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Human Habitats and Malaria Vector Control in Benin: Current Situation and Implications for Effective Control

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Abstract

Long-lasting insecticide-treated nets (LLINs) and indoor residual spraying (IRS) are the main indoor malaria vector tools control tools. The study examined housing characteristics and investigated the relationship between the total volume of household possessions, the volume of the sleeping room, and the hanging of LLINs. A total of 831 bedrooms were randomly selected in Benin in 2015. The findings showed that mud walls were predominant in rural areas (more than 75%), while metal roofs were common (77.3% - 97.9%). Battery-powered lighting was prevalent in rural areas in Northern (97%), while open-flame oil lamps were commonly used in rural areas in Southern (86%). The availability of correct bedding was low, ranging from 1% to 10% in all households. 20% of the bedrooms had at least 50% of their volume occupied by household possessions in urban areas. In rural areas, bedrooms without LLINs had a lower mean rate ratio of the volume occupied by possessions per the total volume of the room compared to bedrooms with at least one LLIN installed ($p < 0.0001$). The characteristics of human habitats are not favourable to the correct use of vector control intervention indoors. It is therefore important to improve people's living conditions as the next step for malaria elimination.

Keywords

Housing, Lighting, Bedding, Possessions, Malaria Vector Control, LLINs, IRS

1. Introduction

In Sub-Saharan African countries, an estimated 80% or more of malaria trans-

mission occurs at night when people are bitten by *Anopheles gambiae* indoors [1]. Long-lasting insecticide-treated nets (LLINs) and indoor residual spraying (IRS) are recommended as the first line intervention by World Health Organization (WHO) for malaria vector control [2] [3]. Over the last 20 years, LLINs and IRS have contributed to reducing malaria cases/infection worldwide by about half [4]. Nevertheless, in some regions, particularly in Africa, malaria remains a public health problem with a trend towards an increase in cases [3]. The last World Malaria report states that the burden of malaria was stable since 2015 in Benin [3]. There is a need to explore barriers in housing that hinder the effectiveness of malaria vector control measures. Poor housing conditions are associated with a wide range of health problems, from infectious to non-communicable diseases [5] [6]. The relationship between housing and health is faced with multiple challenges. A healthy home needs to have a sound structure, to be free of hazards, to provide adequate facilities for sleeping, personal hygiene, the preparation and storage of food, to be an environment for comfortable relaxation, privacy and quiet, and to provide the facility for social exchange with friends, family and others [7]. To address this, the World Health Organization (WHO) has identified several health risks associated with poor housing conditions. These include inadequate living space (crowding), both low and high indoor temperatures, injury hazards within the home, and lack of accessibility for individuals with functional impairments [6]. In Benin, the malaria burden remains high and did not decline clearly in the past 10 years. Each year, around 45% of care-seeking was attributed to malaria [3] [8]. *Anopheles gambiae s.l.* is the main vector of malaria [9]. Malaria prevention in Benin is mainly based on vector control. Thus, Benin has been carrying out a mass distribution of LLINs throughout the country every three years since 2007. In 2017, the National Malaria Control Program (NMCP) published that more than 90% of households have at least one LLIN, but only half of all beds are actually covered. The proportion of the population that sleeps every night on LLINs does not exceed 50% [3]. Indoor residual spraying (IRS) has been implemented for the first time since 2008. Currently, the IRS is implemented in northern Benin. It is estimated that in these regions, the IRS coverage rate exceeds 90% [10]. To ensure LLINs remain in good condition and be used properly, a favourable environment in terms of space and cleanliness is required. Open eave spaces and the absence of window screens contribute to a high entry of vectors into the houses, and therefore to a high exposure to the infected biting of female anopheles. We also hypothesize that the size of the sleeping room could determine the installation of the LLINs. The protection provided by IRS requires contact between vectors and insecticide-sprayed surfaces and therefore these surfaces must be smooth and not encumbered by household properties. In Kenya, a study showed that malaria vector abundance is associated with house structures in Baringo County [11]. A recent study showed that an improvement in the overall housing quality leads to a significant reduction in the incidence of malaria among children under five years old [12]. Explicitly, an improvement from the first percentile measure of

housing quality to the 50th percentile leads to a 32% reduction in the number of malaria cases among children under five. In Benin, in both rural and urban areas, the housing is not standard. A description of the immediate environment where LLINs and IRS are implemented would provide a better understanding of the limitations of their effective use and effectiveness.

2. Study Area

The data were collected in the commune of Djougou in the urban area, and in the communes of Cobly, and Tori Bossito in rural areas. Djougou is located in the north-western Benin, 450 km from Cotonou, the economic capital. Djougou covers 3926 km^2 surface with an altitude of 434 m. The longitude is 1.666667 and the latitude is 9.700000. The population size is estimated at 382,184 inhabitants in 2023 [13]. Cobly is a rural area located in the north-western Benin, located at 638 km from Cotonou. Cobly covered 852 km^2 with an altitude of 434 m. Its longitude is 0.9932 and its latitude is 10.4887. The population size is estimated at 80,000 inhabitants in 2023 [14]. In both regions, the climate is Soudanian and Atacorian. The dry season starts from November to April and the rainy season from May to October. The mean temperature is around 27˚C, ranging between 17˚C and 42˚C [15]. Tori Bossito is a rural area located in southern Benin, 53 km from Cotonou. It covered 328 km^2 and its altitude was 74 m. The longitude is 6.5000 and the latitude is 2.1500. The population size is estimated at 60,000 inhabitants in 2023 [16]. The climate is essentially subequatorial, with two dry seasons (a long dry season from December to March and a short dry season in August and September), and two rainy seasons (a long rainy season from April to July and a short rainy season from October to November). The hottest months (31˚C - 40˚C) are February to April and the coldest months are July to September. In Benin in 2017, the proportion of households with at least one LLIN is 91%. About 45% had enough LLINs for all sleeping units and around 54% of the population slept under LLINs the night before the survey [17]. The coverage of IRS is high more than 95% but the proportion of persons who slept in the rooms is not documented.

3. Methods

3.1. Study Design

A cross-sectional survey was conducted in June 2014 in Djougou and Cobly and in June 2015 in Tori Bossito in the rooms where people usually slept.

