

IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: S Ismail Ahmed Ali and Z Szalay 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012012

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Towards developing a building typology for Sudan

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Abstract. Sudan suffers from hard summers with temperatures approaching 42 0C in the South and 48 0C in the North. In spite of that, the technical solutions in buildings for protection against solar radiation and natural ventilation are generally beyond reach. There isn't sufficient information provided on the characteristics of the building stock, building physics and energy use of buildings in Sudan. The main objective of this research paper is to collect the data from the population and housing census, scientific research papers and different reports, and to use these in preparing a building typology table. The climate in Sudan is divided into three zones: warm desert climate, warm semi-arid climate, and tropical savanna climate zone. The building varies according to the climate zones, geographical feature, and urbanization levels. Building materials range from natural ones like straw, wood, and mud to moderns one like bricks and concrete. Building typology varies from structures to provide temporary shelter to the permanent single or multi-family houses. The main result of this research paper is to identify a building typology in Sudan with reference buildings. This is the first paper that introduced the typology table of Sudan.

1. Introduction

We are living under the mercy of climate. Climate shapes us, it means that our habits, clothing, food, and buildings need to adjust to climate conditions. There are four main climate zones on Earth: cold, temperate, hot-arid and hot- humid zones [1]. Traditional architecture responded to the climatic challenges in every climate zone with locally available solutions.

As the hot-arid climate area where Sudan is located is characterized by excessive heat and glaring sun, there is a focus on designing a shelter to reduce heat impacts and provide shade. Structures in this area were traditionally constructed of massive roofs and walls of adobe. In many developing countries, development efforts often focus on the construction sector to achieve the required level for urban shelter. Sudan as a developing country is still far from providing an adequate level of shelter to its citizens. The harsh environmental and climatic features, worsening economic situation, shortages and the big gap in the scientific data and research prevented the proper adaptation of building materials and technology. On the other hand, there is an incompatibility between the modern building materials and techniques and the country's features and design parameters.

The main purpose of this research paper is to introduce the general features of the Sudanese geodemographic and climate characteristics and to analyze how these features influenced the building stock in the past and in the present. The main goal is to compile relevant information on the building stock of Sudan for establishing a building typology that can be used for further assessment. According to our knowledge, no such building typology existed before in the country, so this can be considered as a first trial effort. A building typology with reference buildings is a useful starting point for energy performance calculations, comfort evaluations, and strategic planning [2].



2. Methodology

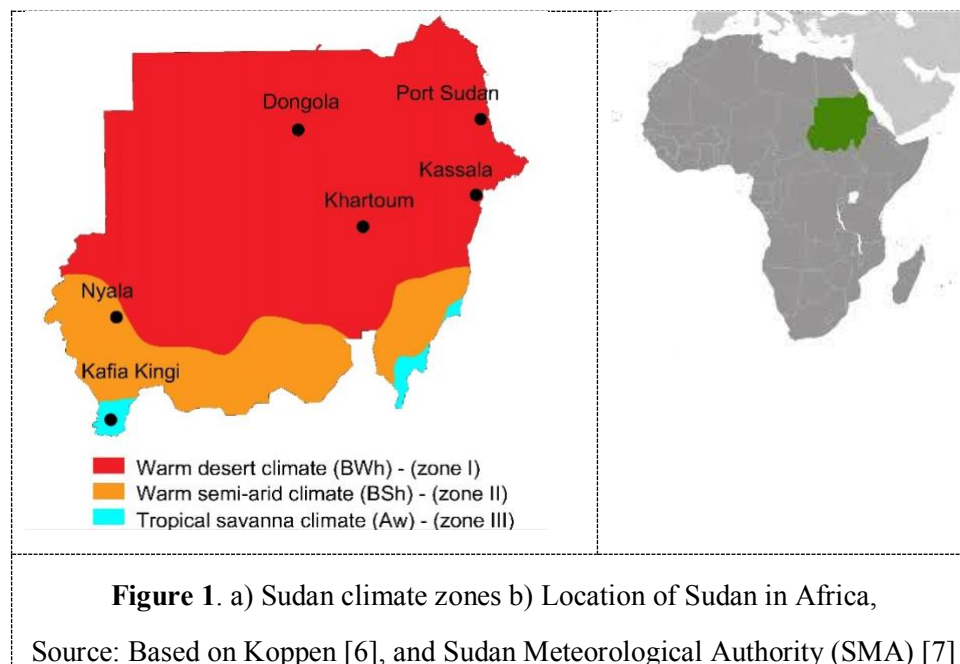
The method used in this paper was to collect statistical data from the different authorities and information from the previous research, and using the data to illustrate and analyze the building typology of Sudan according to the different parameters. First geographical, climate and demographic features are introduced, and the relevant information on the housing stock is described.

