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Thermophysical Properties Enhancement in Construction Materials Based on Cement and Plaster

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Abstract: Enhancing insulating power of buildings envelope saves energy costs and minimizes associated CO_2 emissions. The development of materials with good thermal performance is a major challenge. This work shows the effect of incorporating different additions on the thermal properties of composites based on plaster and cement through a series of experiments. The additives used are among the most widespread wastes in Morocco. Dozens of new samples based on cement and plaster have been prepared and experimentally characterized by the box method to develop environmentally friendly and thermally efficient materials. The results show that increasing incorporation rate of additives significantly improves thermophysical properties of based materials. The addition of 4% alfa and 6% of coffee grounds in plaster matrix and the replacement of cement by 50% of ashes in mortar and concrete record the low thermal properties including thermal conductivity, diffusivity, effusivity and specific heat. The good performance of new materials encourages us to integrate them into the building envelope. The results obtained by the annual simulations conducted for a residential building in Meknes have highlighted the economic and environmental benefits of using these new materials. A reduction of 50% in energy and a limitation of 3029.13 $kgCO_{2eq}/yr$ are observed thanks to an effective combination between the developed materials.

Keywords: Plaster, cement, waste recycling, thermophysical properties, ecological materials, energy efficiency

1. Introduction

The high energy consumption in the building sector has pushed researchers and construction specialists to look for alternative solutions that can reduce this consumption with the least cost (Lu & Lai, 2019). In Morocco, building consumption according to the Ministry of National Spatial Planning represents 33% of total energy consumption with an annual increase rate of 5% (MNSP, 2020). This increase is mostly due to the growth in the ratio of heating and cooling equipment. The building envelope is a decisive key to reducing energy needs and CO_2 emissions and to improving the building's passive energy efficiency and occupant comfort. A high-performance envelope shields the building against external weather by reducing heat loss to the outside during winter and ensuring a certain freshness inside in summer (Rinquet & Schwab, 2017). The choice of materials inserted in the building envelope is considered regarded as a crucial criterion because they directly affect the energy and ecological performance of buildings (Berge, 2019). Their choice must be based on a thorough knowledge of thermal characteristics. From a thermal standpoint, the criteria for selecting materials are essentially based on their capability to conduct heat, their heat transfer rate and ability to control the internal climate (Amine et al., 2018; Lachheb et al., 2019).

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During the last decades, the employment of available and recyclable materials which present good thermomechanical and eco-friendly performances at low cost has been greatly appreciated (Aciu et al. 2018; Tiskatine al., 2018; Keerio et al., 2019; Heidari rt al., 2019). As many researchers have been carried out in this section whose objective is to assess the thermophysical characteristics of existing or innovative materials either numerically by predictive models, experimentally by characterization methods or with both. Derbal et al (2014) developed a simple method that simultaneously estimates the thermal conductivity and heat capacity of building materials. The principle of the method consists in placing the sample to be characterized between two known thermal characteristic materials and recording the increase of the temperature recorded in the interfaces and the ends under the effect of the heat flux applied. The measured temperatures are inserted in a numerical model that allows to determine the thermophysical properties of the studied materials. Yang et al (2019) presented a 3D numerical model that predicts the effective thermal conductivity of the rubber aggregate reinforced mortar. They validated their developed model by comparing with experimental results.

It is interesting to study the influence of carbon fibers incorporation on the cement-based materials mechanical characteristics. The experimental results of tensile and compression tests demonstrate that the mechanical performance of the materials studied is improved when different fractions of carbon fibers are incorporated into the cementitious matrix. (Nguyen et al., 2016; Rangelov et al., 2016; Saccani et al., 2019).

Other research focuses on the materials reinforcement by adding date palm fibers. Djoudi et al (2014) mixed the plaster with date palm fibers of different masses and lengths and observed that the plaster with 2% of fibers with 20 mm long has the best thermal characteristics. The microscopic results show a good interaction between the two components and the results of the model developed correspond well to those of the experiments. Amara et al (2017) presented the experimental and theoretical results of the thermophysical properties of reinforced plaster by different percentages of date palm fibers. They compared the results of the experimental characterization with the theoretical models studied and showed that the conductivity and the diffusivity decrease as the percentages of palm fibers increase. Benmansour et al (2014) treated the thermomechanical properties of the mortar mixed with date palm fibers. The results of the thermal characterization and compression tests show that the thermomechanical properties of the new composite are improved by varying the percentage of date palm fibers 0-30%. They also showed the possibility of using this composite as an insulator. Boumhaout et al (2017) find similar results.