3.2. Population and Sample

A total of 831 rooms were randomly selected: 237 in Djougou, 406 in Cobly, and 198 in Tori Bossito. Only one piece was drawn at random per household.

3.3. Data Collection

A door-to-door questionnaire was administered to the head of the household in

the three study areas to determine the number of individuals in the household, the number of LLINs in the household and a direct observation of the house structure and content was made using a grid. This grid made it possible to collect information on the characteristics of the dwelling, namely the construction materials (type of roof, type of wall, type of floor), type of bedding, type of hanging of LLINs, type of lighting, roof-to-wall spaces, presence of a fireplace or stove or kitchen inside the room. We do not consider the type of toilet and the presence of drinking water. The dimensions of the room were measured in the three study areas. All objects present in the room at the time of the survey were identified and their dimensions were measured only in Djougou and Cobly sites.

3.4. Data Analysis

The lengths, the widths and the heights were measured for the parallelepiped objects, the diameter and height for the cylindrical ones. Then, the surface area and the volume of the room and objects were calculated. The median of the surfaces and volumes was calculated and expressed respectively in m^2 and m^3. The dimensions of the LLINs available in the sleeping room were not measured in situ. The LLINs distributed by the NMCP are generally of medium size: 130 cm × 180 cm × 150 cm or large size: 160 × 180 × 150 cm *i.e.* 3.5 m^3 and 4.3 m^3 respectively. Data were analysed using Stata version 11. Basic descriptive statistics were used to describe the following characteristics of the houses: type of roof, type of wall, type of floor, type of bedding, type of hanging of LLINs, type of lighting, roof-to-wall spaces, presence of a fireplace or stove or kitchen inside the room, type and volume of objects found in the sleeping rooms, and the volume of the sleeping room.

The proportion of the volume of the room occupied by the objects or possession was grouped into five categories: <10, [10 - 25[, [25 - 50[, [50 - 75[, and >75. All the proportions were expressed as a percentage (%). The ratio of the volume occupied by the objects per the total volume of the household was calculated and compared between rural area and urban areas. The comparison was achieved by the Kolmogorov-Smirnov test. Bivariate logistic analysis was conducted in order to highlight the link between the volume of the objects found in the sleeping rooms, and the volume of the sleeping room according to rural (Cobly) and urban areas (Djougou). Significance was evaluated at 5%.

3.5. Ethics

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Comité National d'Ethique pour la Recherche en Santé of the Ministry of Health of Benin (Institutional Review Board N° 00006860; Number 011 of April 24, 2014).

4. Results

4.1. Descriptive Characteristics of the Sleeping Rooms in the Study Areas

The household size was six in Djougou and Cobly and five persons in Tori Bos-

sito.

4.1.1. Lighting Mode

In the urban area (Djougou), about 70.0% of households were electrified. In the rural areas, the majority (97.0%) of households used battery-operated flashlights for lighting in Cobly and the majority usually used open-flame oil lamps in Tori Bossito (86.0%), (Table 1).

Table 1. House characteristics.

	Djougou (urban/north)		Cobly (rural/north)		Tori Bossito (rural/south)	
Variables	**n**	**%**	**n**	**%**	**n**	**%**
Household size						
[1 - 5]	103	43.5	144	35.5	151	76.3
[6 - 8]	81	34.2	172	42.4	36	18.2
≥9	53	22.4	90	22.2	11	5.5
Type of walls						
Cement	121	51.1	1	0.25	47	23.7
Mud	98	41.4	401	98.77	151	76.3
No wall	18	7.6	4	0.99	0	0.0
Type of floors						
Cement	230	97.0	341	84.0	43	21.7
Stones/blocks	3	1.3	3	0.7	0	0.0
Mud/soil	4	1.7	62	15.3	155	78.3
Type of roofs						
Metal-roof	232	97.9	314	77.3	178	89.9
Straw	1	0.42	92	22.7	18	9.1
Tile/Slab	4	1.69	0	0	2	1.0
Type of the sleeping place						
Box spring plus mattress	24	10.1	3	0.7	3	1.6
Box spring plus plastic or vegetable mat	102	43.0	26	6.4	112	58.0
Plastic mat	83	35.0	304	74.9	0	0.0
Vegetable mat	28	11.8	73	18.0	78	40.4
Type of hanging LLINs						
Frame directly	8	9.2	57	21.2	175	88.4
Nails on frame or wall	75	86.2	212	78.8	23	11.6
Others (chairs, supports)	4	4.6	0	0.0	0	0.0
Type of lighting						
Electricity/solar photovoltaics	165	69.6	7	1.7	1	0.5
Flashlight (battery-operated)	57	24.1	396	97.5	26	13.1
Candle/lantern/lamp	15	6.3	3	0.7	171	86.4
Kitchen in rooms						
No	212	89.5	344	84.7	184	92.9
Yes	25	10.5	62	15.3	14	7.1

4.1.2. Building Materials

In rural areas, more than 75% of the walls were made of soil or bar clay and more than 80% of the floors were cemented in the two northern areas (Cobly and Djougou) compared to 21% in the south (Tori Bossito). The majority of the roofs were made of aluminium sheets in Djougou, Cobly and Tori Bossito respectively (Table 1). None of the rooms had the roof-to-wall spaces completely closed (Figure 1).

4.1.3. Windows and Doors

The doors were on average 1.7 m high and 0.5 m wide in Djougou and Cobly but 0.8 m wide in Tori Bossito. The proportion of sleeping rooms with more than one window was higher in urban areas in Djougou (88%) compared to rural: 30% in Tori Bossito and 1% in Cobly (Table 1). None of the rooms had screened windows.

4.1.4. Dimension of the Sleeping Rooms

In the Djougou area, the rooms had a median surface area of 11.1 m^2 (1st quartile = 9.5; 2nd quartile = 12.9) and a median volume of 29.1 m^3 (1st quartile = 22.8; 2nd quartile = 35.7).

In the Cobly area, the rooms had a median surface area of 9.9 m^2 (1st quartile = 8.5; 2nd quartile = 12.2) and a median volume of 24.9 m^3 (1st quartile = 20.3; 2nd quartile = 30.0).

