Transformation Process and Thermal Performance Assessment of Burkina Faso's Housing Typologies

Maria Aguilar-Sanchez , Jose-Manuel Almodovar-Melendo * , Joseph Cabeza-Lainez

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Article

Transformation Process and Thermal Performance Assessment of Burkina Faso's Housing Typologies

Maria Aguilar-Sanchez, Jose-Manuel Almodovar-Melendo * and Joseph Cabeza-Lainez

Department of Architectural Composition, University of Seville, Av. Reina Mercedes 2, 41012 Sevilla, Spain
* Correspondence: jmalmodovar@us.es

Abstract: Burkina Faso is a sub-Saharan African country with a high poverty rate that has quadruplicated its population in the last half fifty years, that is, from 4.5 to 18 million inhabitants. Such demographic changes together with an intense migration process from rural areas to large cities, among other issues, are contributing to a rapid process of socio-cultural transformation. In this context, changes in both traditional and contemporary housing are analyzed and a complete thermo-hygrometric evaluation is carried out by processing significant data from on-site measurements to shed new light on the response of the said dwellings to the environmental and local cultural values. Results show that the introduction of land ownership linked to climate change and the increasing scarcity of natural resources are forcing native ethnic groups to modify their traditional ways of life, threatening their subsistence. Consequently, we can prove that the new building typologies are not in the least suitable for the climatic conditions nor the rich cultural heritage of Burkina Faso. This fact, negatively affects the possibility of revitalizing vernacular and environmentally-oriented solutions for the contemporary world and the necessary advance towards a more sustainable architecture.

Keywords: Burkina Faso; vernacular architecture; thermal performance; sustainable architecture; physical testing-mockups

1. Introduction

Burkina Faso is in fact one of the poorest countries in the world and is currently undergoing a lasting food scarcity. Likewise, the terrorist conflicts that have taken place in Mali [1] are affecting the country's borders and therefore, the population has been subject to territorial isolation in the last years. Added to these problems is the current political instability.

Moreover, the high demographic increment during the last half century, from 4.5 to 18 million inhabitants, and the intense migration from the countryside to large cities are contributing to a demand for housing greater than the one that can be reasonably supplied [2]. As a consequence, informal settlements are growing on the urban peripheries. Likewise, the typical dream of becoming a home proprietor is becoming more widespread, since it is associated with possessing economic wealth and is also a sign of social success [3].

Although Burkina Faso's pre-colonial history does not exclude conflicts, colonization has largely conditioned the heritage of the ethnic groups who had inhabited the country for centuries, as well as it completely changed the structure of the territory [4]. After the independence from France in 1960, the current neocolonialism and the problems outlined above are also producing a negative effect in the protection of the country's cultural heritage. All this is generating relevant transformations in the housing typologies and ways of life, which are increasingly different from their secular tradition [5].

However, Burkina Faso continuous to be an interesting country from the anthropological point of view due to the great variety of cultures that coexist in the same nation [6]. We believe the diversity of Burkinabe ethnic groups also results in a great architectural richness, since they still largely preserve their ancestral ways of life and traditions. In this regard, it must be noted that the last General Population and Housing Census of Burkina Faso shows that 26.3% of the country's population lives in traditional dwellings [2].

In fact, Burkina Faso is a good example of how the harmonious interaction between climate, available natural resources and local ways of life can generate architectural solutions with positive

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values in terms of cultural identity and environmental quality [7, 8]. They represent a set of systems by which a culture has interacted with the environment using the limited resources available in a specific place and moment, to obtain appropriate habitability conditions [9].

Most studies on vernacular architecture have focused on merely formal or compositional features. Only rarely, reference is made to their relationship with local cultures or environmental conditions [10, 11]. Fortunately, this trend has been changing in recent years and nowadays, traditional concepts and techniques are being considered by many architects as a source of knowledge to revitalize solutions from the past and move towards a more sustainable architecture [12, 10].

In the case of vernacular houses in Burkina Faso, traditional construction typologies and techniques represent an important legacy that is not being sufficiently studied. In fact, there are only a few research groups researching vernacular solutions in the West African context. Among the exceptions, we can highlight the CRAterre group and the Association La Voûte Nubienne. Belonging to the first, Basile Kéré [13] is one of the few authors who has disseminated the diversity of local cultures and vernacular architecture in Burkina Faso. It is also worth mentioning the work coordinated by Jean Baptiste Kiéthega [14], which stands out for the detailed study of ancestral knowledge and makes relevant contributions to the heritage conservation and permanence of local cultural identity. Prize-winner Architect Diébédo Francis Kéré is also a prominent figure in this respect.

We want to highlight that the word housing symbolizes in many African languages the clan or lineage as a concept of belonging to a community; thus the process of affiliation or allegiance begins. Consequently, when problems arise around the concept of housing in an African society, they are transferred to its own identity [15].

This manuscript aims to cast new light on the causes and effects of the traditional typologies' process of transformation and the appearance of new housing models. We seek to identify the difficulties of different ethnic groups to maintain their customs and traditions, and the causes leading to these changes, especially those related to the abandonment or transformation of vernacular architectural typologies. In addition, we have carried out a scientific evaluation of the thermal performance of selected typologies, both traditional and contemporary, by resorting to on-site measurement to objectively know if they respond to environmental requirements.

In accordance with the objectives, this work is structured in three phases. First, climatic factors are analyzed to understand the natural environment. Subsequently, housing typologies in Burkina Faso, both traditional and contemporary, are classified and analyzed. More specifically, the formal aspects, construction systems, ways of living and thermal behavior are assembled to find out their response to environmental requirements. The work is focused on a typological analysis in order to understand the process of transformation from traditional to contemporary dwellings and their connection with the local cultures and ways of life. Finally, results are discussed, in order to obtain conclusions regarding their causes and effects.

2. Climatic factors

According to the Köppen climate classification, two types of climate can be found in Burkina Faso. Climate A or Tropical Savannah (Aw), in the southern zone; and Climate B or arid, which corresponds to the central and northern areas. There are two variants in the Climate B, Warm Semi-arid (BSh) and Warm Arid (BWh) [16] (Figure 1).

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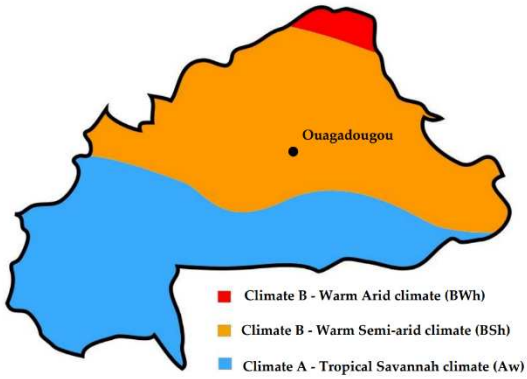

Figure 1. Köppen climate zones in Burkina Faso.