2.1 Geographical features

Sudan is located in North- East Africa. It is bounded by the Red Sea and Egypt from the North, Ethiopia, and Eritrea from the East, South Sudan from the South, Central African Republic, Chad and Libya from the West. Before 2011, Sudan was the largest country in Africa, but due to the secession of South Sudan, its current area is about 1.886 million km² making it number three in Africa and number 16 in the world. Sudan has many wealth resources of water, livestock, fertile lands, diverse forests, minerals (gold and copper), and oil production. The soils of Sudan are classified into six main categories according to their locations and construction: i) desert; ii) semi-desert; iii) sand; iv) alkaline catena; v) alluvial; and vi) ironstone plateau. There are many local variations due to drainage conditions [3], [4].

2.2 Climate of Sudan

Sudan has a composite climate between hot, cool and rainy seasons. The principal climatic elements which affect the building design and comfort are solar radiation, temperature, humidity, wind speed and direction and precipitation [5].



Sudan is classified into three climatic zones (Zone I: warm desert climate, Zone II: warm semi-arid climate and Zone III: tropical savanna climate) as shown in (Figure 1) [6], [7].

In the Northern Part (zone I) warm desert climate zone summer temperatures exceed 43.3 degrees Celsius in the desert zones and rainfall is negligible except in the center, such as the capital Khartoum and Gezira city where rainfall is common between June and September. Dongola, Port Sudan, Kassala, and Khartoum are examples of some cities in this zone (See Figure 1 and 2). The maximum mean temperature registered the highest values in Dongola and Khartoum cities, (Figure 2(a) and Figure 2(b)), while the highest values of humidity are in Port Sudan city because of its coastal location close to the Red Sea (Figure 2(c)). In the capital Khartoum, the average annual temperature is about 26.7 °C;

and the annual rainfall is about 254 mm. The northern part of Sudan has a harsh climate compared to the other parts.

Nyala is located in the South Western warm semi-arid climate zone area (zone II), it has moderate summer and winter temperature and high rainfall and relative humidity values (see Figure 2(c) and Figure 2(d)), this is because its location is close to the tropical savannah region (zone III) [8].

The greatest amount of solar radiation in Sudan is found between 15 and 35 latitude north. Wind speed and direction vary with seasons. In winter, the wind speed ranges between 0.54 m/s to 1.54 m/s in N and NW direction, while in the summer season winds are usually locally supplemented by dust and sand in the direction of NW to SW. Dust storms frequently occur in the desert zone. High temperatures also occur in the southern part, but the humidity is generally high [9].