In the Tori Bossito area, the houses had a median surface area of 11.9 m^2 (1st quartile = 9.5; 2nd quartile = 13.9) and a volume of 24.4 m3 (1st quartile = 19.5; 2nd quartile = 29.5).

4.1.5. Sleeping Place

Correct bedding (box spring plus mattress) was available in 1% to 10% of households in all areas. Most of the beds were made of a vegetable or plastic mat placed on a bed frame (made of wood or clay) or on the ground. Bed nets were attached directly to the room frame or by nail.

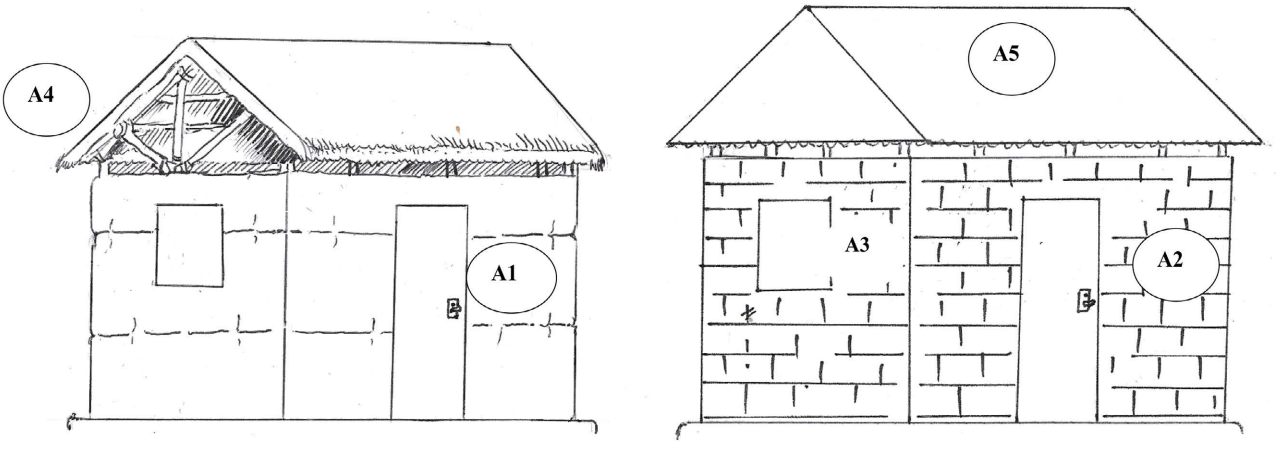


Figure 1. Characteristics of the houses in rural and urban areas, Benin. A1: mud mostly in rural areas; A2: cement mostly in urban areas; A3: window; A4: Open eave spaces/rooms-to-wall spaces in both rural and urban; A5: aluminum sheet.

4.1.6. Type of Objects Found in the Sleeping Rooms

Kitchen or stoves were placed in rooms where people and LLINs co-habited in 7% - 10% of rooms (Table 2). Several types of objects were found in the rooms. The objects were empty or cereal-filled baskets, kitchen utensils, buckets, basins, mats, jars cans filled with water, oil, alcohol, or oil in varying proportions. An example of a sleeping room inside is shown in Figure 2. An average of two sleeping units and two LLINs were found per room. In the south in the Tori Bossito area, 83.3% of households had at least one fixed bed unit compared to 53.2% and 8.1% in Djougou and Cobly respectively (Table 2).

4.1.7. Volume Occupied by the Objects or Goods Placed in the Sleeping Rooms

In the city of Djougou, the median volume of objects in the rooms was 6.99 m^3 (1st quartile = 2.98; 2nd quartile = 16.39) then 24.02% of the bedroom. In Cobly, the median volume of objects in the rooms was 0.33 m^3 (1st quartile = 0.09; 2nd quartile = 1.95) and 1.32% of the bedroom. In Tori Bossito, the median volume of objects in the rooms was 1.44 m^3 (1st quartile = 1.00; 2nd quartile = 2.20) and 5.9% of the bedroom.

In the urban area, the rooms were more occupied by the possessions than in the rural ones. 20% of the rooms had at least 50% of their volume occupied by household possessions or goods, 20% of the rooms had 25% to 50% of their volume occupied, 30% of the rooms had 10% to 25% of their volume occupied and 30% of the rooms had less than 10% of their volume occupied in the urban area (Figure 3(a)). In the rural area, up to 63.3% of the rooms had less than 10% of their volume occupied (Figure 3(b)).

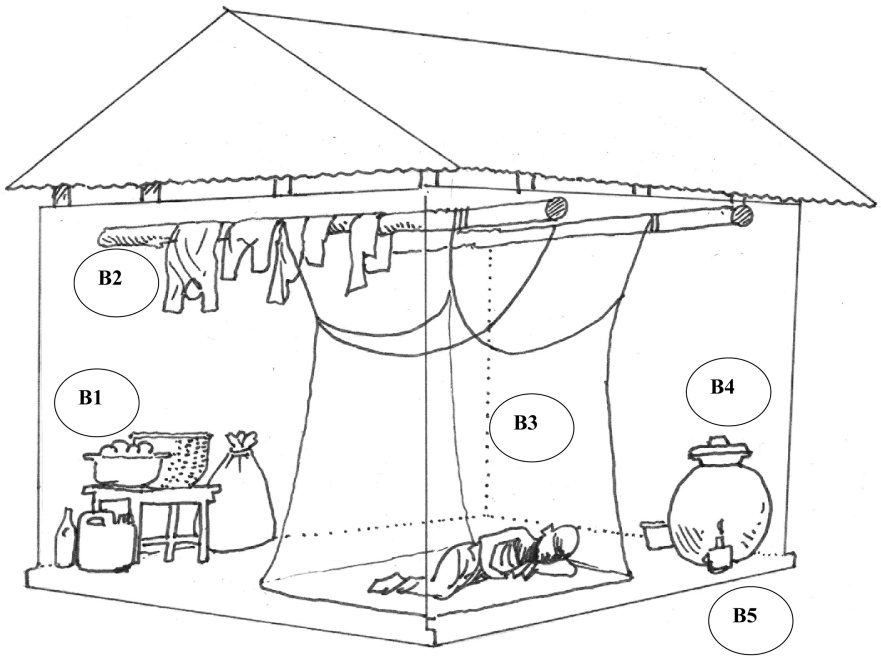


Figure 2. Indoor description. B1: goods and foods; B2: clothing; B3: Insecticide-treated nets; B4: jar of water; B5: open-flame oil lamps.