In addition, the development of environment-friendly and energy-efficient building materials is one of the topics that is the focus of several research projects in Morocco. Lakrafli et al (2012) experimentally investigated the influence of leather waste incorporation on the physical characteristics of cementitious and plaster-based materials. They showed that with increasing waste fractions in the studied composites, significant decreases in density, thermal conductivity and mechanical strength are recorded. They have also demonstrated that treated leather residues can be used as filler or separation products that improve the insulating power of composite materials. Cherki et al (2014) have shown experimentally using the hot plate method that the addition of cork to white cement improves its insulating capacity and energy storage compared to white cement alone. Cherki et al (2014) presented an experimental study on the effect of cork addition on the thermophysical properties of white cement. Using the hot plate method, they showed that the new material has the best characteristics in terms of insulation and energy storage compared to white cement alone. Mounir et al (2015) have shown through thermal characterization by asycetric hot plate and flash methods that the incorporation of wool into clay improves the thermal characteristics of the composite. They observed that the addition of 5% wool allows to have low conductivity and thermal inertia and low transmission factor for a wall of 30 cm thick. As well as the replacement of simple clay by the new composite makes it possible to reduce the consumption of building heating in a dry climate. Lamrani et al (2017) were interested in improving the plaster thermophysical properties through the incorporation of peanut shells. Experimental results obtained with three different characterization methods show a significant decrease in the thermophysical properties of new materials compared to the base material. By increasing the incorporation rate 0-20%, the conductivity and diffusivity decrease from 0.3 $Wm^{-1}K^{-1}$ and 3.75 10^{-7} m^2/s to 0.14 $Wm^{-1}K^{-1}$ and 2.11 10^{-7} m^2/s respectively.

To our knowledge and based on the evaluation of recent work, few studies are interested in the effect of alfa fibers and coffee grounds on the thermophysical properties of plaster and the effect of ash on cement mortar and concrete. As well as most studies deal with thermal conductivity and thermal diffusivity. The relevance of our work can be summarized by evaluating all thermophysical properties of the developed materials and by valuing the energy and economic benefits when integrating these materials into the envelope of a typical building. We chose plaster, cement mortars, and concrete because they are the most frequently used materials in the construction mode in Morocco. And to meet the objectives of the National Energy Efficiency Program which aims to improve the thermophysical properties of building materials, new composite materials based on plaster and cement are being prepared and characterized experimentally to design materials with good thermophysical properties. Initially, a dozens of samples were prepared by mixing the plaster or cement matrix with different percentages of waste such as alfa, coffee grounds and ashes. The resulting composite materials were experimentally characterized by the box method to estimate their thermal properties. Then, annual dynamic thermal simulations were carried out on a residential building situated in Meknes to highlight the integration influence of these proposed materials on the building envelope energy performance. Environmental impact assessments have been conducted to assess the annual amount of CO_2 emissions avoided by the use of these developed materials. Finally, an effective combination of these materials is proposed that allows the maximum reduction of needs and emissions.

Nomenclature

λ_s Sample thermal conductivity ($Wm^{-1}K^{-1}$)
e Sample thickness (m)
S Sample area (m²)
Φ_H Hot flux produced by Joule effect (W)
U Heating resistor voltage (V)
R Heating resistor (Ohm)
L_C Box loss coefficient (W/°C)
Φ_{Loss} Thermal losses through box B1 (W)
T_A Ambient temperature (°C)
T_B Inside box B temperature (°C)
T_H Hot face temperature (°C)
T_C Cold faces temperature (°C)
α Experimental thermal diffusivity (m^2/s)
t Time corresponds to the maximum value of temperature (s)
C_{pexp} Experimental specific heat ($kJkg^{-1}K^{-1}$)
ρ_{exp} Experimental density (kg/m^3)
E_{exp} Experimental thermal effusivity ($JK^{-1}m^{-2}s^{-1/2}$)
E_{rq} Annual energy requirements of building ($kWhm^{-2}yr^{-1}$)
$E_{rq.H}$ Annual energy requirements for heating ($kWhyr^{-1}$)
$Er_{q.C}$ Annual energy requirements for cooling ($kWhyr^{-1}$)
$Qa_{v.CO2}$ Avoided CO_2 emissions (kg/yr)
ES Energy savings (kWh/yr)
EF Grid emission factor (CO_2/kWh)