This article focuses on a housing typology analysis in the central area since it is the largest, the most populated and where the capital Ouagadougou lies. This area has a warm semi-arid climate (Bsh), with rainfall concentrated from June to September. During this more humid period the maximum temperature is lower, as well as the daily thermal amplitude. Climate data and design guidelines from Ouagadougou are shown below in a psychrometric chart using Climate Consultant (Figure 2).

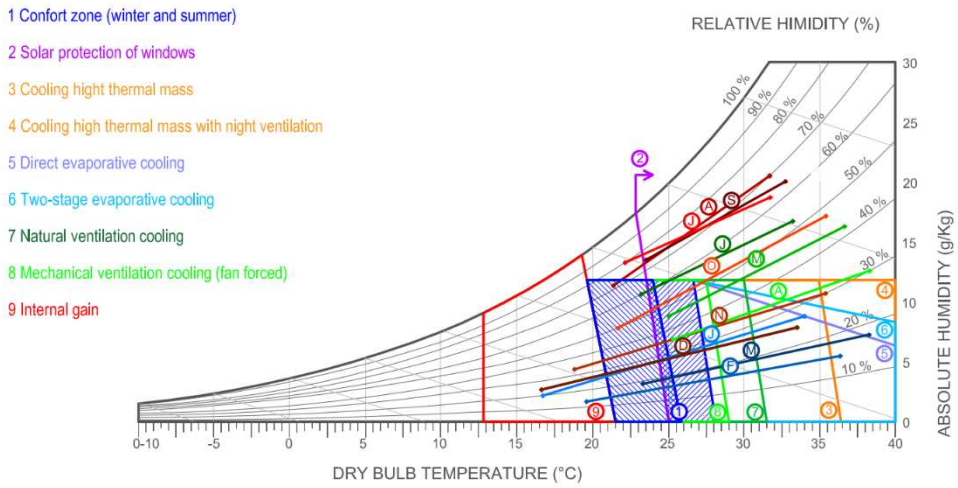

Figure 2. Psychometric chart at Ouagadougou plotted by means of weather consultant.

We must note that climate change is marking a great impact on Burkina Faso. The interactions between soil, vegetation and atmosphere are altering notably rainfall and extending the water shortage period [17]. This fact is causing soil erosion that affects biodiversity and the availability of natural resources. Breil, Panitz and Schädler [18] demonstrate the impact of this process in Sub-Saharan Africa and its consequences in the traditional ways of life in Burkina Faso which are closely connected to Nature's cycles [19].

3. Classification and analysis of housing typologies

In Burkina Faso a clear distinction can be traced between rural and urban habitat, as well as traditional and contemporary architecture. Traditional living models are quite diverse due to the existence of more than seventy different ethnic groups [20]. However, these differences decrease in the cities, where similar housing typologies are found regardless of the ethnic group of origin. Vernacular houses are still 26.3% of the total. However, in urban areas, traditional architecture represents only 3.4%, and more specifically 0.1% in the capital city, Ouagadougou [2].

Due to the great number of ethnic groups and different cultures that coexist in Burkina Faso, the analysis of each of them is not convenient, also because many houses from different ethnic groups present similar characteristics [14]. As we move north, there is a greater presence of temporary housing typologies since non-sedentary ethnic groups, such as the Peul (also known as Fulani or Fula

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people), migrate from north to south as a function of their needs. We will therefore focus the typological analysis on the temporary Peul houses and the sedentary houses inhabited mainly by the Mossi. However, there are other constructions located in very specific areas of the country, such as the troglodytes (excavated in the rock) and the Bobos of Kwa, the bamboo houses of the Senóufos-Goins in Bamfora, etc.

Contemporary homes present significant changes compared to traditional homes and do not correspond to any particular ethnic group, since they are not linked to a specific culture or place but to a certain socio-economic level.

According to the official classification made by the Ministry of Habitat and Urbanism of Burkina Faso [2] and the information from the Population and Inhabitation General Census [4], we have established the following typological classification (Table 1).

Table 1. Housing typologies.

	Nomenclature	Brief description	Location
PTH	Peul traditional house	Traditional temporary house of the Peul ethnic group built with wood and thatch	Rural
MTH	Mossi traditional house	Traditional house made of earth, wood and straw built by the Mossi and other ethnic groups	Rural and urban
PH	Popular house	Detached house with private courtyards and no basic services	Rural and urban
SCH	Share courtyard house	Several dwellings located in the same lot sharing a common courtyard	Urban

Figure 3 indicates the percentage for each typology in the whole country. The PH is the most common typology in Burkina Faso, with 60.8%, followed by the traditional typologies (26.3%) and the SCHs (7.3%).

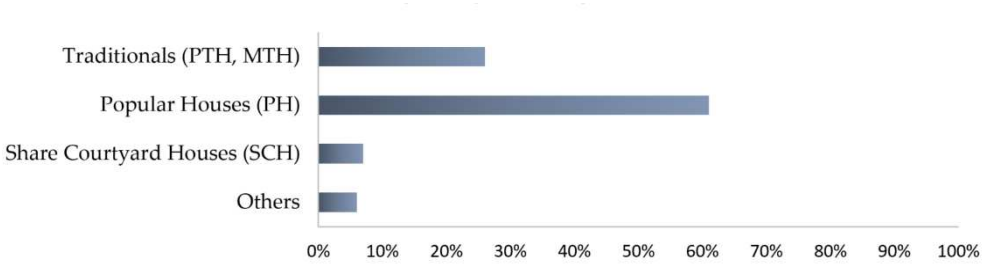

Figure 3. Percentage of each typology in Burkina Faso.

In relation to the thermal envelope of the different housing typologies, in the Ministry report [2] an exhaustive work is developed in terms of identification of roof, wall and floor materials throughout the country. From tables 4.1, 4.2 and 4.3 of this report, Table 2 has been produced.

Table 2. Percentage of materials used in the building envelope.

Envelope	Material	Housing typology			
		Traditional	PH	SCH	Others
Ground floor	Tiling	0.7	17.7	9.3	**72.3**
	Cement mortar	6.3	**74.5**	13.8	5.4
	Rammed earth	38.3	**55.9**	3.3	2.5
	Sand and/or gravel	**52.3**	34.4	1.7	11.6
	Others	42.1	24.7	1.7	31.5
Exterior wall	Solid*	0.0	**57.8**	23.4	18.8
	Semi-solid	0.0	**83.2**	13.5	3.3

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	Rammed earth	31.0	**63.3**	4.0	1.7
	Straw	**72.1**	11.6	0.0	16.3
	Others	43.7	26.7	3.4	26.2
Roof	Concrete	0.0	14.9	8.3	**76.8**
	Asbestos sheet	0.0	**80.6**	12.9	6.5
	Tile	0.0	**85.5**	5.2	9.3
	Earth	17.8	**75.7**	4.0	2.5
	Straw	**93.8**	4.2	0.0	2.0
	Others	**54.8**	15.4	8.0	21.8

* Solid materials are solid brick, concrete block or similar; while hollow brick is considered semi-solid.