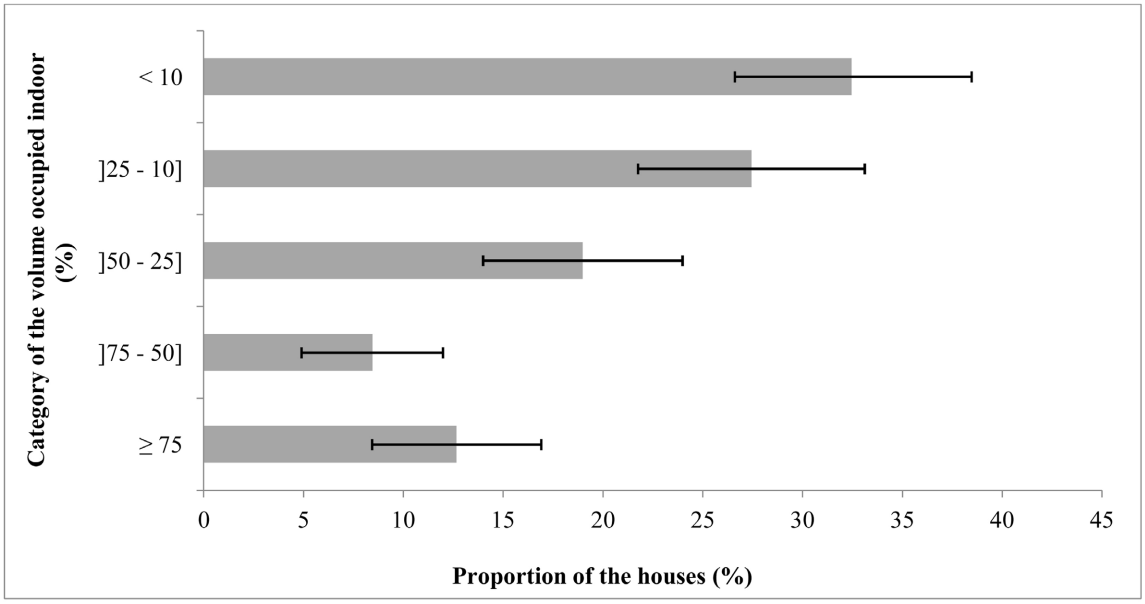
Table 2. Type of objects found in the sleeping rooms, Benin.

	Urbain		Rural			
	Djougou		Cobly		Tori Bossito	
Type of objects	House (n)	%	House (n)	%	House (n)	%
Fixed sleeping place	126	53.2	33	8.1	165	83.3
Empty or filled basket (cereals, coal)	113	47.7	54	13.3	55	27.8
Kitchen utensils	109	46.0	96	23.6	65	32.8
Chair/stool	105	44.3	63	15.5	76	38.4
Cashbox/trunk/value box/cardboard/package	103	43.5	112	27.6	27	13.6
Table	95	40.1	87	21.4	110	55.6
Jute bag filled (clothes, cereals)	92	38.8	92	22.7	34	17.2
Bucket	90	38.0	91	22.4	94	47.5
Bassin	89	37.6	101	24.9	102	51.5
Folded or rolled up mat	87	36.7	248	61.1	24	12.1
Canister (water, petrol, oil, alcohol)	73	30.8	41	10.1	76	38.4
Television	69	29.1	4	1.0	6	3.0
Jar	67	28.3	30	7.4	30	15.2
Closet	66	27.8	2	0.5	9	4.6
Sofa/Armchair	50	21.1	12	3.0	7	3.5
Radio	42	17.7	12	3.0	8	4.0
Television break	17	7.2	0	0.0	0	0.0
Motorcycle/Bike	10	4.2	25	6.2	6	3.0
Refrigerator	9	3.8	0	0.0	0	0.0
Ventilator	5	2.1	0	0.0	0	0.0
Coat rack	4	1.7	0	0.0	0	0.0

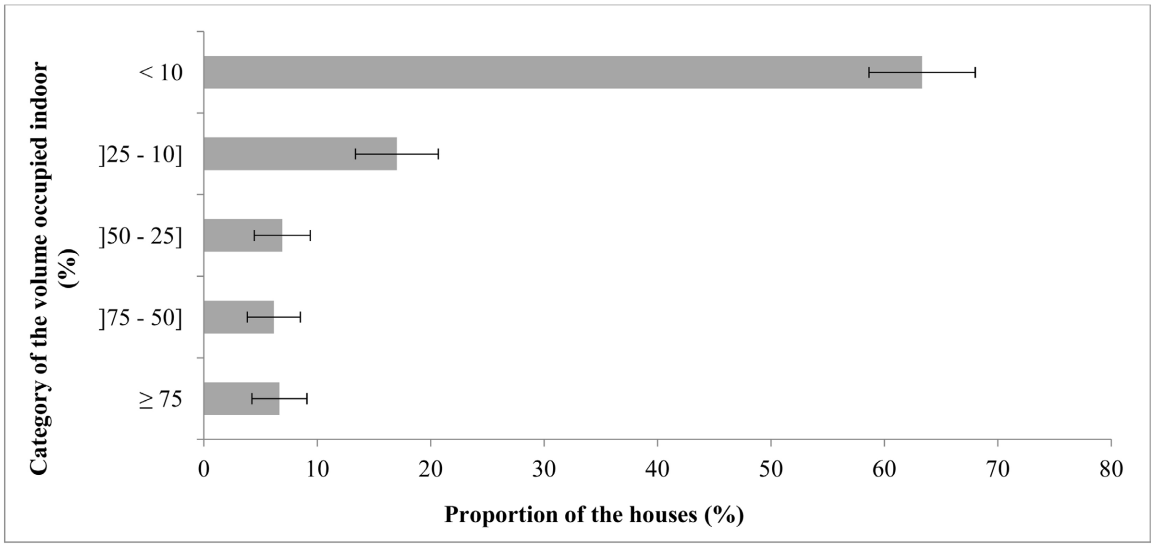
4.1.8. Link between the Total Volume of the Possession and the Volume of the Sleeping Rooms

The mean volume of the household possession was higher in the urban area (Djoujou, mean volume = 9.6 ± 7.90 compared to the rural (Cobly, mean volume = 1.53 ± 2.85), Bartlett test, $p < 0.0001$, (Figure 4). Correlations were not found between the volume of the possession and the volume of sleeping rooms in both areas (rural, $p = 0.4063$ and urban, $p = 0.9322$), (Figure 5).