2. Materials and Methods

2.1 User Materials

The materials used in this study are building materials and local waste widely available in the Meknes region and throughout Morocco. Plaster is a flame-retardant building material from the thermal dehydration of gypsum. Its applications are varied; it can be used as a plaster or mortar for the protective or decorative coating of walls and ceilings, and as a surgical plaster for specific medical purposes. The industrial plaster used in this study consists essentially of calcium sulfate hemihydrate of formula $CaSO_4 \cdot ½ H_2O$, and / or anhydrite $CaSO_4$ or anhydrous calcium sulfate (Iucolano et al., 2018). Sand is a granular material resulting from the disintegration of mineral rocks or organic shells. Its chemical composition shows that it consists mainly of silicon dioxide (88.2% of SiO_2) and calcium oxide (6.1% of CaO). It can be used in foundry, in the kitchen, as raw material of glass and masonry as an aggregate mixed with cement as the case of our work (Olonade et al., 2018). Cement is a hydraulic binder obtained by powdering a clinker consisting essentially of hydraulic calcium silicates to which various products are added such as calcium sulphate (gypsum/plaster), limestone and water. It is generally used in the preparation of concrete, and in the manufacture of tessellations, blocks and mortars (Arfala et al., 2018). The cement used in our case is CPJ 45 manufactured at Lafarge Holcim in Meknes.

Coffee grounds are the residue of coffee brewing, which is considered as one of the world's most consumed beverages at 9 million tons/year according to International Coffee Organization statistics (ICO, 2020). Carbohydrates are one of the important constituents in spent coffee grounds. Coffee grounds are high in sugar, which is broken down into cellulose and hemicellulose with 8.6% and 36.7% respectively. Regarding polymers, coffee grounds contain 21.2% mannan and 13.8% galactan. For proteins, there is about 13.6% of SCG while minerals are low (<1%) (Mussatto et al., 2011). The Alfa fibers used in our study to strengthen plaster are fibers made up of perennial herb leaves, Macrochloa Tenacissima, which occupies a large area in the most arid regions of Morocco as elsewhere. In terms of composition, they contain mainly cellulose, hemicellulose and lignin (Lachheb et al, 2017). They have long been used in handicrafts such as ropes and objects in plaster and as a raw material for paper industry in North African countries.

Fly ash is one of the waste products from coal combustion in large industrial boilers and thermal power plants. Fly ash contains significant amounts of silicon dioxide (31.8%), forms (amorphous and crystalline) of aluminum oxide (28% of Al_2O_3) and calcium (in the form of Calcium oxide (10.53% of CaO) from the strata. In this study, we used JORF Lasfar ashes. They are the only ones in Morocco that can be used in cement and concrete because they are evacuated dry, unlike other plants that remove them wet (Lahlou et al., 1998).

2.2 Samples Preparation

In order to improve thermal properties of plaster, mortar and concrete, which may be used in walls and false ceilings, all samples have a parallelepiped shape with a thickness of 4 cm.

The highest percentage is the maximum number of additives that can be incorporated into base materials due to the mechanical properties loss.

As a result, series of samples (ten samples for each case) corresponding to the different tests were prepared to study their thermophysical properties and choose the best building materials. The basic case consisted of samples without additives. The samples are prepared at room temperature. The base materials are cast and then mixed in the dry state in order to homogenize the mixture. The amount of water required is poured regularly until the mixture reaches the desired consistency. The different sample components are mixed to obtain a ready-to-use material. This material is then poured into molds of dimensions (27 x 27 x 4 cm^3) to obtain the desired samples. All samples were then allowed to dry in an oven set at 50 °C to remove any moisture content in samples pores. The sample is considered dry when its mass stabilizes.

2.3 Thermophysical Properties Measurement

2.3.1 Density

Knowing the samples dimensions, we can determine its volumes, while its masses are measured by means of a digital electronic scale. The samples density is determined as a ratio of mass to volume.

2.3.2 Thermal Conductivity

The materials thermal conductivity is evaluated in steady state by placing the test sample between a hot ambient produced by an electrical resistance and a cold one released by a cryostat (Fig. 1).

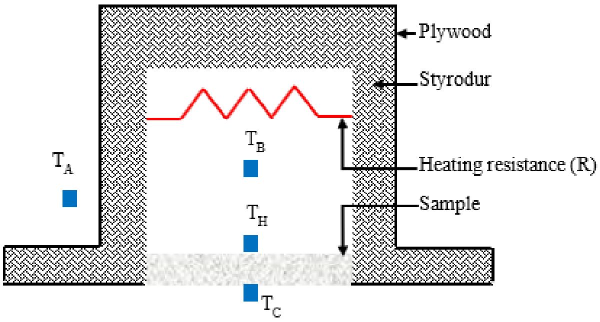


Fig. 1 - Box (B1) for measuring thermal conductivity

By establishing the thermal balance at the box B1, the thermal conductivity λs is given by the following expression:

$$\lambda_s = \frac{e}{S(T_H - T_C)}(\Phi_H - \Phi_{Loss}) \tag{1}$$

Where e and S are the thickness and area of sample, T_H and represent the temperatures of hot and cold facades, Φ_H is the hot flux produced by Joule effect, depending on the heating voltage U and the heating element resistance R, and Φ_{Loss} are thermal losses through box B1 determined as a function the box loss coefficient L_C and the difference between the ambient T_A and internal temperatures of box B1 (T_B).