In Table 2 the highest usage rate of each material is highlighted in bold. Thus, we want to make easier the visualization of the housing typology in which a certain material is more frequently used. For instance, it follows that 80.6% of asbestos-cement layers are used in the PH type.

Different case studies of each housing typology have been analyzed in situ during our field research, all of them located in the central area of Burkina Faso that has a warm semi-arid climate. For this article, one example has been selected for each typology. During the houses' analysis, typological aspects, materials and construction systems, ways of life and thermal performance have been discussed. To assess the thermal performance data loggers were installed in multiple locations of each case study to monitor dry bulb temperature, mean radiant temperature, and relative humidity (Onset Computer Models: U12-012, UX 120-006M, TMC6-HD) and data were recorded every 5 minutes. Among the numerous monitoring series, those carried out during the dry period have been selected, since in the humid season (from June to September) the maximum temperatures are somewhat lower. Table 3 shows the location of each house and date of the monitoring series, and Table 4 characterizes the specific building envelope of each case study.

Table 3. Monitoring series.

Typology	Location	Date
PTH	Bendatoega (Central Region)	21-25 Nov, 2021
MTH	Bendatoega (Central Region)	20-25 Nov, 2021
PH	Saaba (Ouagadougou)	17-21 Jan, 2022
SCH	Nosin (Ouagagougou)	13-18 Mar, 2021

Table 4. Building envelope materials of the case studies

Envelope	Material	Housing typology			
		PTH	MTH	PH	SCH
Ground floor	Tiling				x
	Cement mortar			x	x
	Rammed earth		x		
	Sand and/or gravel	x			
Exterior wall	Concrete block				0.20 m
	Rammed earth		0.18 m	0.24 m	
	Straw	x			
Roof	Asbestos sheet			x	x
	Straw	x	x		
	Ventilated air-space				x

3.1. Peul traditional house (PTH)

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3.1.1. Typology

The Sahel region of Burkina Faso is inhabited by several different ethnic groups, of which the Peul make up about a quarter of the population. In fact, around 62.1% of the population still speak Fulfulde as a vernacular language today [21].

The PTH is made up of several housing units called *casserones*, which have a circular plan from 3 to 6 meters in diameter and 2 m. height. The dwellings of the Bella and Tuareg ethnic groups differ in size and shape from the Peul units. However, due to the requirements of a non-sedentary way of life, they all have in common an ephemeral character, which translates into easily available materials and speed of construction. A Peul family complex is made up of several large houses arranged around a common space generally not delimited. All units are similar in size and are used as rooms for sleeping and storage.

3.1.2. Materials and construction systems

All the construction materials needed to build PTHs are easily found in the surroundings. The walls, made of foliage or thatch, are raised on wooden supports that provide rigidity without the need for any foundation or excavation. Some thatched walls are later covered with earth and cow dung, although more commonly they are covered with several layers of matting until the appropriate thickness is achieved [22]. Finally, the roof area is reinforced to obtain a homogeneous aspect in which walls and roof are integrated as a single unit. As the ground is used for the dwelling floor, it is important to choose a right location and prepare the area before construction. The interior is sometimes decorated with *secco*[1], *nattes*[2] or fabrics, although the ornamentation is usually quite basic due to its temporary use. The construction is done in barely a few days and by only a handful of people (Figure 4).

Figure 4. Views of a Peul traditional house, Bendatoega, Central Region, Burkina Faso.

3.1.3. Ways of inhabiting

The Peul are livestock traders and always take their cattle elsewhere. The animals constitute their main livelihood and provide them with milk, the staple of their diet. Like other pastoral ethnic groups of the Sahel, the Peul move long distances into the central region of the country in search of pastures and water. The seasonality determines their movements. They often harness the dry season between November and May to move and rebuild their homes in other areas. The location of the Peul settlements must be close to a point of water and when possible, with a slight slope to prevent rainwater from stagnating. The food availability for animals feed is also essential when choosing a location. Since the major droughts of the early 1970s, when herd numbers fell dramatically, the Peul have decreased their traditional movement cycles and become increasingly involved in urban migration. Due to its predominance, the Peul is the pastoral ethnic group that interacts the most with the sedentary people of Burkina Faso in both space and daily activities.

3.1.4. Thermal performance

This series, beginning on November 17th of 2021, evaluates the thermal performance of the selected Peul house (Figure 5 and 6). The maximum temperatures are a good indicator of the cooling

[1] Small bunches of straw ears collected in the countryside.

[2] Straw mats used to lie on. Plastic is also used in cities.

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performance of an interior space [23]. The greater the difference between the indoor and outdoor air temperatures, assuming that the outdoor temperature is higher, the better the performance that we can find. Figure 6 shows that the maximum outside temperature is above 35ºC, while the inside is roughly one degree lower. This shows that very little insulation is provided by the thermal envelope. No significant thermal lag is also registered since the thermal envelope is made with light materials easily available in the surrounding. However, the straw roof is effective to protect from direct solar radiation while provide air dissipation throughout the roof. Thus, results show that the temperature difference between the upper and lower indoor area is negligible. High outside daily thermal amplitude is registered, above 15 ºC. The minimum temperature indoors and outdoors are almost the same at the same time due to the lack of insulation and thermal mass.

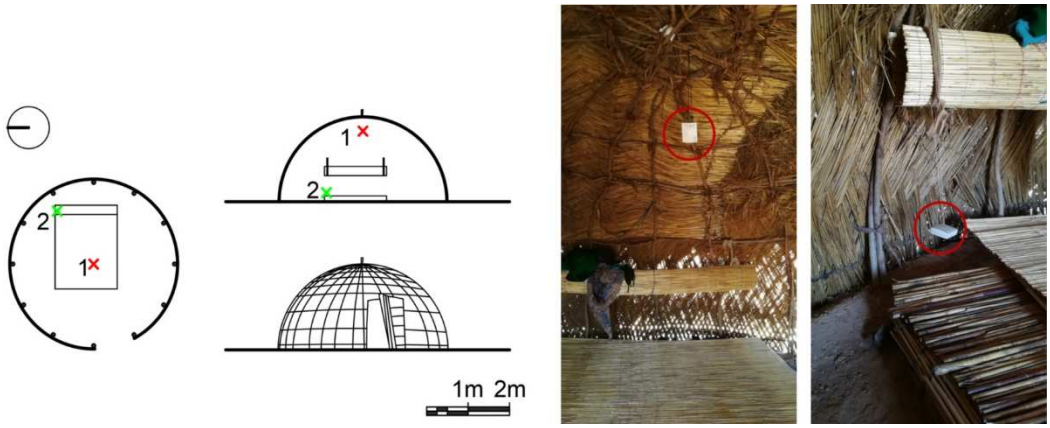

Figure 5. Data loggers' location in the Peul traditional house.