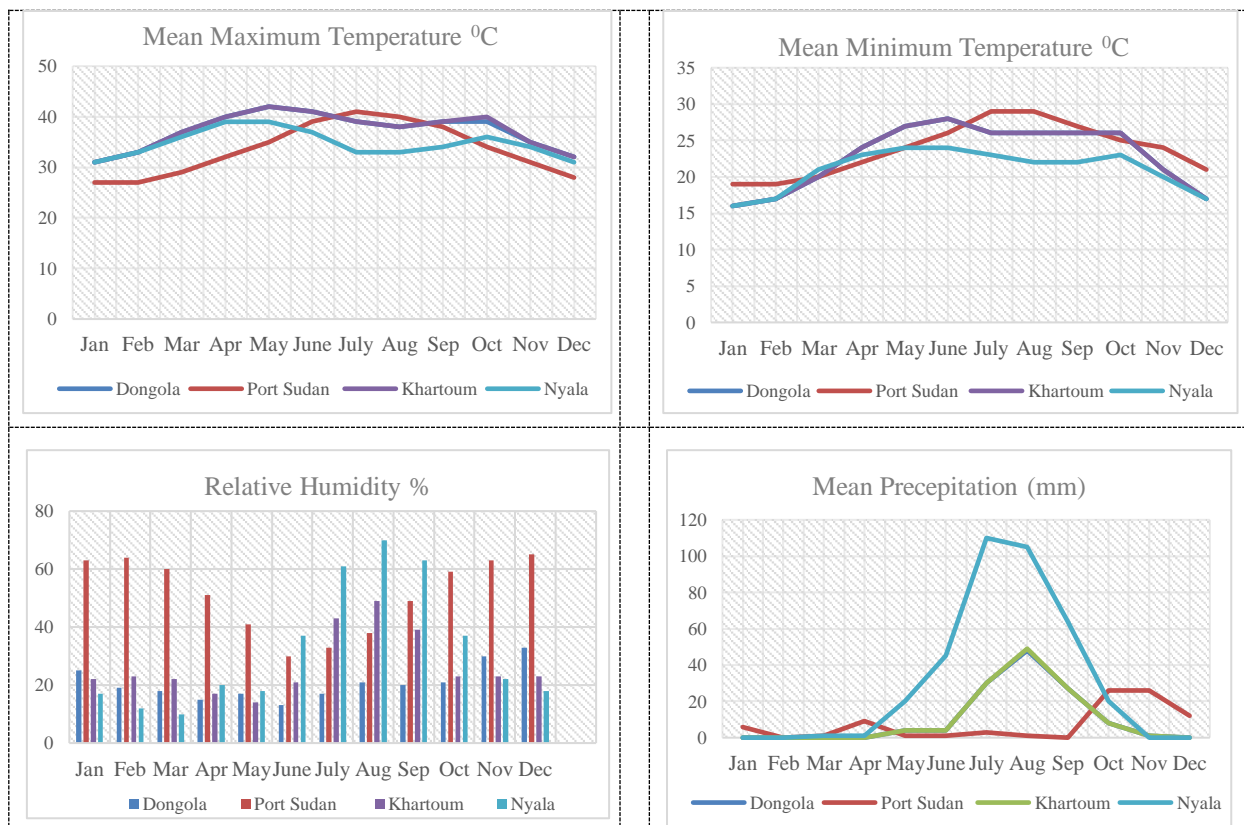


Figure 2. Metrological data of Dongola, Port Sudan, Kassala, Khartoum, Nyala for the: (a) mean maximum temperature for 30 years period (b) mean minimum temperature for 30 years period (c) annual relative humidity in 2009 (CBS) (d) mean precipitation (mm) for 30 years period

