2}{\lambda_c l l}$, and $R_3 = \frac{(E - 2e_2)}{\lambda_{c,l,l}}$ are respectively the thermal resistance of the vertical and the horizontal solid parts of the brick. For the hollow part (figure 3c), and if we assume that that the dimensions are small enough to prevent convective movements, the thermal resistance $R_2$ can be approximated as follows:

$$\frac{1}{R_2} = \frac{1}{R(L_1)} + \frac{1}{R(2L_2)} \Rightarrow R_2 = \frac{1}{R(L_1)} + \frac{1}{R(2L_2)}$$  \hspace{1cm} (2)

Where $R(L_1) = R_{\text{air}} + \frac{2e_2}{\lambda_{c,l,l}} = \frac{1}{L_1} \left( \frac{e_1}{h_1 e_1 + \lambda_{\text{air}}} + \frac{2e_2}{\lambda_c} \right)$ and $R(2L_2) = \frac{2e_2 + e_1}{\lambda_{c,2L_2}}$ are respectively the thermal resistance of the air blade and the solid part. It should be noted that the thermal resistance of the air blade is equal to:

$$\frac{1}{R_{\text{air}}} = \left( h + \frac{\lambda_{\text{air}}}{e_1} \right) L_1 \text{ with } h = f(e_1, e_2)4\sigma T_m^4$$  \hspace{1cm} (3)

In which $L = 180\text{mm}$, $E = 150\text{mm}$, $l = 250\text{mm}$, $L_1 = 37.5\text{mm}$, $L_2 = 3\text{mm}$, $e_1 = 40.6\text{mm}$, $e_2 = 3.5\text{mm}$, $\lambda_c = 0.972 \text{ W/mK}$, $\lambda_{\text{air}} = 0.025 \text{ W/mK}$, $h_1 = 6 \text{ W/m}^2K$. Hence, we find that the thermal resistance of our hollow brick of 150 mm-thick is $7.8539 \text{ m}^2 \text{K.W}^{-1}$.

Hence, the equivalent thermal conductivity could be deduced using the following equation:

$$R_{\text{hollow}} = \frac{E}{\lambda_{\text{hollow}} \cdot L \cdot l}$$  \hspace{1cm} (4)

where $E$, $L$ and $l$ are the brick dimension.
3. Test results: building material database

Table 1 sums up the thermophysical properties of studied samples. The thermal heat capacity of samples is calculated using the following equation:

\[ Cp = \frac{\lambda}{a \rho} \]  

(5)

\( \lambda \) is the thermal conductivity in W/mK, \( a \) is the thermal diffusivity in m²/s and \( \rho \) is the density of the sample kg/m³.

According with the analogy of heat conduction, the thermal conductivity of our hollow brick was found to be 0.424 W/mK, representing a gain of 56% in thermal insulation compared to solid bricks. Note that these results were in a good agreement with thermal conductivity value measured on 7-cm-thick hollow bricks using the boxes method. However, the studied hollow bricks in this work present high thermal conductivity compared to those measured by the Moroccan Agency of Energy Efficiency (AMEE) [6]. This is likely due to the fact that the AMEE measurements were carried out on oven dried specimens.

| Product                | \( \lambda \) [W/mK] | Thermal diffusivity [mm²/s] | Heat capacity [KJ/mK] | Density [Kg/m³] |
|------------------------|-----------------------|-----------------------------|-----------------------|-----------------|
| Insulation boards      | 0.030 ± 0.001         | 1.439 ± 0.027               | 0.992                 | 21              |
| Hourdis                | 1.744 ± 0.002         | 0.981 ± 0.025               | 0.704                 | 2524            |
| Fired clay (solid bricks) | 0.972 ± 0.006     | 0.685 ± 0.020               | 0.965                 | 2040            |
| Hollow bricks Elec. analogy | 0.424 ± 0.020     | 0.631 ± 0.050               | 0.655                 | 950             |
| AMEE [6]               | 0.219                 | 0.420                       | 0.729                 | 716             |
| Cement                | Cement 35            | 0.653 ± 0.007               | 0.447 ± 0.019         | 0.859           | 1700            |
|                        | Cement 45            | 0.699 ± 0.001               | 0.322 ± 0.004         | 1.369           | 1585            |
| Plaster                | 0.531 ± 0.001         | 0.400 ± 0.011               | 0.954                 | 1392            |

4. Thermal performance: case study

4.1. Case study building

The thermal simulations of a residential building located in Oujda City for different wall compositions were performed. The building (figure 4) is a two-story villa with a total floor area of 160 m². The 2D model of the building is presented in the figure 5. The simulations were carried out using the EnergyPlus™ software, version 9.0.1 [7]. Climate information and the used meteorological data are discussed in [3, 8].
According to building practice in Morocco, four main wall compositions are proposed in table 2.