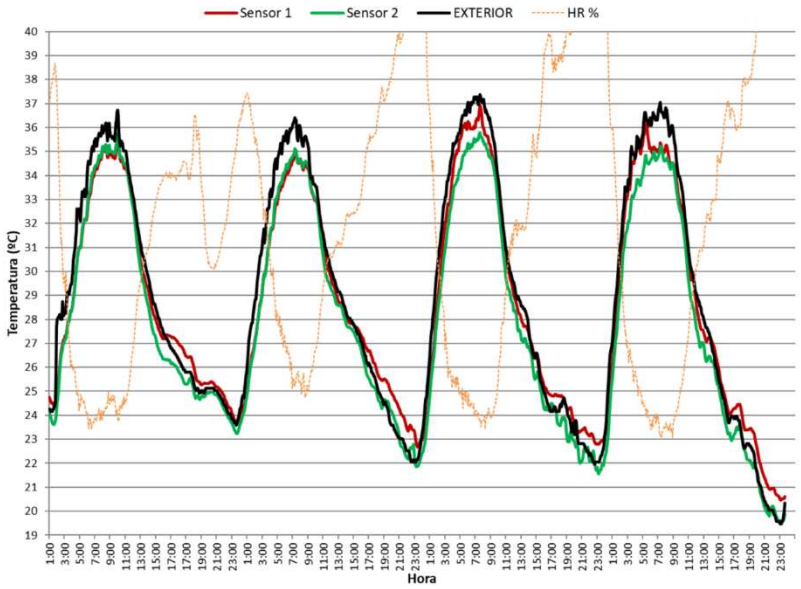

Figure 6. Temperature measured in the Peul House over four days, on November 17-20, 2021.

3.2. Mossi traditional house (MTH)

3.2.1. Typology

The Mossi is the mayority ethnic group in Burkina Faso, representing almost half of the population, and their language, Moore, is one of the most widely spoken by the Burkinabé [20]. The origin of the Mossi is very different from that of the Peul, since they come from the southern region (present-day Ghana) and have a sedentary way of life [24]. The Mossi traditional houses have a circular floor plan, adobe walls and a conical shape roof made of straw. This typology is also used by other ethnic groups in Burkina Faso. For instance, it can be found in the Bissa and Gourmantche cultures established in the center and east of the country, as well as in the Senoufo, Goins and Tella ethnic groups located in the south and the Cascades region. Kiethega [14] pointed out that in the

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circular plan with conical thatched roof dwellings, each ethnic group reflects small differences in construction, but the morphological base and materials are the same (Figure 7). Although this typology is used by different cultures[3], it is known as Mossi, and the settlements are usually made up of several modules[4], which are arranged around a central space with a roughly oval shape. The complex is delimited by a curved wall with a single entrance door.

Figure 7. External view of the Mossi traditional house, Central Region, Burkina Faso.

3.2.2. Materials and construction systems

All the materials used in the MTHs construction are available in the surrounding. However, some of them need a previous elaboration process. For example, adobe bricks must be manufactured and the wood must be dried before being used. It is also necessary to weave the mats, as well as braid the *dâ*[5] strings. The walls of approximately 0.20 m thick are generally built with rammed earth [25], and covered with mud, cow dung, coal (ashes) and water. To build the roof, available wood is sought in the environment together with some type of oil or ointment to repel termites and other insects. *Secco*, herbs, *dâ* barks, climbing plants or natural fibers are also collected [20].

3.2.3. Ways of inhabiting

The Mossi economy is based on the cultivation of cotton, maize, groundnuts and rice; although most of them also grow their own crops of tomatoes, onions, peppers, etc. The patriarch and his wife each have their own *casserone*. Sometimes, when the family is polygamous, each woman also has her own kitchen in a closed room, but usually it is cooked outside in the complex central space. The common space is mainly made up of a central patio around which the different modules are arranged. In addition to the kitchen, there are one or more hangars in the common space which are mainly used to rest during the hottest hours of the day. The traditional dwellings do not have electricity or water supply. The latrine is generally located in a corner of the common space enclosed by a low wall. Water is extracted from wells shared by different families.

3.2.4. Thermal performance

In this series that began on November 22nd of 2021, the maximum outdoor temperature is above 35ºC with a daily thermal range over 15 ºC (Figures 8 and 9). The difference between the maximum outdoor and indoor temperature is only around 2 ºC, but somewhat higher than in the previous PTH. The thermal lag is also higher, reaching values over 2 hours. We must note that the walls are made of adobe, which provides higher thermal inertia than in the PTH although the roof is still made of light materials. The difference between the minimum indoor and outdoor temperatures is 2-3 ºC when the minimum ambient temperature is in the range of 20-24ºC. Thus, there is a larger cooling potential by means of night ventilation, which also can contribute to reduce the maximum indoor temperature. Finally, Figure 9 shows peaks in the indoor air temperature because food is often prepared from 1pm to 3pm, and from 11pm to 1am.

[3] Even the Peul of Burkina Faso use this typology when they settle down.

[4] Each adult man usually has his own module, but when the family is polygamous, each woman also has one.

[5] It is an annual plant originally from Africa also known as Guinea hemp.

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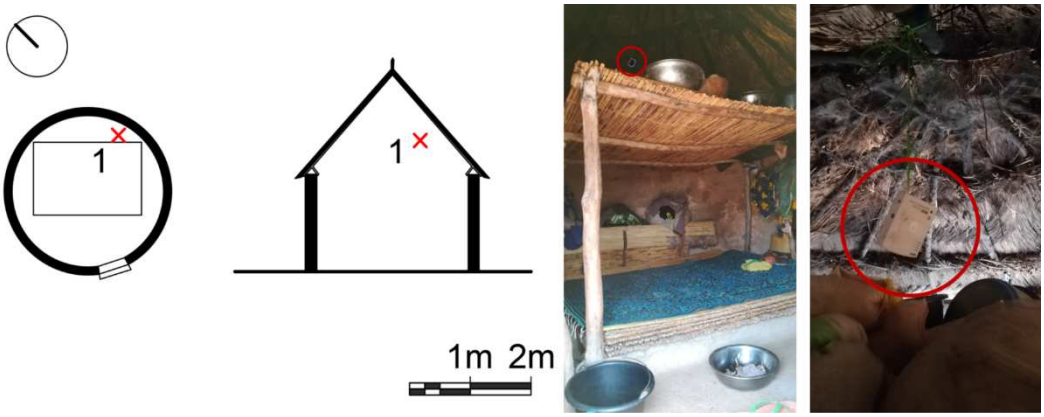

Figure 8. Data loggers' location in the Mossi traditional house (MTH).