2.3.3 Thermal Diffusivity

The thermal diffusivity is quantified in Box B2 in transient mode using the flash method (Fig. 2).

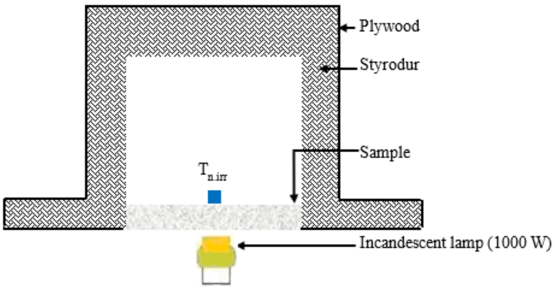


Fig. 2 - Box (B2) for measuring thermal diffusivity

The measurement principle consists in exposing the sample for a few seconds to the effect of a flash produced by two incandescent lamps and to record the rise in temperature of the sample non-irradiated side as a function of time, then to calculate the thermal diffusivity of material as the average value of the following three equations:

$$\alpha_1 = \frac{e^2}{t_{5/6}^2}\left[1{,}15\, t_{5/6} - 1{,}25\, t_{2/3}\right] \qquad (2)$$

$$\alpha_2 = \frac{e^2}{t_{5/6}^2}\left[0{,}76\, t_{5/6} - 0{,}926\, t_{1/2}\right]$$

$$\alpha_3 = \frac{e^2}{t_{5/6}^2}\left[0{,}618\, t_{5/6} - 0{,}862\, t_{1/3}\right]$$

$$\alpha_{\text{exp}} = \frac{\alpha_1 + \alpha_2 + \alpha_3}{3} \qquad (3)$$

2.3.4 Specific Heat

The specific heat is one of important characteristics which serve for the thermal evaluation of building constructions and for the determination of buildings energy balance.

The specific heat of samples is determined by knowing experimentally their thermal conductivities (λ_{exp}), thermal diffusivities (α_{exp}) and densities (ρ_{exp}).

The specific heat can be deduced as follows:

$$Cp_{exp} = \frac{\lambda_{exp}}{\rho_{exp} . \alpha_{exp}} \qquad (4)$$

2.3.5 Thermal Effusivity

The thermal effusivity designates the thermal exchange potential of a material with its surroundings.

As an essential parameter for quantifying the material thermal inertia, thermal effusivity (Eexp) is defined based on the thermophysical characteristics of samples by:

$$E_{exp} = \sqrt{\rho_{exp} . Cp_{exp} . \lambda_{exp}} = \frac{\lambda_{exp}}{\sqrt{\alpha_{exp}}} \qquad (5)$$

2.4 Energy and Environmental Calculation

2.4.1 Building Description

The studied structure is a mono zone of 80 m^2 of living space with south and west facades and has seven zones: living room, two bedrooms, kitchen, courtyard, hall, shower and WC. The characteristics of building and operating conditions for this simulated building are given in Tab. 1.

In this study, the building model is based on a typical construction in Morocco where the thermophysical properties of the envelope materials have been taken from the TRNSYS library (Tab. 2) (Klein, 1988). The exterior walls consist the building envelope are composed of 10 cm thick of double walls made of hollow bricks, 5 cm of air blade and 1.5 cm of cement mortar on both surfaces (inside and outside). The roof is composed of 16 cm thick hourdis, 4 cm of concrete, 10 cm of cement coating, 1 cm of tile outside and 4 cm of plaster as a false ceiling inside. The low floor on solid ground consists of 10 cm thick of concrete slab, with 7 cm of cement mortar and 1 cm of tile inside.