In the urban, the mean rate ratio of the volume occupied by the possession per the total volume of the rooms was 0.34 in the rooms without LLINs and 0.38 in the rooms with at least one LLIN in place. This mean rate ratio did not influence the installation of the LLINs in the room, $p = 0.4230$. In the rural area, the mean



(a)



(b)

Figure 3. (a) Proportion of houses according to the volume occupied by objects, urban area. (b) The proportion of houses according to the volume occupied by objects, rural area.

rate ratio of the volume occupied by the possession per the total volume of the rooms was lower in the rooms without LLINs (r = 0.04) compared the rooms where at least one LLIN was installed (r = 0.07), p < 0.0001 (Figure 6).

5. Discussion

Vector control intervention gives mitigated satisfaction on malaria elimination according to recent publications in some Sub-Saharan African countries [3]. In the areas where malaria is endemic, vector control is the most recommended strategy to prevent the disease. Knowing that the majority of vector biting (80%) occurs indoors in the sleeping room, it makes sense to describe the sleeping room

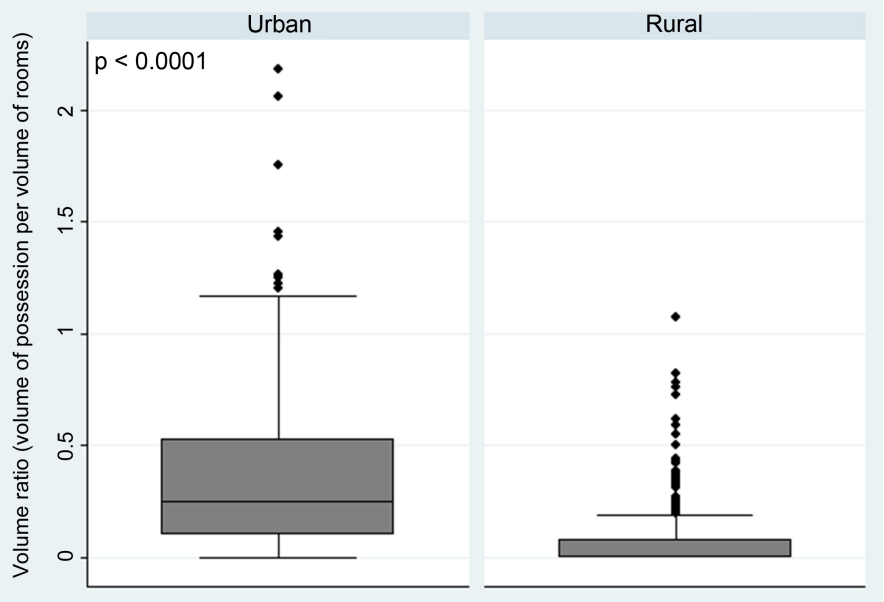


Figure 4. The mean volume of the household possession according to the zone (rural versus urban).

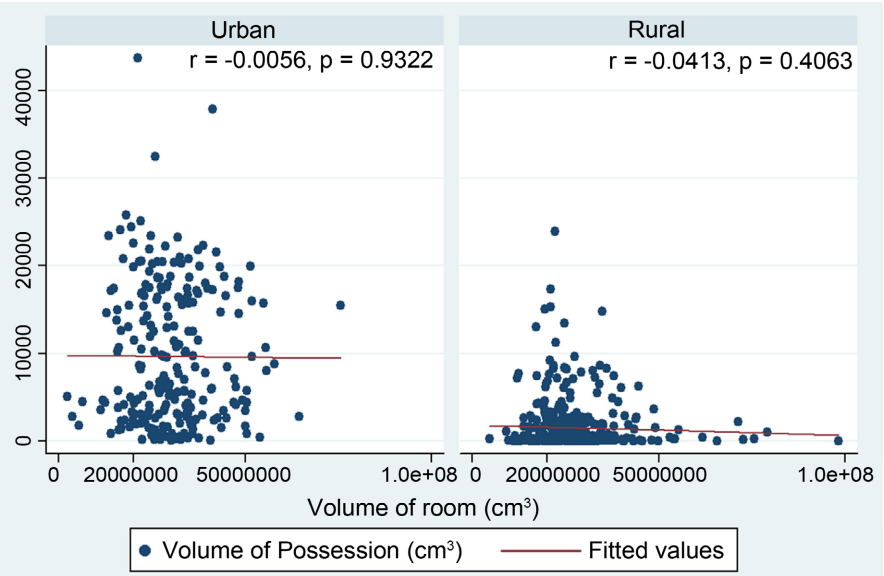


Figure 5. Link between the volume of possession and the volume of sleeping rooms in both areas.

capacity to favour successful malaria elimination. In this study, we characterized the immediate environment where LLINs and IRS are implemented by collecting and processing data on the type of housing, the volume of the room where individuals usually sleep, the household possession in those rooms and the volume they occupied. The data from sleeping rooms in north and south Benin in both rural and rural areas were considered for the analysis. We also look for the link between the total volume of household possessions, the volume of the sleeping room and the installation of LLINs.