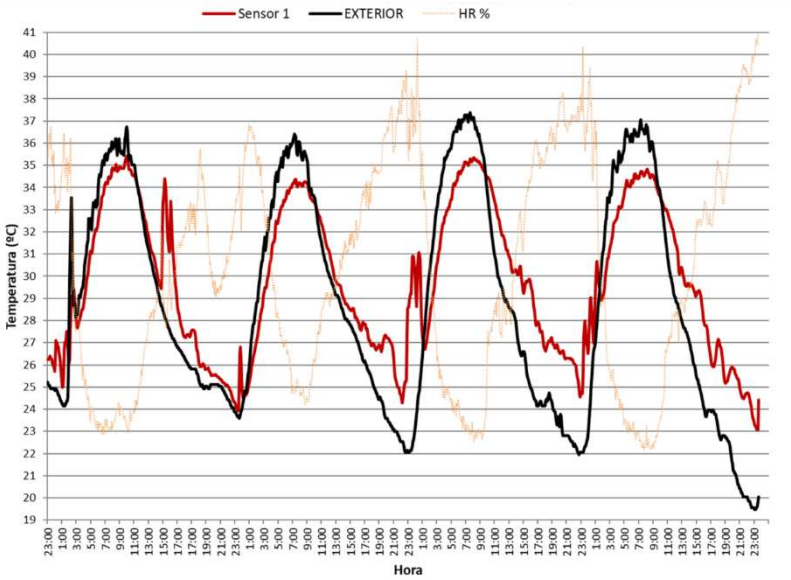

Figure 9. Temperature measured in the MTH over four days, on November 22-25, 2021.

3.3. Popular house (PH)

3.3.1. Typology

The PH is the predominant housing typology for the majority of Burkinabé (60.8%). This typology is built mainly on the urban peripheries but is also replacing traditional dwellings in rural areas. The PH is made up of one or several rooms with a rectangular floor plan of about 25m2. The width and length dimensions correspond to the sheet modules used in the roofs, which are usually 2 x 0.92 m pieces of asbestos. Thus, joining 14 sheets in two bands, a space of 3.5 m wide by 7 m long (24.5 m2) is achieved. These houses do not generally have a kitchen or bathroom inside and they do not necessarily have water supply systems and sanitation (Figure 10).

Figure 10. Popular house (PH), Saaba, Burkina Faso.

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Although the basic module of the PH has a rectangular plan, different types of unit distribution in the plot can be found. We can mainly distinguish two sub-typologies, the disperse PH and the compact PH. The disperse PH is a house with different constructions spread on the plot around an open space, while the compact one has only one unit or building with at least two interior rooms. Other auxiliary buildings may appear on the plot, but all the inhabited rooms are in the same building. Most of the compact PHs are located in cities, while in rural areas the disperse PH is more frequent since the available space is greater.

3.3.2. Materials and construction systems

The walls are built mainly with rammed earth but in some cases with concrete blocks. The walls of the humblest building located in the urban peripheries and rural areas are generally made of earth, while closer to the city center, more concrete blocks can be found. The selected house has load-bearing rammed earth walls 0.24 m thick with a single-sloped asbestos sheet roof, supported by wooden beams without internal ceiling. The floor consists of a cement slab, and the openings do not have fenestration or mosquito nets, only a horizontal mobile slat system. As the traditional houses, most of the PHs are self-built and they are associated with constructions of low economic status.

3.3.3. Ways of inhabiting

The typical construction of a PH is inspired by traditional elements. For instance, the outdoor space is used for domestic activities. Thus, the importance that has traditionally been given to the open space design is maintained in both disperse and compacted PHs. More specifically, the modules layout on the plot, the location of the trees and hangars. However, this legacy of the exterior space utility is opposed to the latest trends of the idealized new western constructions, whose plans are designed with intent for living inside in mind and prioritizing the internal distribution over the conformation of the outside spaces. This typology is the most widespread in Burkina Faso as it is affordable and has some advantages in relation to contemporary typologies, as well as certain reminiscences of traditional architecture.

3.3.4. Thermal performance

In this typology the adobe walls provide thermal mass but also limit the roof height that is lower than in other typologies, generally around 2.5 m. The roof is made of a 6 mm thick asbestos sheet with a thermal conductivity of 1 W/Mk and thermal resistance of 0.006 m^2k/W. This value is almost negligible from a thermal protection point of view. Consequently, in this series beginning on January 26th of 2022 (Figures 11 and 12), the maximum indoor temperature is even several degrees higher than the ambient temperature (Figure 12). On the other hand, the asbestos sheet has a very low thermal inertia and therefore heats up very quickly. The graph 12 shows that the negative effect of the asbestos sheet nullifies the thermal mass provided by the adobe walls because the thermal lag in almost 0. Therefore, this typology has a really negative thermal performance.

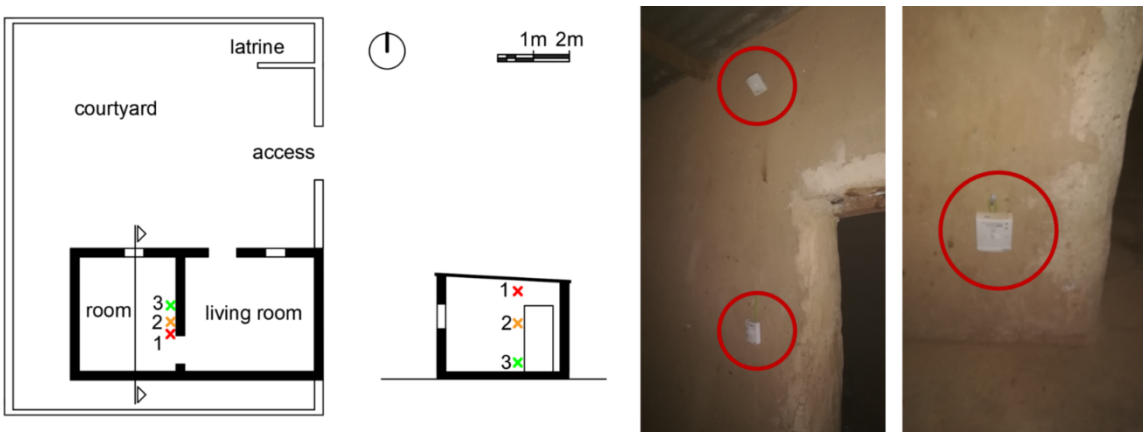

Figure 11. Location of data loggers in the popular house, Saaba (Ouagadougou).