Table 1 - Characteristics of studied building

Parameters	**Description**
Nombre of floor	1
Plan shape	Rectangular
Total area	80 m^2
Windows area	10% to floor ratio
Floor height	3 m
Orientation	South
External wall U-value	0.884 $Wm^{-2}K^{-1}$
Floor U-value	1.335 $Wm^{-2}K^{-1}$
Roof U-value	1.467 $Wm^{-2}K^{-1}$
Infiltration rate	0.6 ACH
Solar absorptance	0.6
Set point for cooling	26 °C
Set point for heating	20 °C

Table 2 - Thermophysical properties of the materials constituting the building walls

Materials of construction	**Material characteristics**		
	Conductivity $Wm^{-1}K^{-1}$	**Thermal Capacity $kJkg^{-1}K^{-1}$**	**Density kg/m^3**
Concrete	1.8	0.92	2300
Brick	0.35	0.794	720
Tiles	1.70	0.7	2300
Plaster	0.5	1.045	1150
Hourdis	1.23	0.65	1300
Air Blade	0.0936	1.007	1.204
Mortar cement	1.2	0.84	2000

The glazing is simple with a U value of 5.74 $Wm^{-2}K^{-1}$, which is considered the popular window types used in Moroccan buildings. The windows surface areas are 4.48 and 4 m^2 in the south and west house facades, respectively. The outside door consists of heavy wood and oriented South with a surface of 3 m^2. The door U-values is 3.33$Wm^{-2}K^{-1}$. The occupied thermal areas are heated and cooled using a reversible heat pump with a performance heating coefficient of 3.4 and a cooling energy efficiency of 3.

2.4.2 Energy Requirements

The annual loads due to the building heating and cooling are determined through the TRNSYS energy simulation software, adopting the reference temperatures (20 °C in winter and 26 °C in summer).
The annual energy requirements of building (E_{rq}) are calculated by using the following equation:

$$E_{rq} = \frac{E_{rq.H} + E_{rq.C}}{TSC} \tag{6}$$

Where $E_{rq.H}$ and $E_{rq.C}$ are the annual energy demand for heating and conditioning air calculated on the basis of reference temperatures in $kWhyr^{-1}$, TSC is the total living area given in m^2.

2.4.3 Environmental Assessment

In this study, the mitigation of CO_2 emissions through reducing energy consumption in residential buildings by integrating new materials developed into the building envelope is evaluated.

The most currently used approach for calculating emissions is that based on calculation using emission factors and energy savings achieved during an activity.
The avoided CO_2 emissions (in kg/year) are estimated using the formula below:

$$Q_{av.co_2} = ES * EF \tag{7}$$

ES stands for energy savings [kWh/yr] calculated by multiplying the specific annual energy requirements of the building related to thermal comfort (E_{rq}) and the total living area.

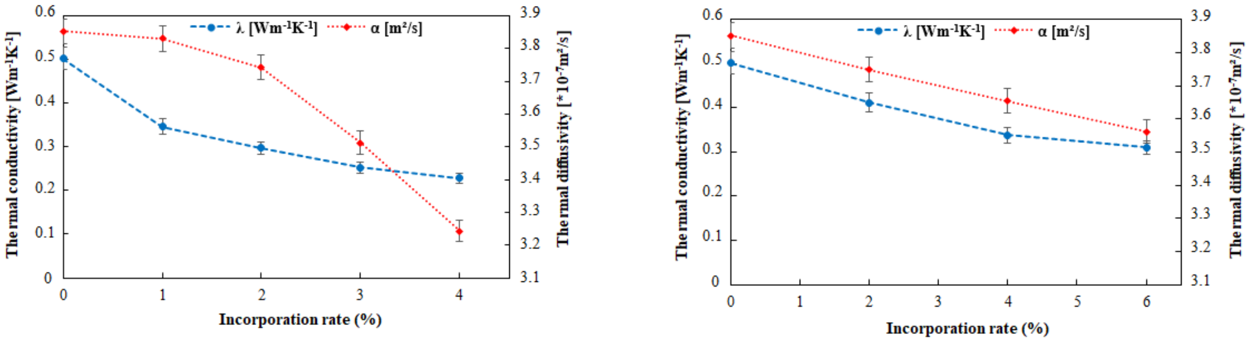
EF represents the emission factor of grid (0.74 kg of CO_2/kWh for Morocco (Lachheb et al., 2019). A multiplier coefficient allows us to move from measuring an activity to measuring greenhouse effect that this activity generate.