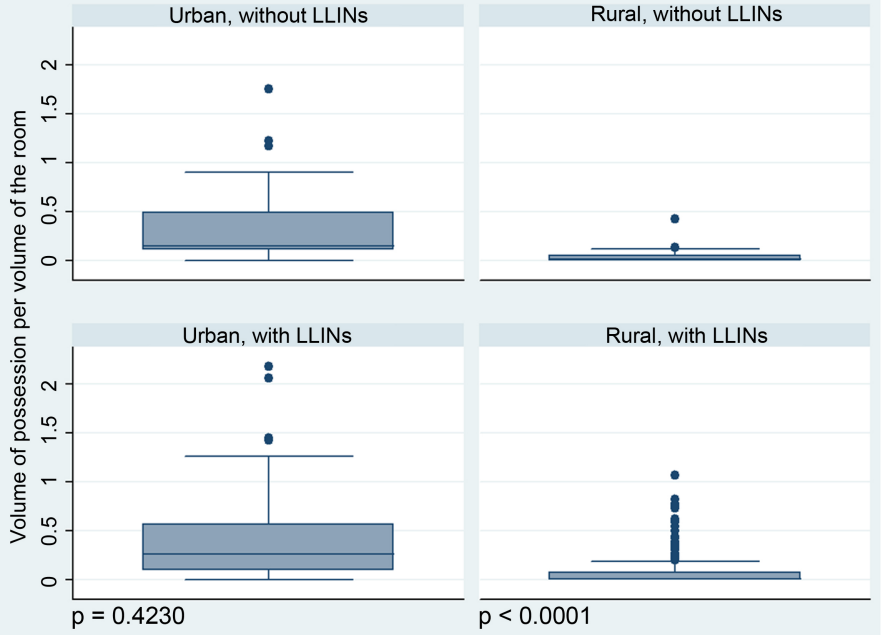


Figure 6. Volume of possession per the volume of the room according to the zone and the installation of the long-lasting insecticide-treated nets.

5.1. Housing Structure and Operations

In Benin houses, the rate of access to electricity is low. The national household electrification rate is only 28.2% and 4.5% in rural areas in 2014-2015 [18]. Between 2016 and 2020, less than 5% of the population of Cobly and 5% - 10% of the population of Tori Bossito had access to electricity. In contrast, in Djougou, 40% of the residents had access to electricity [19]. A big contrast was found between the mode of lighting of rooms in the South (open-flame oil lamps) compared to the North (flashlights powered by batteries). In the South, the lamps were powered by palm oil, which is very common in the South due to the presence of palm trees. Later, kerosene replaced palm oil. The presence of open flames poses a fire hazard, including the risk of fire with mosquito nets, which can result in burns to household members. It is important to exercise caution and take necessary safety measures to prevent such incidents [20]. In the northern region, the lamps were powered by shea butter and later by kerosene. But a major change was observed in our study in the northwest where the majority of households now use flashlights powered by batteries. This change could be explained by the high cost of kerosene and by the easy access to flashlights in the north-western areas. The roof-to-wall spaces and the darkness prevailing in the rooms can be favourable to the endophilia and endophagy of mosquito vectors [21] [22]. Then, unlit rooms could contribute to the high aggressive density of malaria vectors in homes. In the same, features of substandard housing, including the default of roof ceilings and grid windows, and inadequate food storage have long been identified as contributing to the intrusion by disease vectors (e.g., insects and rats) and the spread of infectious diseases [5]. Mud-walled houses

had also higher vector density than other wall types [11]. The study investigated the relationship between the total volume of household possessions, the volume of the sleeping room, and the hanging of LLINs and examined how these factors were interconnected and their possible contribution in the inefficient use of LLINs and IRS as vector control measures.

5.2. Issues for Long-Lasting Insecticide-Treated Nets Hanging, Use and Effectiveness

Toé *et al.* showed that the physical integrity and the use of LLINs are closely linked to the type of environment they are found [23]. In the current survey, a significant volume of the possession is stored inside the sleeping rooms mainly in the urban area. The implication is that the full-time hanging of the LLINs can be compromised in terms of misuse and sometimes the drop-out of the LLINs due to discomfort. LLINs are usually attached with twine or wood from the frame or a nail attached to the wood or in the wall. Open flame lighting, type of bed frames, presence of kitchens or other vertebrates and arthropods in bedrooms, style of LLINs hanging can quickly the physical integrity of the bed net and then shorten its lifetime and decrease its effectiveness. For example, all bedrooms examined were potentially dusty, poorly lit, and installed in crowded environments, which can pose challenges to the durability of mosquito nets, and ultimately the effectiveness of LLINs.

According to the study, it seems that individuals, disease vectors, and vector control measures coexist within sleeping rooms that have clay walls and are typically covered with aluminium sheet metal. The presence of aluminium induces high indoor temperature. Moreover, the room's doors, and windows are small, particularly in rural areas. The design of the sleeping rooms indicates a microenvironment where it is likely to be very hot. Consequently, inconsistent usage of LLINs may be expected as a result. In Nigeria, the majority of LLINs users (68.2%) were observed to stay outdoor between 7.00 p.m and 11.00 p.m before going to the bedrooms [24]. The primary reason for inconsistent usage of LLINs is the discomfort caused by high indoor temperatures in houses [25] [26] [27]. This sleep pattern exposed them to mosquito bites before sleeping under mosquito nets, thereby hampering the overall effectiveness of mosquito nets.

5.3. Issues for Sleeping in Indoor Residual Spraying Houses and Effectiveness

The presence of objects in the room can obstruct the contact between disease vectors and insecticide-treated walls, thereby reducing the effectiveness of the intervention. Cluttered boxes containing clothes and utensils are particularly attractive resting spots for Anopheles mosquitoes. Additionally, the uneven surface of earthen bar walls, characterized by bumps and crevices, serves as potential resting sites for vectors following blood feeding. In western Cameroon, in homes where fire is made *A. funestus* rests at the bottom of the walls to escape

smoke and soot, while *A. gambiae* tolerates them [28]. The absence of insects in the entry traps used for insecticide experimentation can lead to distorted results and potentially provide overly optimistic information regarding vector mortality rates [29]. The type of resting places preferred by insects can greatly impact the effectiveness of home treatments [30]. Finally, the persistence of insecticides varies according to the substrate. In Benin, it was described that the earth walls, the most important type of wall in the study area, are not in favour of a good remanence of IRS [10] [31].