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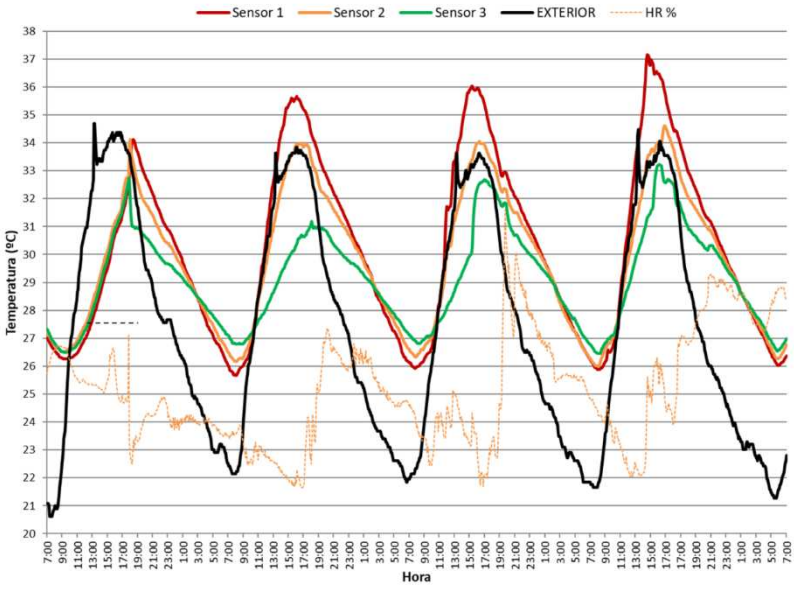

Figure 12. Temperature measured in the Popular House over four days, on January 26-29, 2022.

3.4. Shared courtyard house (SCH)

3.4.1. Typology

The ensuing typology is made up of several single-family houses located on the same plot that share a common area, generally an open patio. In this constructions lives large part of the humble population in urban areas who does not have financial resources to have their own house, since they are often built for rent. There are many variants of the SCH, from a single room called *rentrer-coucher*, that means "enter and sleep", to SCHs equipped with a living room, bedroom(s), kitchen and a full bathroom (Figure 13). There are also several ways of sharing the patio, from three houses onwards. Although this typology only represents 7.3% throughout the country, it is the second most frequent in urban areas with 17.2% [4]. In most cases, the home entrances are separated by small walls to distinguish the space of each neighbor, but in other occasions these separations are not built and the resulting space is shared among all neighbors.

Figure 13. Views of the shared courtyard house, Nosin (Ouagadougou).

3.4.2. Materials and construction systems

This houses are built with load-bearing walls made of concrete block approximately 0.20 m thick and a roof made of wooden beams covered by asbestos sheets and present a false ceiling with a ventilated air-space. The floor is covered by ceramic tiles and the windows do not have any type of glass or mosquito net, just a horizontal mobile slats system. All the openings are located on the same façade, so no cross ventilation is provided.

3.4.3. Ways of inhabiting

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They are popularly known as *celibaterium*, which comes from *celibateur* that means single in French. In traditional houses the celibaterium is the module or room where a family young male who is still single lives. Nowadays, single men who migrate from rural areas to cities and couples with children live in this typology. Although the SCHs usually have at least two rooms, the interior spaces are very small, so they generally do not have kitchens inside. The toilet and latrine modules are shared with other dwellings in the patio that is also used for other activities such as cooking, washing clothes, receiving visits, etc.

3.4.4. Thermal performance

In this series, beginning on March 13 of 2021, the difference between the maximum outdoor and indoor temperatures is around 7-8ºC (Figures 14 and 15). This house is located between party walls with only one façade facing the patio. The higher compactness in relation to the previous typologies helps to reduce the thermal exchange with the exterior while provide more thermal mass. In fact, a thermal lag of more than 5 hours is recorded. The total openings area is less than 25% of the only outside façade, which contributes to reduce the solar incidence radiation indoors. The minimum inside temperature is of 5-6ºC above the minimum ambient temperature due to the difficulty of providing cross ventilation at night. The asbestos roof, although has a plastic false ceiling with an air-ventilated space, has still a very negative impact on overheating the interior space, since the difference temperature recorded 0.30 m from the floor and the ceiling reaches more than 3 ºC.

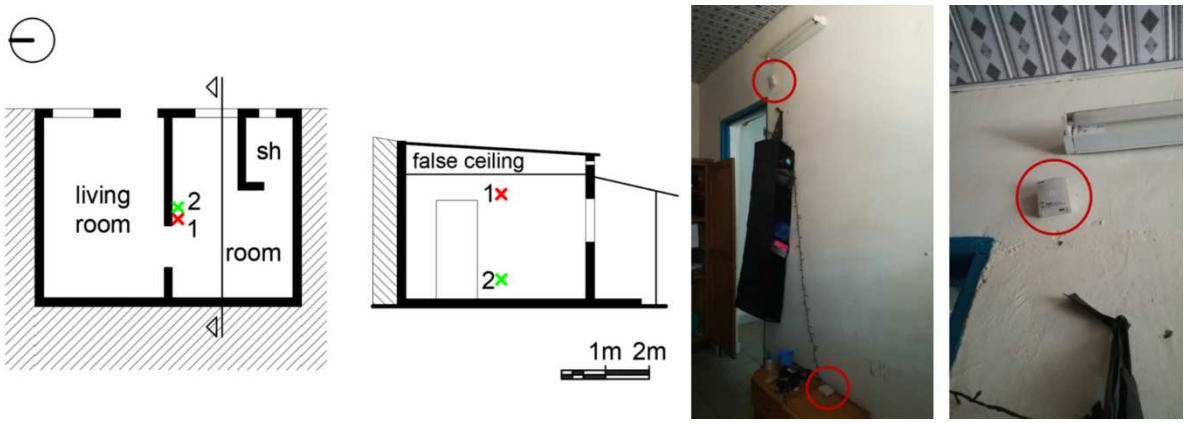

Figure 14. Location of data loggers in the shared courtyard house, Nosin (Ouagadougou).