Table 2. Wall compositions.

| Wall code | Description                                                                 |
|-----------|-----------------------------------------------------------------------------|
| W1        | Simple hollow brick wall                                                     |
| W2        | Double hollow brick wall with 100 mm-thick air gap                           |
| W3        | Double hollow brick wall with 30 mm-thick insulation board                    |
| W4        | RTCM building envelope = W1 + 6cm-thick insulation board in the roof         |

The parameter inputs of the dynamic thermal simulation are listed in table 3.

Table 3. Parameter inputs.

| Parameter                  | Value          | Schedule                       |
|----------------------------|----------------|--------------------------------|
| Heating set point          | 20 °C          | On (all days)                  |
| Cooling set point          | 26 °C          | On (all days)                  |
| People                     | 4 persons      | Occupancy schedule (figure 6)  |
| Activity level             | 120 W/person   | Depends on occupancy           |
| Lights                     | 10 W/m²        | Depends on occupancy           |
| Electrical equipment       |                |                                |
| Fridge 130W                | Daily running time 24h |
| TV 80 W                    | Daily running time 4h |
| Pc 200 W                   | Daily running time 3h  |
| Laptop 60 W                | Daily running time 3h  |
| Phone charger 6W           | Daily running time 12h |
| Infiltration               | 0.6 h⁻¹        | On (all days)                  |

The building was assumed to be occupied by four persons according to the schedule fraction indicated in figure 6. Internal gains were introduced to correspond to an artificial lighting of 10 W/m², a desktop (200 W), a fridge (130 W), TV (80 W), Laptop (60 W) and phone charger (60 W).

The walls are coated by a 15mm-thick mortar layer. The properties of mortar are of cement 35 in Table 1. Cement 45 is used for the conception of the floor/roof screed. The roof is a plaster on the inside (4 cm), with hollow-core (hourdis) slab (16 cm), cement coating (4 cm), screed (5 cm) and tile on the outside (1 cm). The ground floor is a reinforced concrete slab (20 cm) with screed (5 cm) and tile inside (1 cm). The glazing is compliant double with a thermal transmittance of 3.33 W/m²K.
4.2. Annual loads and discussion

The annual energy consumption of studied envelopes, are presented in figure 7a. The results show that building with simple hollow brick wall consume 69.2 kWh/m², exceeding the maximum admissible by 30%. The use of air gap is a good practice for designing efficient wall. Using 10 cm of air blade can reduce the heating/cooling loads by 15%, compared to the reference case (i.e. simple hollow brick wall).

Unlike air gap, the use of insulation boards is better for design efficient walls with small thickness, representing an energy saving of 17.9% compared to the reference. The simulation show that the use of 6cm-thick insulation boards in walls allows the construction of compliant buildings located in cold Moroccan semi-arid climates.

Figure 7b represents the average monthly indoor temperatures of the studied building. The results show that available practices for building construction in Morocco are only efficient for passive heating. Therefore, further studies on passive cooling techniques are greatly required for achieving low-energy buildings in Morocco.

Besides the high embodied energy of today's industrial building materials, the results show that they are ineffective for designing lightweight thermally efficient buildings, especially in passive cooling. For this reasons, the recourse to traditional architecture for the conception of low-environmental impact habitat models with excellent summer thermal comfort levels is needed [9, 10]. Moreover, further studies on reinforcing earthen construction practices using unfired clay bricks are recommended [11].

**Figure 6.** Occupancy schedule.

**Figure 7.** Performance of studied envelopes: (a) annual loads (b) average monthly temperatures.
5. Conclusion
A local building material database for eastern Morocco was developed. The thermal conductivity of most used XPS insulation boards at local level was found to be around 0.03 W/mK. While, the thermal conductivity values of local cement-based products range from 0.65 to 0.7W/mK. It was found also that the hollow bricks are thermally more efficient than their associated solid bricks. The air pores improve the thermal insulation quality of red bricks. The study of pore’s position and geometry are encouraged to design high-performant bricks. Thermal dynamic simulations of a typical residential building located in eastern Morocco region using the studied products were carried out. The finding results show that buildings with simple hollow brick walls are poorly insulated, resulting in a huge energy consumption for maintaining the occupant comfort level. The energy needs of simple hollow brick wall building for heating and cooling exceeds the maximum admissible energy consumption by 30%. The use of double hollow brick walls with an air gap (10 cm) can reduce the annual energy consumption by 15% compared the first case. However, the use of 3cm-thick XPS insulation boards in walls instead of air gap are highly recommended.

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