5.4. Link between the Total Volume of the Possession and the Volume of the Sleeping Rooms

It was observed that the possession of goods was higher in urban areas compared to rural areas. However, no correlation was found between the volume of possessions and the size of sleeping rooms in both rural and urban settings. This suggests that households do not tend to store a quantity of personal belongings and equipment regardless of the size of the bedroom. However, for smaller rooms which are more common, the risk is that there may not be enough space to install LLINs. Field studies often report that LLINs are placed in the living room every night and removed every morning, likely because there is insufficient space in the bedrooms for their installation. When the mean rate ratio of the volume occupied by possessions compared to the volume of the room increases, it suggests that the remaining space in the sleeping rooms decreases. In rural areas, households with a smaller volume of possessions were less likely to hang long-lasting insecticidal nets (LLINs) compared to households with larger quantities of possessions, and this finding is statistically significant**.** One hypothesis is that in rural areas, the possessions owned by households can serve as indicators of wealth and people's behaviour, whereas in urban areas, this relationship may be less straightforward. A higher level of wealth in rural areas may be associated with a greater likelihood of using LLINs [6] [32] [33]. Providing affordable housing options can help individuals afford housing that meets their needs while simultaneously improving their health. Affordable housing, such as social housing, can be encouraged through the funding of an affordable housing supply or through subsidies [6].

6. Conclusion

The physical characteristics of the bedrooms described in the study were found to be unfavourable for achieving effective vector control using LLINs and IRS whereas these methods are widely recommended as malaria vector control tools. The study highlights that factors such as construction materials, type of bedding, lighting types, roof-to-wall spaces, and the presence of fireplaces inside the rooms, the volume of possessions and room size can negatively impact the installation and utilization of LLINs and IRS and their effectiveness. Addressing these challenges by improving housing conditions, ventilation, lighting, and reducing

overcrowding is crucial to enhancing malaria elimination in sub-Saharan African countries. Overall, the study emphasizes the importance of holistic approaches that encompass housing improvements, vector control measures, and a deeper understanding of human behavior to effectively combat malaria and other vector-borne diseases in resource-constrained settings.

Conflicts of Interest

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

References

[1] Huho, B., Briët, O., Seyoum, A., Sikaala, C., Bayoh, N., Gimnig, J., *et al*. (2013) Consistently High Estimates for the Proportion of Human Exposure to Malaria Vector Populations Occurring Indoors in Rural Africa. *International Journal of Epidemiology*, **42**, 235-247. https://doi.org/10.1093/ije/dys214

[2] World Health Organization (2021) Global Technical Strategy for Malaria 2016-2030. 2021 Update.

[3] World Health Organization (2022) World Malaria Report 2022. World Health Organization, Geneva, 293.
https://www.who.int/publications/i/item/9789240064898

[4] Bhatt, S., Weiss, D.J., Cameron, E., Bisanzio, D., Mappin, B., Dalrymple, U., *et al*. (2015) The Effect of Malaria Control on *Plasmodium falciparum* in Africa between 2000 and 2015. *Nature*, **526**, 207-211. http://www.nature.com/articles/nature15535

[5] Krieger, J. and Higgins, D.L. (2002) Housing and Health: Time Again for Public Health Action. *American Journal of Public Health*, **92**, 758-768.
https://doi.org/10.2105/AJPH.92.5.758

[6] World Health Organization (2018) WHO Housing and Health Guidelines. World Health Organization, Geneva, 149 p. https://apps.who.int/iris/handle/10665/276001

[7] Haines, A., Bruce, N., Cairncross, S., Davies, M., Greenland, K., Hiscox, A., *et al*. (2013) Promoting Health and Advancing Development through Improved Housing in Low-Income Settings. *Journal of Urban Health*, **90**, 810-831.
http://link.springer.com/10.1007/s11524-012-9773-8
https://doi.org/10.1007/s11524-012-9773-8

[8] Ministry of Health B (2022) Annuaire des Statistiques Sanitaires 2021. Ministry of Health, Cotonou, 297.

[9] Damien, G.B., Djènontin, A., Rogier, C., Corbel, V., Bangana, S.B., Chandre, F., *et al*. (2010) Malaria Infection and Disease in an Area with Pyrethroid-Resistant Vectors in Southern Benin. *Malaria Journal*, **9**, Article No. 380.
https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-9-380
https://doi.org/10.1186/1475-2875-9-380

[10] Odjo, E.M., Salako, A.S., Padonou, G.G., Yovogan, B., Adoha, C.J., Adjottin, B., *et al*. (2023) What Can Be Learned from the Residual Efficacy of Three Formulations of Insecticides (Pirimiphos-Methyl, Clothianidin and Deltamethrin Mixture, and Clothianidin Alone) in Large-Scale in Community Trial in North Benin, West Africa? *Malaria Journal*, **22**, Article No. 150.
https://malariajournal.biomedcentral.com/articles/10.1186/s12936-023-04572-9
https://doi.org/10.1186/s12936-023-04572-9

[11] Ondiba, I.M., Oyieke, F.A., Ong'amo, G.O., Olumula, M.M., Nyamongo, I.K. and Estambale, B.B.A. (2018) Malaria Vector Abundance Is Associated with House Structures in Baringo County, Kenya. *PLOS ONE*, **13**, e0198970. https://doi.org/10.1371/journal.pone.0198970

[12] Nabassaga, T., Bah, E.H. and Faye, I. (2019) Quality Homes for Sustainable Malaria Prevention in Africa. Working Paper Series 2438. https://ideas.repec.org/p/adb/adbwps/2438.html

[13] World Population Review (2023) Djougou Population 2023. https://worldpopulationreview.com/world-cities/djougou-population

[14] Nambima, S. (2023) République du Bénin. Ministère de la Décentralisation et de la gouvernance locale. Histoire résumée de Cobly. https://decentralisation.gouv.bj/public/commune/8/cobly/#:~:text=Quatre%20arrondissements%20%28Cobly%2C%20Kountori%2C%20Tapoga%20et%20Datori%29%20la,villages%20pour%20un%20peu%20plus%20de%2080.000%20habitants

[15] Biaou, C.F. (2006) Monographie de la commune de Djougou. Bénin. Afrique Conseil. http://www.ancb-benin.org/pdc-sdac-monographies/monographies_communales/MONOGRAPHIE%20DE%20LA%20%20COMMUNE%20DE%20DJOUGOU.pdf

[16] Akouakou, R. (2023) République du Bénin. Ministère de la Décentralisation et de la gouvernance locale. Histoire résumée de Tori Bossito. https://decentralisation.gouv.bj/public/commune/22/tori-bossito/#:~:text=Sa%20population%2C%20essentiellement%20agricole%20est%20estim%C3%A9e,%C3%A0%20plus%20plus%2060%20000%20habitants

[17] Ministère du Plan et du Développement Institut National de la Statistique et de l'Analyse Économique (INSAE) Cotonou, Bénin. Cinquième Enquête Démographique et de Santé au Bénin (EDSB-V) 2017-2018. ICF, Rockville, 74. https://www.insae-bj.org/images/docs/insae-statistiques/sociales/Sante/Enqu%C3%AAte%20D%C3%A9mographique%20et%20de%20Sant%C3%A9%20au%20B%C3%A9nin%20(EDSB)%20de%202017-2018.pdf

[18] International Energy Agency (IEA) and the World Bank (2015) Sustainable Energy for All 2015—Progress toward Sustainable Energy. Washington DC.