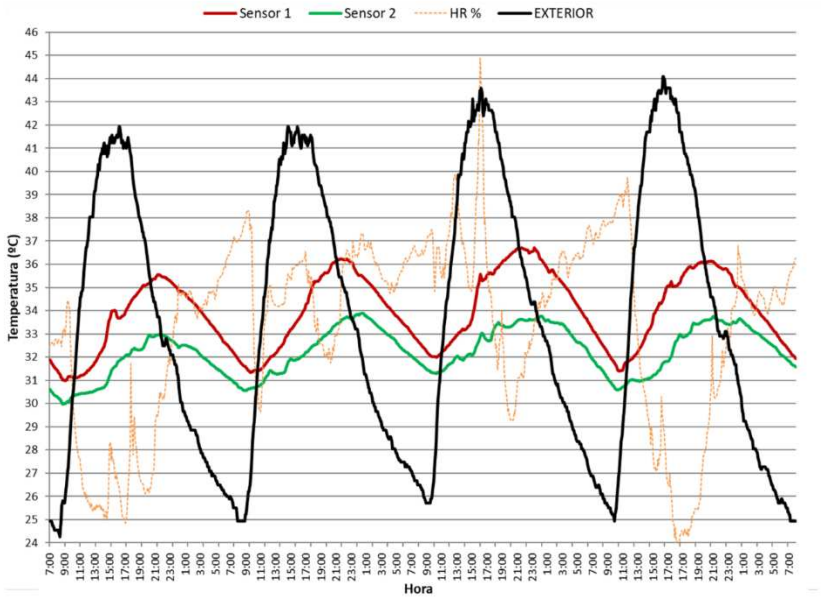

Figure 15. Temperature measured in the shared courtyard house over four days, on March 13-16, 2021.

4. Comparison of the thermal performance

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All series are compared with each other with a ratio that permits the comparison across different measurements, performed at different times and during different weather conditions. This number is called the temperature difference ratio (TDR) and was proposed by Givoni [26] with good results to compare passive cooling systems with different configurations and have been widely used in other research [27, 28, 29]. TDR is determined by comparing the average reduction of the maximum temperature inside the cell with the average swing as expressed in the following equation:

$$TDR = (T_{max.out} - T_{max.ins})/(T_{max.out} - T_{min.out}) \quad (1)$$

Where: $T_{max.out}$ = maximum temperature outside (◦C), $T_{max.ins}$ = maximum temperature inside (◦C) and $T_{min.out}$ = minimum temperature inside (◦C).

The numerator is the difference between the indoor maximum temperature and the outside maximum, and the denominator is the outdoor swing. A higher TDR value indicates that there is a larger temperature difference between exterior and interior values and we have a higher cooling potential.

Accordingly, we have compared experimental data obtained in each typology using TDR as a function of the outdoor temperature swing (Figures 6, 9, 12 and 15). Since TDR is calculated daily, each point in Figure 16 contains day-length data. A trend-line is plotted for each series.

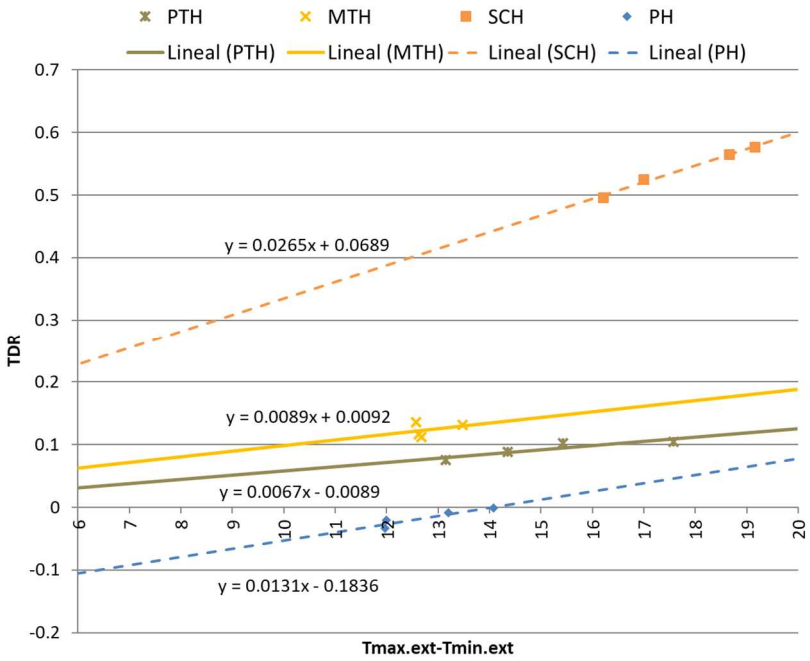

Figure 16. Correlation between the daily outdoor temperature swing and the daily TDR in different housing typologies.

Figure 16 shows that traditional houses have a better thermal performance than PHs. More specifically, the PTH is around 65% and the MTH 75% higher than the PH for an outdoor temperature swing of 15ºC. The worse cooling potential of the PH is mainly due to the asbestos sheet that has too little insulation (thermal resistance of 0.006 m2k/W) and high emittance (around 0.7-0.8). Therefore, the PH roof produces a continuous overheating of the interior space, more intense in the central hours of the day due to the low thermal inertia of the asbestos cement. However, traditional roofs made with branches and straw easily available in the natural environment reduce overheating, because they protect from direct solar radiation while providing some air permeability that contributes to the dissipation of indoor heat.

Moreover, the window-to-wall ratio of traditional houses is minimal because the entrance door is the only opening, and therefore, the incidence solar radiation indoor is minimized. Due to the air permeability of the walls and roof in the PTH the outdoor and indoor temperatures are quite similar. We must note that the PTH is a fast build house which uses light materials easily available and is therefore adapted to the temporary way of life of the Peul. In addition, the cooling potential of the MTH is 20% better than the PTH when an ambient temperature swing of 20ºC is registered. This is

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because the adobe walls of the MTH provide more thermal mass which contributes to the reduction of the inside daily temperature swing.

On the other hand, the SCH thermal performance is 75% higher than the PH when the daily ambient temperature swing is 20ºC. This results from the fact that SCHs are more compact, since they are located between party walls and therefore, the thermal exchange through the building envelope is reduced. In addition, both the SCH and the PH have a roof made of asbestos sheets but in the case of the SCH a false ceiling with a ventilated air space is also installed. Moreover, the SCH patios play an important thermal role. During the night time, the colder air is confined inside the patios due to its higher density. If during the day they are protected from the sun by means of vegetation or other traditional shading elements such as hangars or porches, a microclimate can be created that can significantly contribute to cool the adjacent spaces. For all these reasons, an adequate design of patios is a major factor in the thermal performance of the SCH. On the other hand, the patios have a cultural relevance since they are connected with the local tradition as a place for meeting and carrying out daily activities.

4.1.1. Temperature difference ratio (TDR) prediction

Based on the experimental results, the equations that predict the TDR in each typology are listed below.

$$TDR\ (PTH) = 0.0067\ (T_{max.out} - T_{min.out}) - 0.0089;\ \text{where } R2=0.92. \quad (2)$$

$$TDR\ (MTH) = 0.0089(T_{max.out} - T_{min.out}) - 0.0092;\ \text{where } R2=0.89. \quad (3)$$

$$TDR\ (PH) = 0.0131\ (T_{max.out} - T_{min.out}) - 0.1836;\ \text{where } R2=0.95. \quad (4)$$

$$TDR\ (SCH) = 0.0219\ (T_{max.out} - T_{min.out}) - 0.0689;\ \text{where } R2=0.97. \quad (5)$$

After TDR is calculated for a building using Eqs. (2)-(5), it is possible to predict the indoor maximum temperature using Eq. (6) and solving for $T_{max.ins}$.

$$T_{max.ins} = T_{max.out} - [TDR*(T_{max.out} - T_{min.out})] \quad (6)$$

Where outdoor maximum and minimum temperatures, or daily temperature swing, must be known. These simple equations derived from the experimental work permit us to calculate internal maximum temperatures as a function of outdoor maximum temperature and daily swing. However, series should be carried out in more case studies to determine the thermal performance limits of the analyzed typologies.

