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Thermal Characterization of Concrete and Cement Mortar from Construction Sites and Industrial Production Units in the City of Ouagadougou with a View to Standardization in Energy Certification

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Abstract

The present study allowed to carry out a thermal characterization of concrete and cement mortar. Thermal tests were carried out with the KD2 Pro device, on concrete and mortar samples taken from twenty-six (26) construction sites of office buildings and two (2) industrial production units in the city of Ouagadougou. The tests were carried out on rectangular specimens after four weeks (4) of conservation on the site of construction or production of materials. This study seeks to determine the thermal properties of the materials, in particular the thermal conductivity, the thermal diffusivity and the thermal capacity of the samples, in the real conditions of execution of the buildings and environment. The thermal conductivity varies from 1.413 to 1.965 W/m·K, 0.940 - 1.658 W/m·K and 0.703 - 1.149 W/m·K respectively for concrete, cinder block mortar and plaster mortar. Regarding the other properties, especially the capacity and thermal diffusivity, the values vary respectively, from 1070.59 - 1974.67 kJ/kg·K and (3.74 - 6.70) × 10^{-7} m^2/s for concrete, from 1123.69 - 1586.81 kJ/kg·K and (3.38 - 5.65) × 10^{-7} m^2/s for plaster mortar and 1202.51 - 1736.01 kJ/kg·K and (3.82 - 7.36) × 10^{-7} m^2/s for the mortar of building blocks. The conductivity, capacity and thermal diffusivity of industrial mortar vary from 1.019 - 1.229 W/m·K, 792.18 - 1862.58 J/kg·K and (2.75 - 6.80) × 10^{-7} m^2/s, respectively. Only the correlations made between the thermal properties and the density of the samples of the plaster mortar, give good relations namely R^2 = 0.9308 for the thermal conductivity, R^2 = 0.7823 for the thermal capacity and $R^2 = 0.9272$ for the thermal diffusivity. This study contributes to the establishment of a thermal regulation in Burkina Faso for the adoption of the West African Economic and Monetary Union (WAEMU) Directive 05 on energy efficiency in buildings.

Keywords

Concrete, Mortar, Thermal Conductivity, Thermal Capacity, Thermal Diffusivity

1. Introduction

In the construction sector in Burkina Faso, several types of materials are used for the construction of buildings, including concrete, cinder block, mortar and earth materials, etc.

The national demand for cement in 2021 is estimated at 3,000,000 tons [1]. This amount of cement is mainly used in the production of some of the above-mentioned materials, for the realization of the structure, the envelope, the partitions, the buildings and many other facilities of the built environment.

The construction of buildings for public or private office use is mainly dominated by the use of concrete, cinder block and cement mortar. Indeed, these materials are qualified as definitive materials, because their mechanical and physical properties are known and quantifiable according to standardized tests. Moreover, the production methods and execution techniques of these materials are mastered by the construction actors in Burkina Faso.

Statistics from the technical services of the department in charge of construction on building permit applications show a low use of earth materials (BLT, BTC, etc.), both for private construction projects and those of the State and its branches. According to [2], who studied "The paradox of social considerations of compressed earth block building materials in Burkina Faso: materials for the poor or luxury materials", socio-cultural considerations are the main reason for the low use of these materials. Among these reasons, there is the use of earth materials perceived as a factor of poverty, symbolic perceptions related to the red color and the durability of the material over time. Increasingly, research on the characterization of earth materials is being carried out in Burkina Faso in order to determine their mechanical and thermo-physical properties. To this end, the article [3] on "Thermo-physical and mechanical study of local materials stabilized for use in housing in Burkina Faso" has characterized the BLT from two quarries (Yimdi and Bobo-Dioulasso) and BTC stabilized with lime and hibiscus canabinus fibers.

In addition, the implementation of Directive No. 05/20207CM/UEMOA laying down energy efficiency measures for buildings in WAEMU member states adopted in 2020 requires each member country to apply minimum thermal standards for the building envelope. The implementation of this directive requires knowledge of the thermal properties of building materials in the construction sector.

However, the literature encountered is not sufficiently supplied with thermal characterization studies of concrete and cement mortar produced in Burkina. At the international level, the question is widely addressed by several authors. For example, a study in [4] carrying out the "non-destructive evaluation of reinforced concrete structures" shows that the thermal properties of these materials depend not only on the nature and thermal properties of the aggregates but also on their proportions in the concrete and cement mortar; as well as the nature of the cement [5]. The aggregates used in the production of concrete and cement mortar on building sites and industrial units are of various nature and form (granite crushed, sand, gravel, quarry sand, quartz etc.). This is why it is essential to have the thermal properties of these construction materials in order to better study the energy performance of buildings.

This study contributes to the standardization of construction materials through the thermal characterization of concrete and cement mortar produced on construction sites and in industrial units in the city of Ouagadougou.

2. Samples Characterization Methodology

The characterization of a material consists in analyzing the properties from in situ or laboratory tests, following well defined scientific principles and methods. Thermal characterization, in particular, consists in determining the thermal properties of samples. These properties allow the study of the behavior of materials with respect to thermal stresses.

2.1. Choice of Construction Sites

The identification of the construction sites was done with the help of the National Laboratory of Buildings and Public Works (LNBTP). The main selection criterion was the type of use of the buildings under construction. For this reason, only sites where the buildings under construction are for office use were included in this study. A total of twenty-six (26) construction sites were identified in the city of Ouagadougou. All of the construction sites identified are large and complex, ranging from single-storey to 10-storey buildings. **Figure 1** and **Figure 2** illustrate some of the construction sites through images.