3. Results and Discussions

3.1 Measurement Results

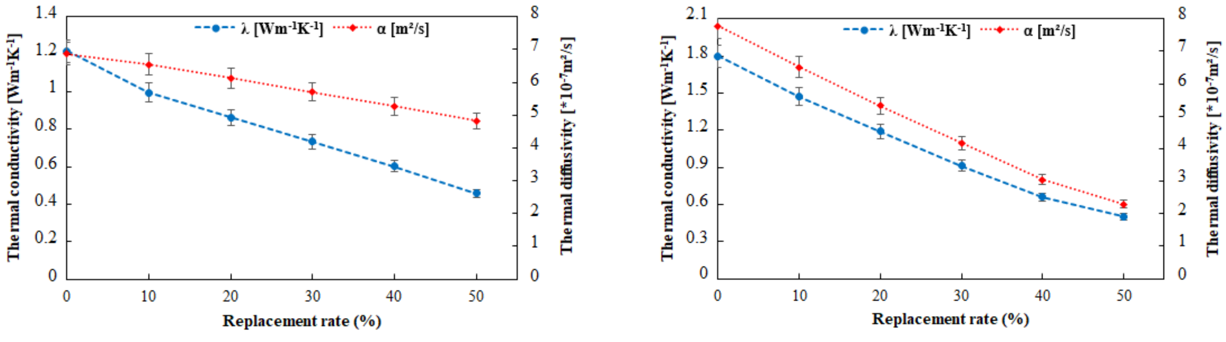
Thermal characterization is performed by the box method conceived to determine the materials thermal conductivity and diffusivity. Figure 3 shows the thermal conductivity and diffusivity results of conventional materials (plaster, mortar and concrete) and the samples studied with different rate of incorporation. These results prove that by increasing additives rate the thermophysical characteristics are reduced. For the plaster matrix, the maximum reduction in conductivity and thermal diffusivity is achieved with 4% of alfa fibers and 6% of coffee grounds. Significant decreases in thermal conductivity are recorded. The thermal conductivity decreases from 0.502 $Wm^{-1}K^{-1}$ to 0.228 and 0.31 $Wm^{-1}K^{-1}$, ie reductions of 54.5% and 38.2% respectively for plaster-alfa and plaster-coffee-grounds. This reduction is mainly due to the low thermal conductivities of fibers alfa and coffee grounds, which are 0.068 and 0.17 Wm^{-1}K-1 respectively. The thermal diffusivity is also reduced with a reduction rate lower than that of the thermal conductivity. It decreases from 3.852 10^{-7} m^2/s to 3.243 10^{-7} and 3.561 10^{-7} m^2/s with a reduction rate of 15.8% and 7.5% for same materials and with same percentages.

For the cementitious matrix, the maximum reduction of conductivity and thermal diffusivity is obtained with 50% of ashes as replacement of the cement in the mortar and the concrete. It is found that the thermal conductivity values decrease 1.216-0.457 $Wm^{-1}K^{-1}$ (39.7% reduction) for ash mortar and 1.8-0.509 $Wm^{-1}K^{-1}$ (49.4% reduction) for ash concrete by increasing the percentage of ash 0-50%. A similar result was obtained by Bentz et al (2011) where the impact of ash on the thermal conductivity of concrete and mortar is studied. Similarly, the thermal diffusivity decreases by increasing the percentage of replacement and reaches its maximum at 50% is a reduction of 16.8% for ash mortar and 46.2% for ash concrete. These decreases are due to the low density and conductivity of ash compared to those of cement.



(a) Plaster with alpha (PA)

(b) Plaster with coffee grounds (PCG)



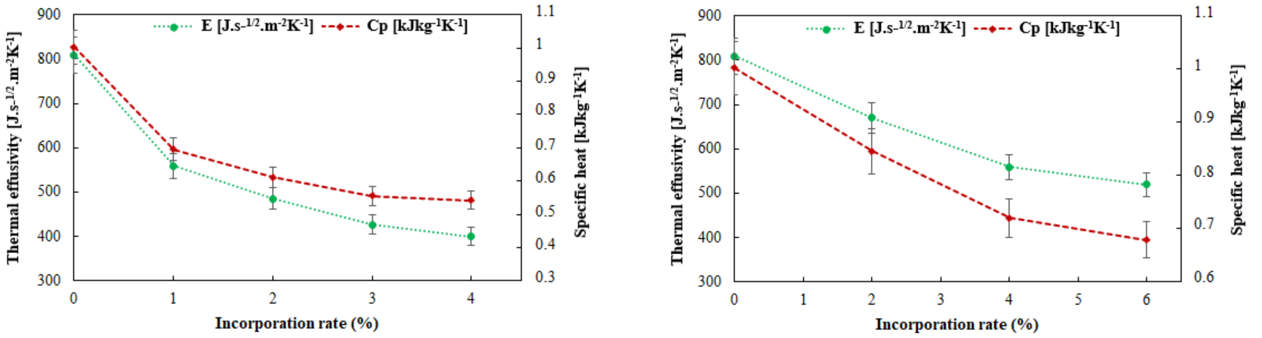
(c) Ash mortar (AM)

(d) Ash concrete (AC)

Fig. 3 - Effect of the studied dosage rate on the thermal conductivity and diffusivity