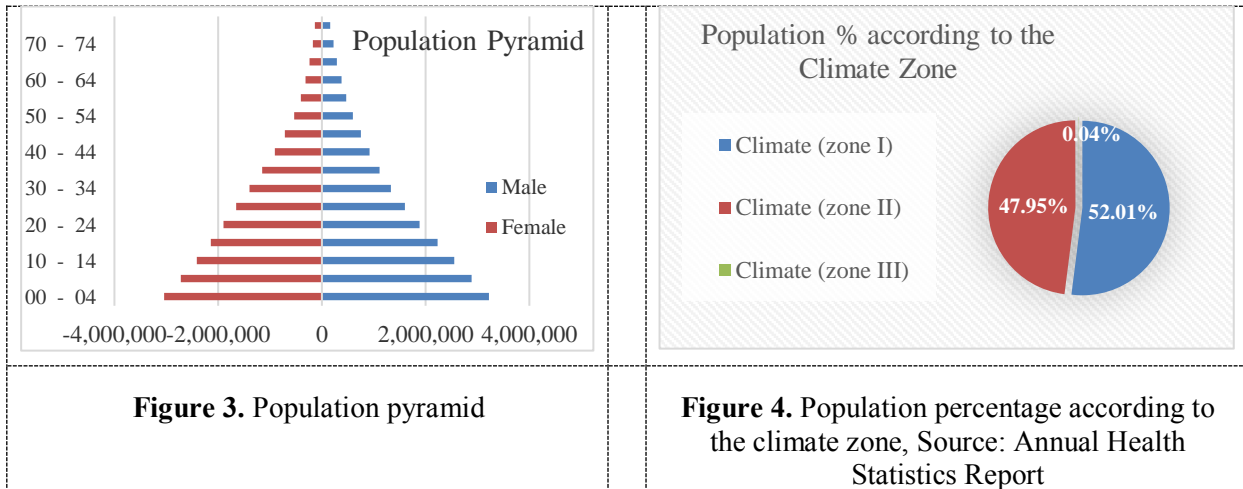
Source: World Metrological Organization, Sudan Metrological Authority and Central Bureau of Statistics [8].

2.3 Demographic

The population of Sudan has increased by 49.5% in the past 25 years, reaching 41 511 526 million in 2018, growing at 2.8% rate per annum. The urban population is estimated at about one-third (34.6%) of the total, which indicates that Sudan is still predominantly rural. With this rate of increase, the population could double in about 16 years [10], [11].

Sudan's population pyramid is young and growing, so it belongs to the expansive type (Figure 3). In the population distribution, around 41% of the population is under 15 years, 56% is between 15 to 64 years and 3% of the population is more than 65 years old. Life expectancy is low due to the health

and economic system. Most of the population is confined to two climate zones. About 52% of the population lives in the warm desert climate zone and 48% in the warm semi-arid climate zone. Only 0.04% live in the tropical savannah climate (Figure 4 and 1). A conflict region between South and North Sudan in this area (Kafia Kingi City) due to the rich natural resources there [12].

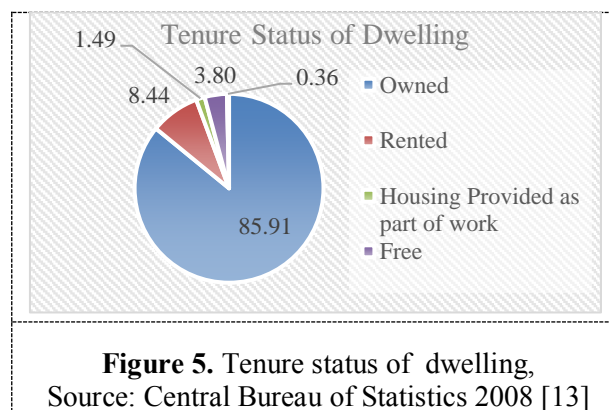


Source: Annual Health Statistics Report 2017 [12]

2.4 Tenure status of dwellings

Most Sudanese live in simple houses of their own or rent from landlords or agricultural-scheme authorities. Housing can be classified into four types according to tenure status as shown in Figure 5: owned, rented, provided as part of work and free dwelling.

Figure 5 illustrates that most of the dwellings are owned, about 86%, while housing provided as part of work registered the lowest value. The government doesn't play a big enough role in supporting affordable housing [13].



2.5 Building materials in Sudan

The building materials in Sudan are classified into three types: (a) modern materials: i.e., concrete, red brick with cement mortar, cement bricks and corrugated iron sheets; (b) traditional permanent materials: red bricks combined with mud bricks for wall construction, mud construction for walls and roofing made from sticks, thatch and mud; and (c) traditional materials: i.e., thatch used for roofing and for walls. In first class areas (classification according to the residential area level), residential buildings are made of red bricks with clay or cement mortar, reinforced concrete ceilings, and roofs or corrugated iron sheets for roofing [14].