Given the increase in the number of industrial production units in Burkina Faso and particularly in Ouagadougou, it is important to know the thermal properties of the materials produced there. This is why we identified two industrial units in order to characterize the mortar of cinder block which they produce.

All the construction sites listed for this study are geolocated and **Figure 3** represents the mapping of the construction sites and industrial units.

Figure 1. Headquarters of the FBDES in Ouaga 2000.

Figure 2. CORIS BANK building in area ZACA.

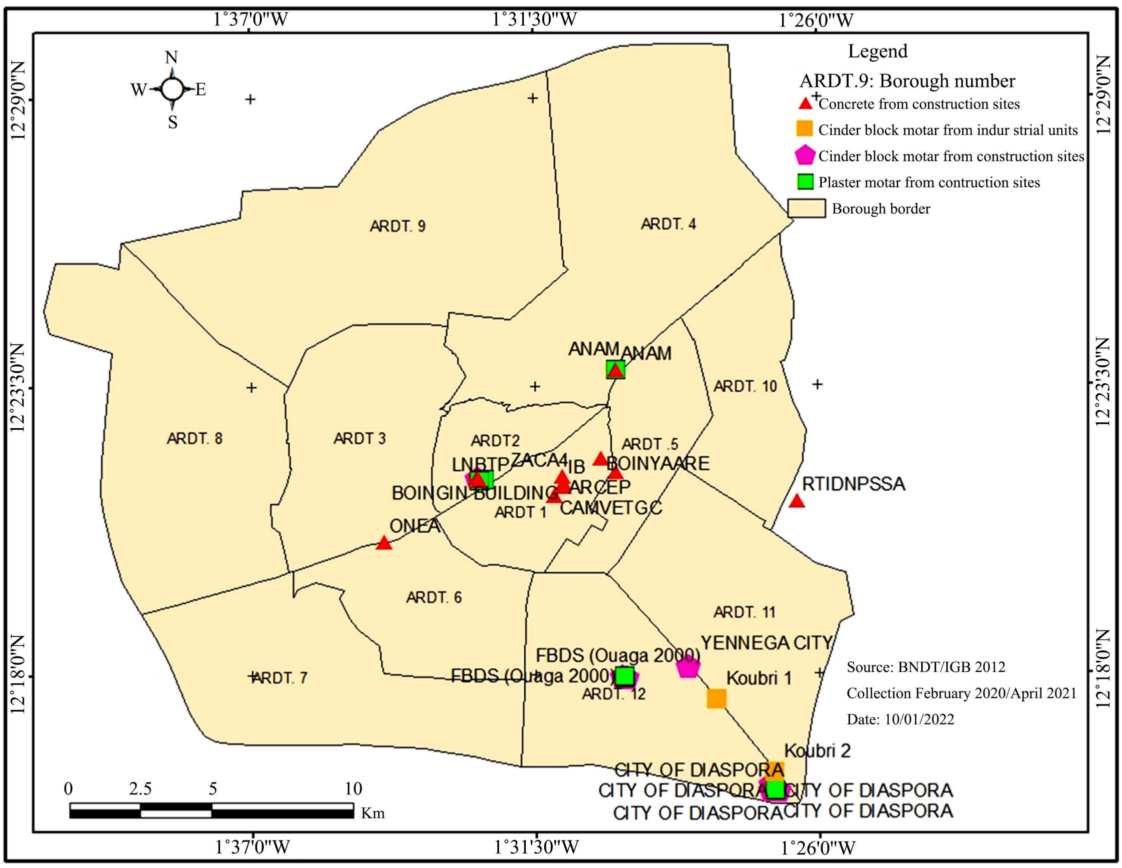

Figure 3. Mapping of construction sites and production units.

2.2. Sampling and Treatment of Test Pieces

Two types of molds are used to collect the material samples. The single-test molds with dimensions 40 cm × 20 cm × 10 cm (**Figure 4**) and the triple-test molds with dimensions 20 cm × 20 cm × 10 cm (**Figure 5**). These two types of molds were used for both the concrete samples and the two types of cement mortar.

The concrete samples are taken from the batches formulated at the time of the execution of the elements of the structure, in particular the columns and the floors. For the whole of the building sites the dosage of the concrete in cement is 350 kg/m^3. The samples of mortar of coating are taken during the execution of the plastering of the walls of the buildings and during the confection of the cinder blocks on site for the mortar of cinder block. The rendering mortar and the cinder block mortar are respectively dosed at 400 kg/m^3 and 350 kg/m^3. The aggregate and cement compositions of the materials collected are given in **Table 1**.

Figure 4. One-tube mold.

Figure 5. Triple-tube mold.

Table 1. Granular and cementitious composition of materials per cubic meter.

	Materials	Crushed granite (5/15 or 15/25)	River sand (0/3)	River sand (0/5)	Quarry sand (0/5)	Cement/CEM I
	Concrete	0.6 Volume	-	0.4 Volume	-	350 kg
Mortar	**Plaster**	-	1 Volume	-	-	300 kg
	Construction site cinder block	-	-	1 Volume	-	300 kg
	Industrial cinder block	-	-	-	1 Volume	300 kg

The concrete, cinder block mortar, and render mortar samples were taken in situ and unannounced. This avoided circumstantial batch formulations for the purpose of the study. Thus, the samples taken will faithfully reflect the real thermal properties of these materials in the local context of building construction projects in Burkina Faso.