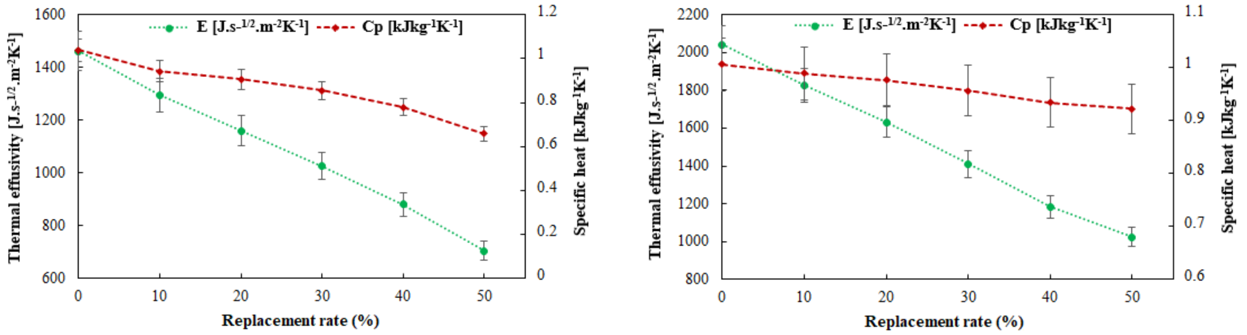
From Figure 4, it is clear that the specific heat and the thermal effusivity values of new materials are lower than those of conventional materials. The coefficient of samples specific heat and thermal effusivity variation is closer to that of thermal conductivity and thermal diffusivity. For plaster-based materials, the specific heat decreases from 1.002 to 0.542 $kJkg^{-1}K^{-1}$ for plaster with 4% alfa and 0.679 $kJkg^{-1}K^{-1}$ for plaster with 6% coffee ground. Whereas for cementitious materials, the specific heat decreases 1.039- 0.659 $kJkg^{-1}K^{-1}$ for ash mortar and 1.006-0.922 $kJkg^{-1}K^{-1}$ for the ash concrete with 50% ashes.

Concerning thermal effusivity, the reduction of thermal conductivity, specific heat and density of new materials leads to the reduction of thermal effusivity. We can observe that thermal effusivity of alpha-plaster is reduced by 50.5%, by 35.7% for the coffee grounds plaster, by 29.9% for ash mortar and by 30.8% for ash concrete.



(a) Plaster with alfa (PA)

(b) Plaster with coffee grounds (PCG)



(c) Ash mortar (AM)

(d) Ash concrete (AC)

Fig. 4 - Variation in the thermal effusivity and specific heat of samples studied

The results presented in this work demonstrate that the incorporation of alfa and coffee grounds in low amounts in the plaster matrix and the replacing cement by ashes in mortar and concrete composition can positively affect the thermal properties of these materials.

3.2 Simulation Results

For the energetic benefits assessment of new materials integration in residential houses envelope, annual dynamic thermal simulations with a step of one hour are carried out using the TRNSYS software under Moroccan climatic conditions.

The hypotheses adopted during the simulation are as follows:

- Initial temperature and humidity are set at 20 °C and 50%.
- Thermal bridges and shading effects are not taken into account.
- Heating is activated when the internal temperature is below 20 °C.
- In summer, the air conditioner is switched on when the internal temperature is above 26°C.
- Infiltration and ventilation are set at 0.6 volume per hour.
- The wall and roof absorption factor is 0.6 at the front and back.
- The long wave emission coefficient is 0.9 at the front and back.
- The internal and external convection heat transfer coefficients are respectively 3 $Wm^{-2}K^{-1}$ and 17.8 $Wm^{-2}K^{-1}$.

The energy evaluation of these new materials has been determined when they are included in the building walls composition. Plaster-based materials are used as a false ceiling and cement-based materials are used in exterior walls and floors. Table 3 show the annual energy requirements of building under study for the different configurations.

Table 3 - Buildings annual energy needs and the of CO_2 avoided amount for the various cases studied

Buildings	Bth.c $kWhm^{-2}yr^{-1}$	CO_2 amount avoided kg/yr
Build. Ref	208	-
Build. PA4%	158.55	1646.685
Build. PCG6%	165.41	1418.247
Build. AM50%	156.28	1722.276
Build. AC50%	147.62	2010.654