Residential buildings may be classified according to the building materials into straw huts, mud and adobe houses, red bricks houses and apartment houses (Figure 6 (a)). About 65% of the houses are from mud and adobe material, and a very low percent of the houses are apartments. This reflects the low level of urbanization in Sudan.

Another classification is according to the residential area level (Figure 6 (b)). The first and second class residential areas should be durable materials, while the houses in the third class residential areas can be constructed of semi-durable materials. Most of the houses are at the medium level, “the third class housing “and the percentage of the illegal houses are very high. This reflects the slow urban planning process. The top materials that have been used in houses are mud and adobe for wall, straw and palm leaves for roof construction (Figure 7 (a) and figure 7 (b)). Concrete and cement blocks registered the lowest percentage [15].

* Note: the data about the building materials, residential area classes and wall and roof materials of the house are rather old (from 1968). The main reason is to show the classification and the materials that have been used in the past. This survey is used by several authors [16]. According to our knowledge, there is no new data available.

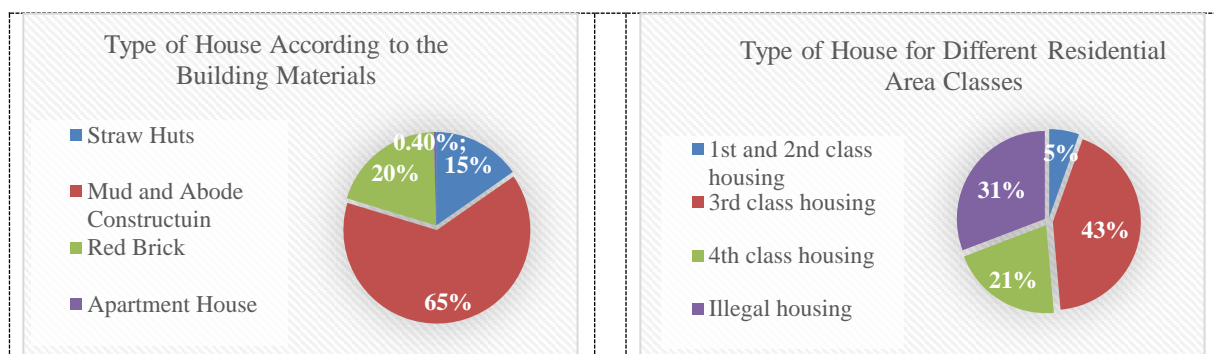


Figure 6. Type of house according to the: (a) building materials. (b) residential area classes
Source: Household Sample Survey 1968