For the first phase, five (05) specimens per type of material are taken on each building site, during the second phase the number of specimens is reduced to three (03). At the level of the industrial units, four (04) specimens of cinder-block mortar are taken on each site. Figures 6-9 show the images of the specimens of the various materials.

Figure 6. Plaster mortar.

Figure 7. Mortar of cinder block (Building site).

Figure 8. Mortar of cinder block (industrial).

Figure 9. Building site concrete.

The curing of the various specimens was carried out on the construction sites for the concrete, rendering mortar and cinder block mortar samples and on the manufacturing sites for the industrial cinder block mortars, thus undergoing the same local climatic conditions as the construction materials of the buildings. After four weeks on site, the samples are transported to the laboratory for thermal testing.

2.3. Thermal Properties and Characterization Methods

The different properties characterizing materials are defined by physical quantities that are all functions of temperature. The study of the thermal properties of materials, consists in determining by a recognized method the thermal conductivity (λ), the thermal capacity (Cp), the thermal diffusivity (α), the thermal resistance (r) and the thermal effusivity (E) [6].

Several methods allow to characterize the thermal properties of a material. These are steady state methods (hot plate, box method), and transient methods. All these methods are applicable, knowing that the objective to be reached when one wants to carry out an experimental study is the precision and the reliability of the results [7]. He shows that the choice of a method will depend on several factors, the most important of which are:

- The reliability of the results and the duration of the measurement;
- The cost of acquisition and maintenance of the measuring devices as well as their robustness;
- And the availability of the devices.

With regard to these factors, the method used by the KD2-Pro instrument, which has advantages in terms of simplicity of use, speed of measurement and the ability to operate in situ in any hygrothermal conditions, and respecting the physical state of the environment is used [8]. The KD2 Pro instrument is equipped with heated needle probes developed by the Decagon Company (2009) to simultaneously measure thermal conductivity (λ), thermal diffusivity (α), heat capacity (Cp) and thermal resistance (r). The SH-1 probe adapted for solid and granular materials is used in this study.

The duration of the measurement depends on the volume of the specimen; the more voluminous the specimen, the longer the time required to obtain accurate results. With regard to the dimensions of our specimens given above, a duration of ten (10) minutes is retained for the measurement time. In order to take into account, the thermal gradient, fifteen (15) minutes of pause are observed between two successive measurements to allow the probe to cool down. **Figure 10** and **Figure 11** illustrate images of the thermal tests performed.

2.4. Results and Discussions

2.4.1. The Density of Materials

Table 2 represents the mass densities of the concrete, cinderblock mortar and plaster mortar samples and the cinderblock from the construction sites and production units. These values are obtained from the ratio between the measured masses and the volume of each sample.

Figure 10. Thermal testing of cement mortar samples.

Figure 11. Thermal testing of concrete samples.

Table 2. Density of samples (kg/m³).

Sites	Concrete from construction sites	Cinder block mortar from construction sites	Plaster mortar from Construction sites	Cinder block mortar from industrial unit
Site 1	2095	1977	1703	2109
Site 2	2273	1970	1714	2153
Site 3	2606	1927	1483	-
Site 4	2683	1781	1491	-
Site 5	2471	1873	1683	-
Site 6	2333	1955	-	-
Site 7	2821	1731	-	-
Site 8	2713	2185	-	-
Site 9	2650	-	-	-
Site 10	2550	-	-	-
Site 11	2371	-	-	-
Site 12	2467	-	-	-

2.4.2. Thermal Properties of Concrete Samples

Figure 12 shows the thermal conductivities and thermal capacities and Figure 13 the thermal diffusivities of the concrete samples from the sites studied. The values presented are averages obtained on the three (03) or five (05) specimens taken from each site.

The thermal conductivity values of the concrete samples measured vary between 1.413 ± 0.21 and 1.965 ± 0.02 W/m·K. The thermal properties of the cement paste, the nature of the aggregates and their proportions in the concrete could justify these differences. Indeed, [9] shows that the porosity and the water content influence strongly the thermal conductivity and the thermal capacity of the cement paste and of the aggregates, thus on that of the concrete. For [10], the difference in density is also a reason for the differences in these values.

Moreover, the average thermal conductivity deduced from these values for all the sites is 1.73 ± 0.16 W/m·K. This average value of the thermal properties of the concrete of the sites of the city of Ouagadougou is similar to that of [11].

The values of the thermal capacities obtained range from 1.071 ± 0.17 to 1.975 ± 0.11 kJ/kg·K. These differences are relatively proportional to those found in the densities (see Table 2) of the same samples. This is also the same observation made by [12] in his study entitled "structural concrete with improved thermal insulation properties: experimental approach". Indeed, he shows that the thermal capacity increases with the increase of the density.

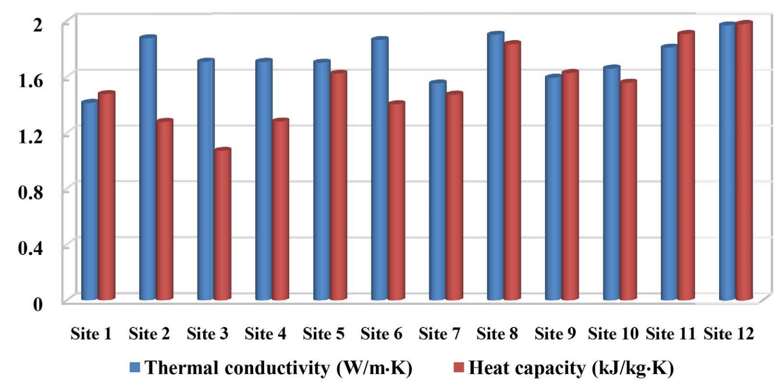

Figure 12. Conductivity, heat capacity of concrete samples from construction sites.