The use of plaster with 4% alfa as a false ceiling in the building studied reduces the annual requirements of 208 $kWhm^{-2}yr^{-1}$ to 158.55 $kWhm^{-2}yr^{-1}$, a reduction of 23.77%. While in the case plaster with 6% of coffee grounds, annual requirements decrease up to 165.41 $kWhm^{-2}yr^{-1}$ (20.47%), which shows that alfa plaster material saves more energy compared to that of coffee grounds with a difference of 3.3%. For cement-based materials inserted in the external walls and floors it is found that the maximum saving is obtained with concrete with 50% of ash where the annual requirements have decreased to 147.62 $kWhm^{-2}yr^{-1}$ while for mortar with 50% ash annual requirements reaches 156.28 $kWhm^{-2}yr^{-1}$ a decrease of 24.86%. Comparing the annual requirements with the new materials to those of the base building, we find that the proposed materials participated in reducing the energy requirements of the building with an average rate of 24.5% over the base case. On the environmental standpoint, the amount of CO_2 that can be avoided due to lowering energy consumption in the studied building is quantified (Tab. 3). Each reduced kWh corresponds to a given amount of CO_2 emissions that will be mitigated.

Based on the energy savings achieved with the news materials, the CO_2 avoided amount can be calculated using Eq (7). Table 3 show the annual amount of CO_2 avoided for the different configurations. The amount of CO_2 emissions avoided varies significantly with the amount of energy saved due to the integration of new materials in the envelope. The maximum amount of CO_2 avoided is achieved with the configuration of ash concrete thanks to the maximum savings recorded. It is of 2010.65 $kgCO_{2eq}$/yr. Followed by the configuration of the ash mortar with 1722.27 $kgCO_{2eq}$/yr, then by that of plaster alpha with 1646.68 $kgCO_{2eq}$/yr and finally we find the configuration of plaster coffee grounds with 1418.24 $kgCO_{2eq}$/yr due to the small saving realized compared to other configurations. This information can also serve as a quick tool to estimate the environmental benefits of improving the thermophysical properties of building materials.

Based on the study of each proposed material effect, the aim is to formulate a building envelope design that presents the minimum annual energy requirements and the maximum reduction of CO_2 emissions.

By comparing the results obtained, the most effective combination was selected. The annual energy requirements and CO_2 avoided quantities for the different case studies are presented in Fig. 5.

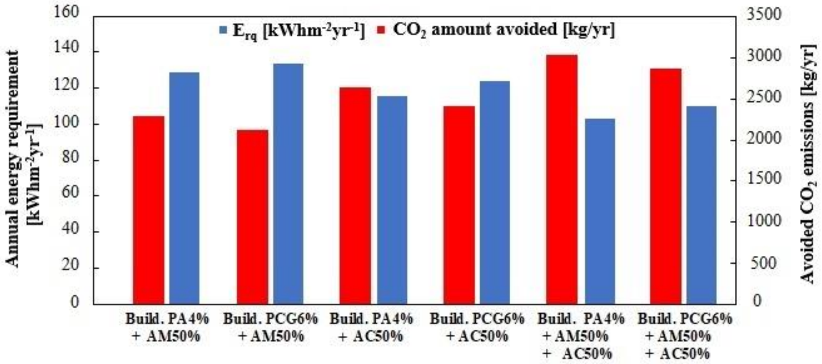


Fig. 5 - Variation in annual energy requirements and CO_2 amount avoided for different configurations studied

The insertion of alpha plaster and ash mortar and concrete in the walls composition of the studied building reduces the energy requirements by half and avoids the emission of 3029.13 $kgCO_{2eq}$/yr.

4. Conclusion

This article demonstrates the potential of using waste as a reinforcement in plaster and cement based building materials. This minimizes significant quantities of waste each year and saves the quantities of cement and plaster required for plaster mortar, cement mortar and concrete products.

In this work, a set of experiments was performed to assess the influence of adding coffee grounds and alfa fibers to plaster and replacing cement with ash in cement mortar and concrete on their thermophysical properties including conductivity, diffusivity, specific heat and thermal effusivity.

The experimental results presented show that the conductivity and thermal diffusivity of plaster decrease from 0.5 $Wm^{-1}K^{-1}$ and 3.852 10-7 m²/s to 0.228 $Wm^{-1}K^{-1}$ and 3.243 10-7 m²/s respectively with 4% of alfa fibers and to 0.31 $Wm^{-1}K^{-1}$

and 3.561 10-7 m²/s with 6% of coffee grounds. It is also noted that replacing cement with 50% of ash reduces the conductivity and thermal diffusivity of cement mortar by 39.7% and 16.8% respectively and by 49.4% and 46.2% for concrete. On the other hand, it is shown that the specific heat and thermal effusivity of the base materials studied are also significantly reduced.

The influence of the integration of new materials developed on the energy and environmental performance of buildings is tested through annual dynamic thermal simulations. It has been shown that an efficient combination integration of developed materials in a typical building envelope in Meknes contributes to a 50% reduction of annual energy needs and a limitation of 3029.13 $kgCO_{2eq}$/yr.

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