5. Main factors affecting transformation in the ways of life

This section analyzes the main causes and effects that are influencing changes in the ways of life of Burkina Faso. Specifically, the reduction of natural resources, the introduction of new materials and the transformation of the land ownership system.

5.1. Reduction of natural resources

The materials used in Burkina Faso's vernacular architecture have traditionally been free and easy to find in the natural environment. However, climate change and rapid population growth are accentuating a progressive environmental degradation [17]. Thus, basic materials such as wood or straw have nowadays a monetary cost and their prices are gradually increasing. We must note that these materials have to be replaced periodically and their availability is less and less guaranteed.

Due to this situation, some authors [18] have demanded a greater investment in research on the climatic and ecosystem cycles of this region to obtain better results to combat drought problems. The development of systems such as the proposed by the West African Monsoon (WAM)[6] can contribute to the reduction of the humanitarian crisis in Burkina Faso, since the variations in the seasonal precipitation cycles have a direct impact on the habitat, as well as the availability of natural resources required for traditional houses construction.

5.2. New materials

The progressive scarcity of basic construction materials affects both temporary and sedentary traditional houses, and is forcing rural populations to replace ancestral construction systems. For example, the traditional straw roof is being replaced by asbestos layers. Although this material has a

[6] Climate analysis system aimed at predicting rainfall in the Sahel.

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higher initial cost, most families prefer this option to avoid having to redo the roof every few years due to the progressive lack of availability and cost increase of traditional materials [30].

The simple massive introduction of asbestos sheets is leading to create a new housing typology, since the rectangular geometry and rigidity of asbestos sheets are incompatible with the traditional circular and oval shape. Therefore, traditional circular houses are being replaced by new rectangular constructions [3]. As the morphological transformations occur at different speeds, mixed housing complexes in which traditional *casserones* and rectangular modules covered with asbestos sheets are increasingly common. The Mossi vernacular house is adapted to the climate and has important patrimonial values in which an ancient tradition of a unique culture is reflected. However, a mixed housing complex with materials not adapted to local conditions generates serious thermal problems and a loss of cultural identity [31]. In addition, they tend to become slums because they are often built on the urban peripheries, generating precarious settlements with lack of basic services, such as water supply systems and sanitation [32].

5.3. Transformation of the land ownership system

The concept of property, as it is known in the West, did not exist before the colonization of Burkina Faso. The nomadic cultures of the Sahel used to make agreements and concessions with the sedentary groups with which they were in contact [4]. As a consequence, the traditional temporary way of life of the Peul does not contemplate land ownership [3, 17]. Due to the processes of legalization of land, it is increasingly difficult for the Peul to maintain their traditional way of life, closely linked to land ownership. Therefore, they tend to become sedentary. The new Peul generations are clearly conditioned by the new neoliberal urban model, and informal settlements have great difficulties in consolidating and remaining in the future [32], especially those located on the urban peripheries, such as Ouagadougou or Bobo-Dioulasso.

6. Conclusions

This research has analyzed transformations in the cultural context and natural environment of Burkina Faso that are causing changes in the traditional ways of life and decisively influencing the transformation of the architectural typologies.

Climate change, that particularly affects Burkina Faso, is negatively impacting the availability of natural resources used in traditional construction, increasing the cost of products such as wood and straw, which were previously obtained directly from nature at no cost. As traditional earthen walls are also being used in new typologies mainly located in precarious settlements of the urban peripheries, the use of adobe is being associated to a low social status. In addition, due to the limited industrialization of the country, good quality adobe bricks are much more expensive than concrete blocks. All this causes a gradual abandonment of traditional materials that are replaced by others considered modern or more durable, such as concrete blocks and asbestos sheets.

The ways of life are transforming differently in each ethnic group although with some common causes and effects. While the Peul become increasingly sedentary due to the limited land available to settle, the Mossi modify their traditional home with the introduction of new materials, such as asbestos sheets. The constructions in both cases are being affected by the increasing scarcity of natural resources such as wood and straw, which are forcing different ethnic groups to look for alternatives that modify their traditional housing typology.

In the PH, outdoor spaces are very important as in traditional constructions. Whether the PH is dispersed or compact, the care to the outdoor space is maintained, especially the layout of the different modules on the plot, the location of trees and the utility of the open spaces. However, this legacy contrasts with the latest trends in Western housing which are focused on living inside, prioritizing the internal distribution over the conformation of the external space.

In short, there is a tendency in Burkina Faso to live in homes that do not respond to traditional cultural values. Moreover, the new typologies are not adapted to local climatic conditions and therefore do not generate an adequate level of thermal comfort. A paradigmatic case is the PH, which today represents the way of life of the majority of burkinabé (60.8%) and is increasingly replacing traditional typologies even in rural areas. The PH have a thermal performance markedly worse than traditional houses. More specifically, 65% lower than the PTH and 75% lower than the MTH for an ambient thermal swing of 15 ºC. In fact, the maximum interior temperatures registered in the PH are even higher than the maximum ambient temperature; in other worlds, it is hotter indoors than

outdoors of the houses. This is mainly due to the asbestos roof that produces a continuous overheating of the inner space. Although the SCHs improve the thermal performance of the PHs, they also reach interior temperatures above 30ºC.

The new housing typologies are not sufficiently connected with the local environmental and cultural values since urban policies have been more focused on the problems generated by the rapid population growth and other dynamics than on preserving the architectural and cultural heritage. We must note that the ethnic groups of Burkina Faso are repositories of a secular experience of adaptation to the environment from which lessons can be learned for the future. For this reason, studies aimed at revitalizing environmental and cultural values of vernacular architecture in the contemporary world should be part of the current debate on urban development in Burkina Faso.

We consider that each of the Burkinabé cultures has its own singularities and values, and in the exchange of this diversity lies one of the greatest wealth of this country which has maintained a harmonious coexistence of different ethnic groups and religions for centuries. The fact that individually we can aspire to progress from our singularity does not mean that as a society we cannot "fly" in a coordinated way towards the same objective. In this sense, we subscribe to the Mossi proverb that says *Luiili pa yigd n paam taab ye* (not all birds fly at the same height).

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