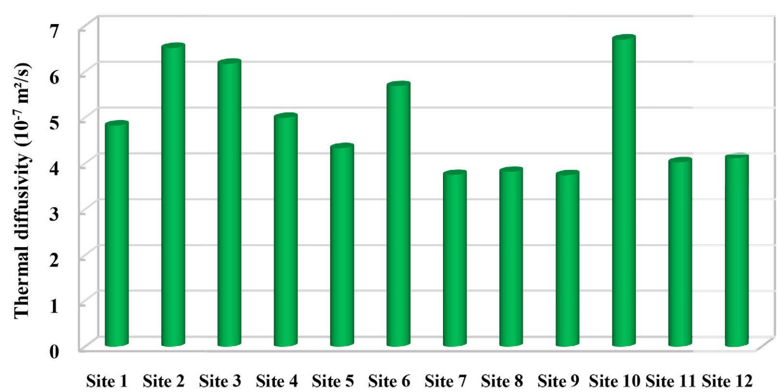

Figure 13. Thermal diffusivity of concrete samples from construction sites.

Similarly, it appears that the values of the heat capacity of concrete for all the sites are higher than those found in [11] whose values vary from 0.850 to 0.950 kJ/kg·K for concretes of density between 2200 - 2400 kg/m³. These differences could be explained by the difference in specific heats, proportions of aggregates (crushed granite and sand) according to [13], and the difference in water content of the samples according to [12].

Figure 13 shows the thermal diffusivities of the concrete samples from the studied sites. The values presented are averages values obtained on the three (03) or five (05) specimens taken from each site.

The thermal diffusivity values of concrete in construction sites between 3×10^{-7} m²/s and 7×10^{-7} m²/s are in agreement with the literature, in particular those of [14] [15] [16].

2.4.3. Thermal Properties of Cinder Block Mortar Samples from Construction Sites

Figure 14 shows the thermal conductivities and thermal capacities, and Figure 15 shows the thermal diffusivities, of the cinder block mortar samples from the construction sites.

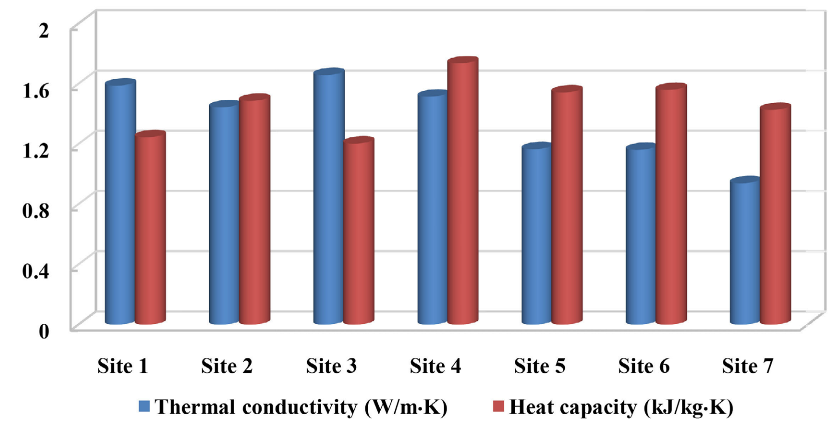

Figure 14. Conductivity and heat capacity of cinder block mortar samples from construction sites.

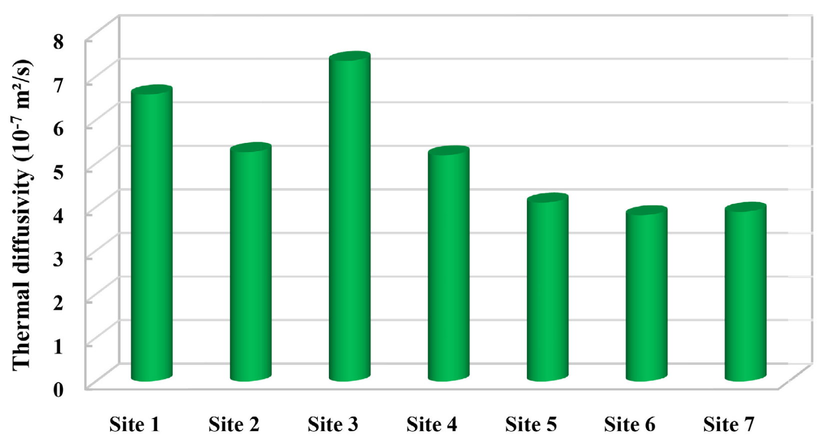

Figure 15. Thermal diffusivity of cinder block mortar samples from construction sites.

We note a variation in the values of the thermal conductivity of the mortars of the building sites ranging from 0.940 ± 0.069 to 1.658 ± 0.09 W/m·K. This variation can be explained by the difference in the proportions of sand/water/cement [17] [18] in the mortar batches formulated on the building sites.