[19] Ministère de l'Energie (2021) Bilan énergétique et indicateurs 2016 à 2020. Direction Générale des Ressources Énergétiques, Cotonou, 26.

[20] Egrot, M., Houngnihin, R., Baxerres, C., Damien, G., Djènontin, A., Chandre, F., *et al*. (2014) Reports of Long-Lasting Insecticidal Bed Nets Catching on Fire: A Threat to Bed Net Users and to Successful Malaria Control? *Malaria Journal*, **13**, Article No. 247. https://doi.org/10.1186/1475-2875-13-247 https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-13-247

[21] Leandro-Reguillo, P., Thomson-Luque, R., Monteiro, W.M. and De Lacerda, M.V.G. (2015) Urban and Architectural Risk Factors for Malaria in Indigenous Amazonian Settlements in Brazil: A Typological Analysis. *Malaria Journal*, **14**, Article No. 284. http://www.malariajournal.com/content/14/1/284 https://doi.org/10.1186/s12936-015-0806-0

[22] Ngadjeu, C.S., Doumbe-Belisse, P., Talipouo, A., Djamouko-Djonkam, L., Awono-Ambene, P., Kekeunou, S., *et al*. (2020) Influence of House Characteristics on Mosquito Distribution and Malaria Transmission in the City of Yaoundé, Cameroon. *Malaria Journal*, **19**, Article No. 53. https://malariajournal.biomedcentral.com/articles/10.1186/s12936-020-3133-z https://doi.org/10.1186/s12936-020-3133-z

[23] Toé, L.P., Skovmand, O., Dabiré, K.R., Diabaté, A., Diallo, Y., Guiguemdé, T.R., *et al*. (2009) Decreased Motivation in the Use of Insecticide-Treated Nets in a Malaria Endemic Area in Burkina Faso. *Malaria Journal*, **8**, Article No. 175. https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-8-175 https://doi.org/10.1186/1475-2875-8-175

[24] Omonijo, A. and Omonijo, A.O. (2019) Assessment of the Status of Awareness, Ownership, and Usage of Long-Lasting Insecticide Treated Nets after Mass Distribution in Ekiti State, Nigeria. *Journal of Parasitology Research*, **2019**, Article ID: 1273714. https://doi.org/10.1155/2019/1273714

[25] Carrasco-Tenezaca, M., Jatta, E., Jawara, M., Bradley, J., Pinder, M., D'Alessandro, U., *et al*. (2021) Effect of Roof Colour on Indoor Temperature and Human Comfort Levels, with Implications for Malaria Control: A Pilot Study Using Experimental Houses in Rural Gambia. *Malaria Journal*, **20**, Article No. 423. https://malariajournal.biomedcentral.com/articles/10.1186/s12936-021-03951-4 https://doi.org/10.1186/s12936-021-03951-4

[26] Cohee, L.M., Nankabirwa, J.I., Greenwood, B., Djimde, A. and Mathanga, D.P. (2021) Time for Malaria Control in School-Age Children. *The Lancet Child & Adolescent Health*, **5**, 537-538. https://linkinghub.elsevier.com/retrieve/pii/S2352464221001589 https://doi.org/10.1016/S2352-4642(21)00158-9

[27] Koenker, H.M., Loll, D., Rweyemamu, D. and Ali, A.S. (2013) A Good Night's Sleep and the Habit of Net Use: Perceptions of Risk and Reasons for Bed Net Use in Bukoba and Zanzibar. *Malaria Journal*, **12**, Article No. 203. https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-12-203 https://doi.org/10.1186/1475-2875-12-203

[28] Mouchet, J. and Gariou, J. (1961) Répartition géographique et écologie des anophèles au Cameroun. *Bulletin de la Société de Pathologie Exotique*, **54**, 102-107.

[29] Smith, A. (1962) Effects of Dieldrin on the Behaviour of *A. gambiae*. *Bulletin of the World Health Organization*, **26**, 120-125.

[30] Smith, A. and Hocking, K.S. (1962) Assessment of the Residual Toxicity to *Anopheles gambiae* of the Organophosphorus Insecticides Malathion and Baytex. *Bulletin of the World Health Organization*, **27**, 231-238.

[31] Djènontin, A., Aïmihouè, O., Sèzonlin, M., Damien, G.B., Ossè, R., Soukou, B., *et al*. (2013) The Residual Life of Bendiocarb on Different Substrates under Laboratory and Field Conditions in Benin, Western Africa. *BMC Research Notes*, **6**, Article No. 458. https://bmcresnotes.biomedcentral.com/articles/10.1186/1756-0500-6-458 https://doi.org/10.1186/1756-0500-6-458

[32] Howden-Chapman, P., Chapman, R. and Baker, M.G. (2023) Valuing Social Housing Needs to Take a Broader View. *Journal of Epidemiology and Community Health*, **67**, 803-804. https://doi.org/10.1136/jech-2013-202812

[33] Lindberg, R.A., Shenassa, E.D., Acevedo-Garcia, D., Popkin, S.J., Villaveces, A. and Morley, R.L. (2010) Housing Interventions at the Neighborhood Level and Health: A Review of the Evidence. *Journal of Public Health Management and Practice*, **16**, S44-S52. https://journals.lww.com/00124784-201009001-00008 https://doi.org/10.1097/PHH.0b013e3181dfbb72