The average thermal conductivity calculated on all the sites is 1.353 ± 0.266 W/m·K. This value is higher than that obtained for the rendering mortar which is 0.940 ± 0.214 W/m·K. This result is explained on the one hand by the combined effects of the difference in sand grading (fine sand 0/5 used for the rendering and coarse sand 0/10 used for the cinder block) and the difference in cement dosage (paragraph 2.2) used in the two materials and on the other hand by the non-respect of the prescribed aggregates and cement dosage.

The correlations established between thermal conductivity and porosity by [19] in his study "correlation between P-wave velocity and thermal conductivity of heterogeneous and porous materials" and by [20] in his study "thermal properties of cement mortar with different proportions of mixture" give good dependency relations. These authors show that the thermal conductivity decreases with increasing porosity, with coefficients $R^2 = 0.9138$ and $R^2 = 0.95$ respectively. These two studies allow us to see the existing relationship between the grain size of the sand and the thermal conductivity of the cement mortar for the rendering or for the cinder block.

The interpretation of the results of [19] and [20] suggests that the finer the sand, the lower the thermal conductivity of the formulated mortar. This assertion is only valid in cases where the cement dosages are the same because [21] in his study shows that the thermal conductivity increases with the increase of the cement dosage and with the water content according to [22].

The values of the thermal capacity of the cinder block mortars of the construction sites obtained vary between 1.203 ± 0.31 and 1.736 ± 0.21 kJ/kg·K. For [23] the density of the samples could explain these differences. The average heat capacity obtained on all the building sites is 1.490 ± 0.186 kJ/kg·K.

The thermal diffusivity values of the cinderblock mortar samples taken from the construction sites obtained range from 3.82×10^{-7} m²/s to 7.36×10^{-7} m²/s. The calculated average value is 5.18×10^{-7} m²/s. These average values of thermal diffusivity of the cinder block mortar from the construction sites are lower than those of [20] which are of the order of 10^{-6}.

2.4.4. Thermal Properties of Plaster Mortar Samples from Construction Sites

The thermal conductivities, thermal capacities and thermal diffusivities of the plaster mortar taken from the building sites are given in **Figure 16** and **Figure 17** below. These are the average values of the samples per site.

The thermal conductivity of plaster mortars varies from 0.703 ± 0.04 to 1.149 ± 0.18 W/m·K. As with concrete, the thermal properties of cement mortar depend on those of the cement paste, sand and their proportions [13]. The difference is mainly dependent on the proportions of sand/water/cement in the

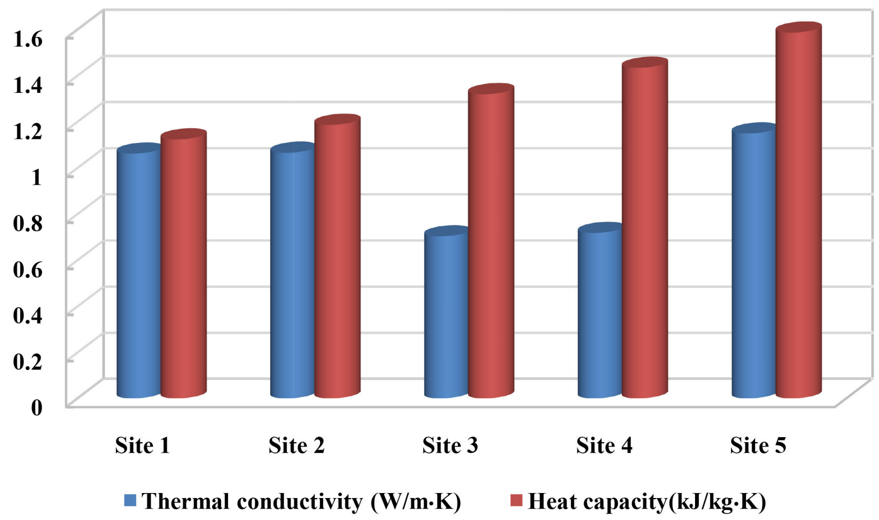

Figure 16. Thermal conductivity and capacity of plaster mortar samples from construction sites.

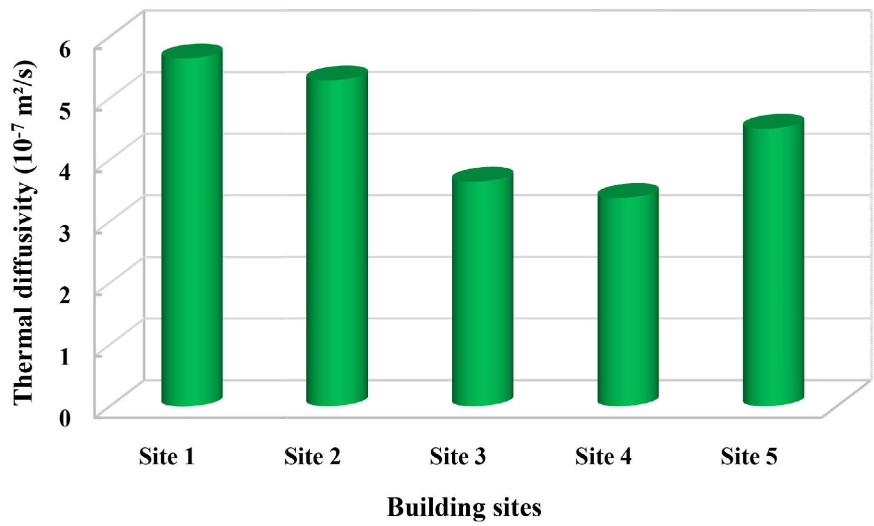

Figure 17. Thermal diffusivity of plaster mortar samples from construction sites.

construction sites according to [17]. The same study shows that the conductivity of cement mortar decreases with increasing sand ratio. Indeed, with the increase of the sand rate, the global porosity would be reduced but the porous structure (closed porosity) could be improved with finer pores with the consequence of the decrease of the conductive surface of the material.

Due to the absence of technical control and the lack of rigor in the control of the execution, sometimes accompanied by a motivation of easy gain, the formulation of the rendering mortars in the building sites does not necessarily respect the technical prescriptions.

Nevertheless, without making a comparison, the average thermal conductivity 0.940 ± 0.214 W/m·K of the rendering mortar obtained on all the sites remains relatively similar to that of [11] which is 1.15 W/m·K.

The values of the thermal capacities ranging from 1.124 ± 0.102 to 1.587 ± 0.09 W/m·K are higher than the values found in [11]. These values are evidence of the heat storage capacity of the plasters contributing strongly to the total thermal capacity of the envelope walls of the constructed buildings. The average thermal diffusivity value calculated for the plaster mortar is 4.49 × 10^{-7} m^2/s.

2.4.5. Thermal Properties of Cinder Block Mortar Samples from Industrial Units

With regard to the increasingly important investments in the construction of buildings, the increase of the industrial units of production and for the taking into account of the requirements of the directive 05 of the WAEMU on the energy efficiency of the buildings, it is necessary to study the thermal properties of the materials which are produced there. One notes an increasingly important demand of industrial cinder blocks on the building sites, the current tendency is to give up the manual production to the benefit of the industrial production.

The values of the thermal conductivities presented in Figure 18 are averages values obtained with the five (05) specimens of each industrial unit. We note a small difference in values of thermal properties studied between the two production units. The respect of the cement dosage and the use of the same type of granulometry of quarry sand could justify this result.

The average thermal conductivity 1.132 ± 0.043 W/m·K obtained from the two units is lower than that of the cinder block mortar from the construction sites. The average heat capacity obtained from all the industrial units is 1.151 ± 0.141 kJ/kg·K and the average thermal diffusivity is (4.97 ± 0.426) × 10^{-7} m^2/s.

2.4.6. Relationship between Thermal Properties and Densities of Concrete and Mortar Samples from Construction Sites and Industrial Units

1) Correlation between thermal conductivity and density of samples

Figures 19-22 present the results of the different correlations carried out between the thermal conductivities of concrete and cement mortar samples taken

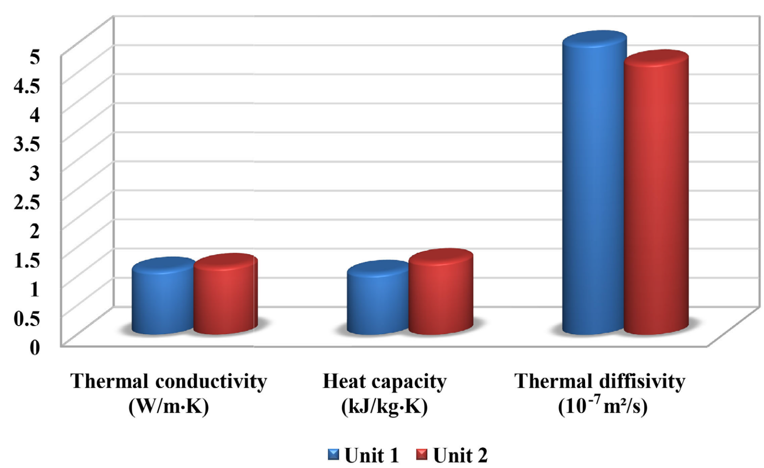

Figure 18. Thermal conductivity, capacity and diffusivity of cinder block mortar samples from industrial units.

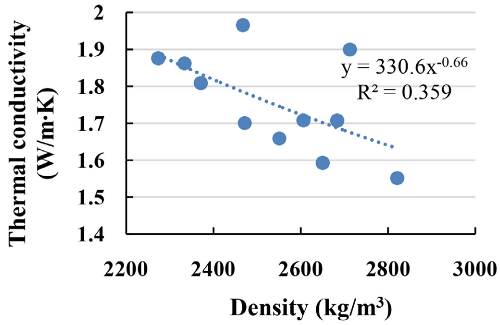

Figure 19. Correlation between thermal conductivity and density of concrete from construction sites.

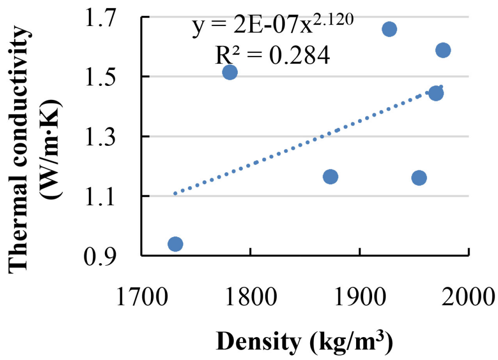

Figure 20. Correlation between thermal conductivity and density of cinder block mortars from construction sites.

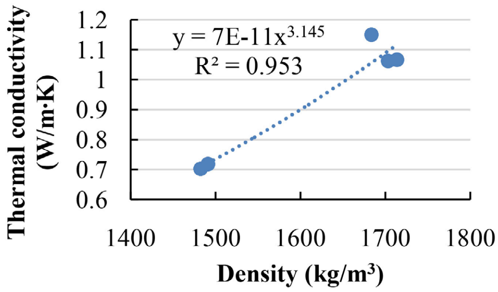

Figure 21. Correlation between thermal conductivity and density of plaster mortar from construction sites.

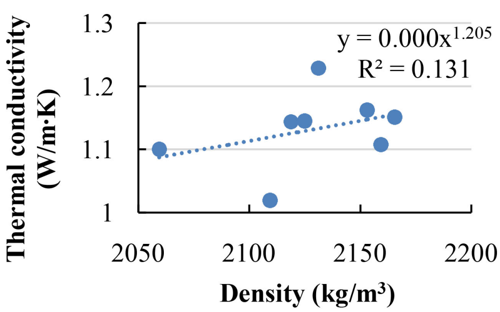

Figure 22. Correlation between thermal conductivity and density of cinder block mortar from industrial units.

on building sites and industrial production units. Only the power law presents the highest correlation coefficients compared to the other laws (linear, polynomial, exponential).

The correlation coefficient between the thermal conductivity and the density of the rendering mortar is the highest (R^2 = 0.9308), it reflects a good dependence between these two properties. This is also the observation made by [24] in his study of the physical-thermal properties of mortars based on composite aggregates. The study of the influence of the water content on the thermal conductivity of external thermal mortars of [25], leads to a similar result (R^2 = 0.8779) with the exponential law, while [20] obtains good results with the polynomial law where the correlation coefficient is R^2 = 0.9258.

The good relationship of dependence between the thermal properties and the density of the rendering mortar is probably linked to the respect of the quality of the aggregates and the formulated batches, taking into account the rigor applied during the rendering works. This allows to have an almost identical quality of the rendering mortar on the studied sites.

2) Correlation between heat capacity and density of samples

The correlations made between the thermal capacities and the densities of the concrete and cement mortar samples are presented in **Figures 23-26** below.

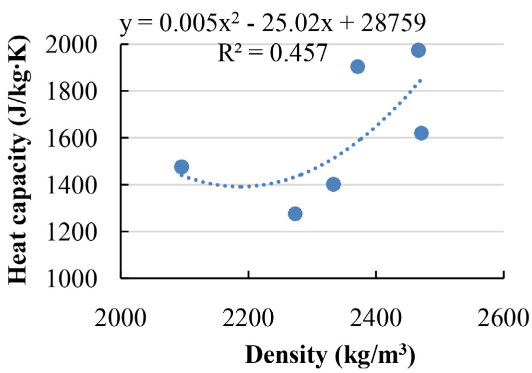

Figure 23. Correlation between the thermal capacity and density of concrete from construction sites.

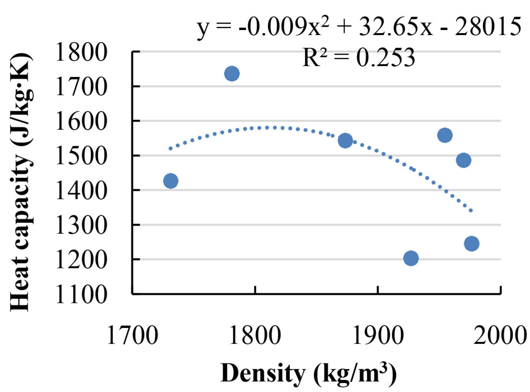

Figure 24. Correlation between heat capacity and density of cinder block mortars from construction sites.

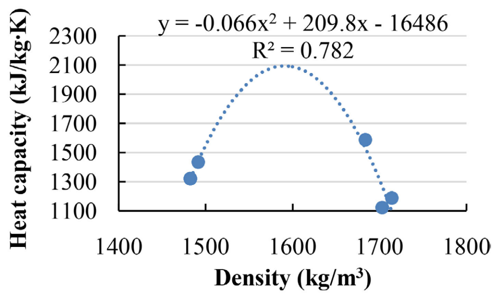

Figure 25. Correlation between thermal capacity and density of plaster mortars form construction sites.

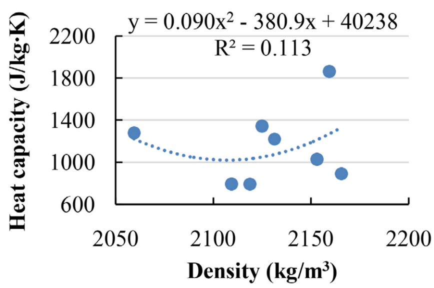

Figure 26. Correlation between thermal capacity and density of cinder block mortars from industrial units.

The correlation between the thermal capacity and the density of plaster mortars gives acceptable results (R^2 = 0.7823); this result is similar to that of [12]. For concrete, construction mortar and industrial mortar, the correlation coefficients obtained are low. This reflects a weak dependence between the thermal capacity and the density of these materials.

3) Correlation between thermal diffusivity and sample density

We note very low values of coefficients for the correlations carried out between the thermal diffusivities and the densities of the samples of concrete, mortar of cinder block taken on building sites and the mortar of cinder block of the industrial units (**Figures 27-30**). These coefficients reflect a weak dependence between the thermal diffusivity and the density of these materials. The correlation coefficient R^2 = 0.9272 between the thermal diffusivities and the densities of the samples of plaster mortar taken on the building sites, illustrates a strong dependence of these properties, this result is in agreement with the work of [20].

2.4.7. Proposal of Thermal Properties of Concrete and Mortar for Thermal Regulation in Burkina Faso

Within the framework of the implementation of a thermal regulation and to take into account the community texts on the energy efficiency of buildings, it is essential for Burkina Faso to have the thermal properties of the construction materials. This study will contribute to the achievement of this objective through the thermal characterization of concrete and mortar from construction sites and industrial units.

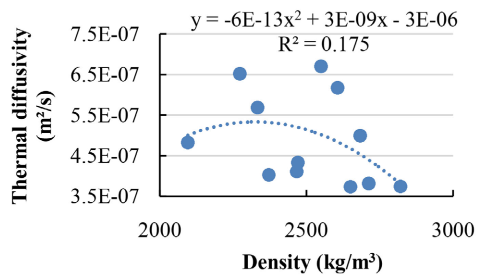

Figure 27. Correlation between thermal diffusivity and density of concrete from construction sites.

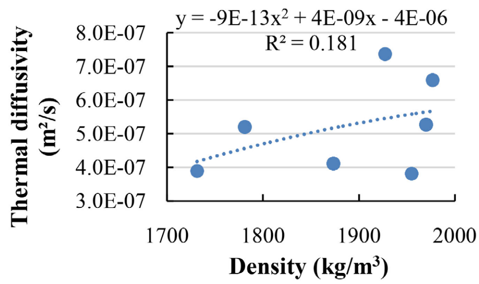

Figure 28. Correlation between thermal diffusivity and density of cinder block mortars from construction sites.

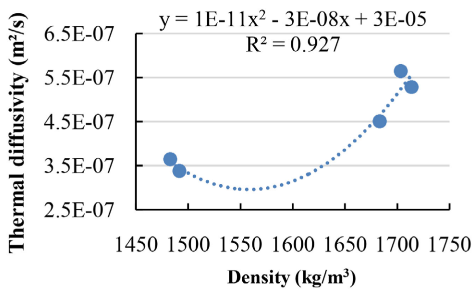

Figure 29. Correlation between thermal diffusivity and density of plaster mortars from construction sites.

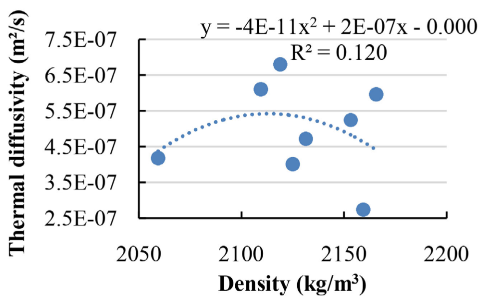

Figure 30. Correlation between thermal diffusivity and density of cinder block mortars from industrial units.

To do this, the values of thermal properties and densities of concrete and cement mortar from construction sites and industrial units are summarized in Table 3 below.

Table 3. Thermal properties of concrete and cement mortar materials taken.

Materials		Thermal conductivity (W/m·K)	Thermal capacity (J/kg·K)	Thermal diffusivity (*10^{-7} m^2/s)	Density (kg/m^3)
Concrete		1.413 - 1.965	1070.59 - 1974.67	3.74 - 6.70	2095 - 2700
Mortar from construction sites	**Plaster**	0.703 - 1.149	1123.69 - 1586.81	3.38 - 5.65	1400 - 1800
	Cinder block	0.940 - 1.658	1202.51 - 1736.01	3.82 - 7.36	1700 - 2200
Cinder block mortar from industrial units		1.019 - 1.229	792.18 - 1862.58	2.75 - 6.80	2050 - 2200

3. Conclusions

This study provides an answer to the problem of standardization of construction materials in Burkina Faso through the thermal characterization of concrete and cement mortar produced by mechanical and industrial processes in the city of Ouagadougou.

At the end of the thermal tests carried out with KD2 Pro on the samples taken in the construction sites, we note that the thermal conductivity varies from 1.413 - 1.965 W/m·K, 0.940 - 1.658 W/m·K and 0.703 - 1.149 W/m·K respectively for concrete, cinder block mortar and render mortar samples; thermal diffusivity varies from 3.74 - 6.70 10^{-7} m^2/s, (3.82 - 7.36) × 10^{-7} m^2/s and (3.38 - 5.65) × 10^{-7} m^2/s and respectively for concrete, cinder block mortar and render mortar samples. On the other hand, for the cinder block mortar samples taken from the industrial units, the thermal conductivity and thermal diffusivity vary from 1.019 - 1.229 W/m·K and (2.75 - 6.80) × 10^{-7} m^2/s respectively.

There is a strong dependence between the thermal properties and the density of the mortar samples, as evidenced by the values of the correlation coefficients R^2 = 0.9308 and R^2 = 0.9272 obtained respectively, between the density and thermal conductivity and between the density and thermal diffusivity of the samples.

For a greater representativeness and a better appreciation of the thermal properties of these materials, this study should not only be extended to all the cities of Burkina Faso, but also be compared with the results of thermal tests to be carried out on samples formulated in the laboratory.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Nomenclature

FBDES: Burkinabe Economic and Social Development Fund

ZACA: Zone of commercial and administrative activities

λ: Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)

C: Thermal capacity (J/kg·K)

α: Thermal diffusivity (m^2/s)

E: Thermal effusivity ($J \cdot K^{-1} \cdot m^{-2} \cdot s^{-1/2}$)

r: Thermal resistance ($m \cdot K \cdot W^{-1}$)

ρ: Density (kg/m^3)