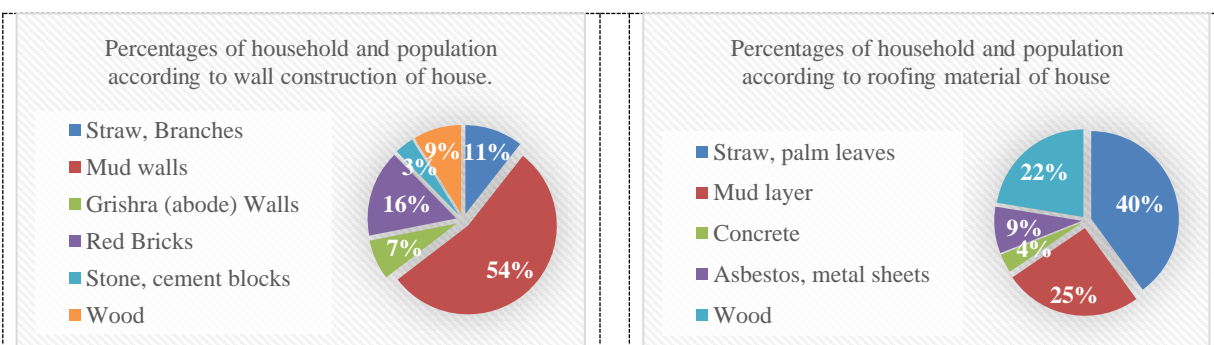
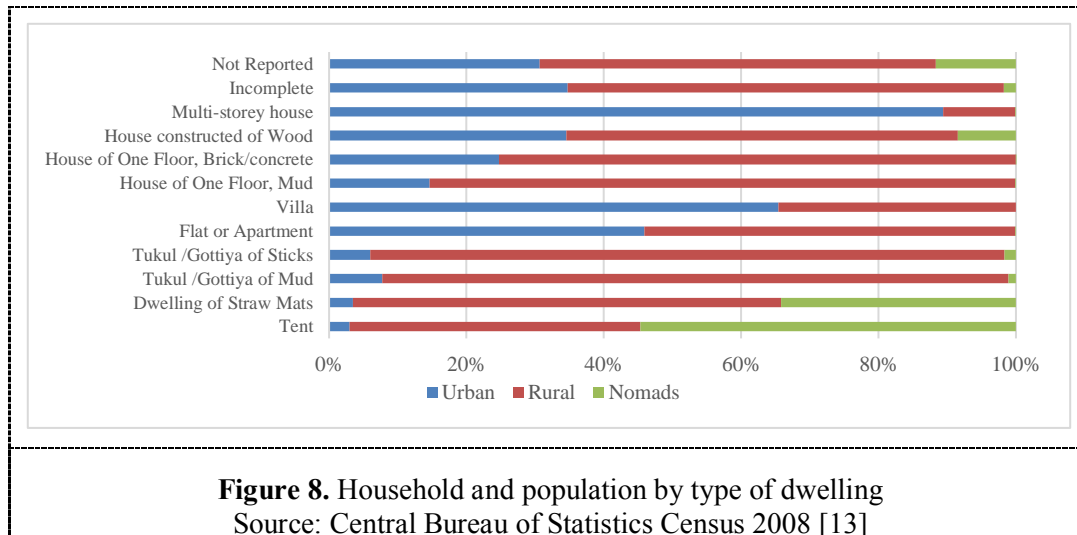


Figure 7. Percentage of household and population according to the (a) wall construction of the house (b) roofing material of the house. Source: Household Sample Survey 1968

2.6 Building construction development in Sudan

There is a big difference in the level of construction activities in Khartoum, the South, and North Darfur. The region of the Southern part and Darfur suffer from the low level of their built environment, due to the war, conflicts and the lack of economic development. There is a shortage of building materials due to draught and the huge need for shelter [17]. The most common houses in the rural part are the so-called Gottiya made of straw or millet stalks covering a wooden skeleton.

At the last census in 2008, over half of all housing units were Gottias (single rooms with round mud walls and a conical straw roof); about one-third were Menzils (multi-room houses with toilet facilities). Almost every house, even in the cities, has a walled courtyard or garden [18].



According to the collected data from 2008 census reports, dwellings in Sudan are classified into different types: tent, dwelling of straw mats, Tukul or Gottiya of mud, Tukul or Gottiya of sticks, flat or apartment, villa, single-storey mud house, single-storey brick or concrete, house constructed of wood and multi-storey house. Most of the urban population live in a multi-storey house and the rest in temporary and traditional houses. In the rural population, one-floor mud houses and Tukul or Gottiya stick houses are the common types, while multi-storey houses rarely exist (Figure 8). The nomadic population depends on temporary materials, like straw mats and other temporary materials.

2.7 Heating and cooling devices:

Simple devices like fans and air coolers are used for cooling in Sudan. The data showed that these devices are used by about 18.17% of the total population for fans and 3.94% for air coolers. Most of these devices are used by the urban population rather than the rural population (Figure 9 and Table1). The data in Figure 9 may be unreliable due to a large amount of not stated answers.

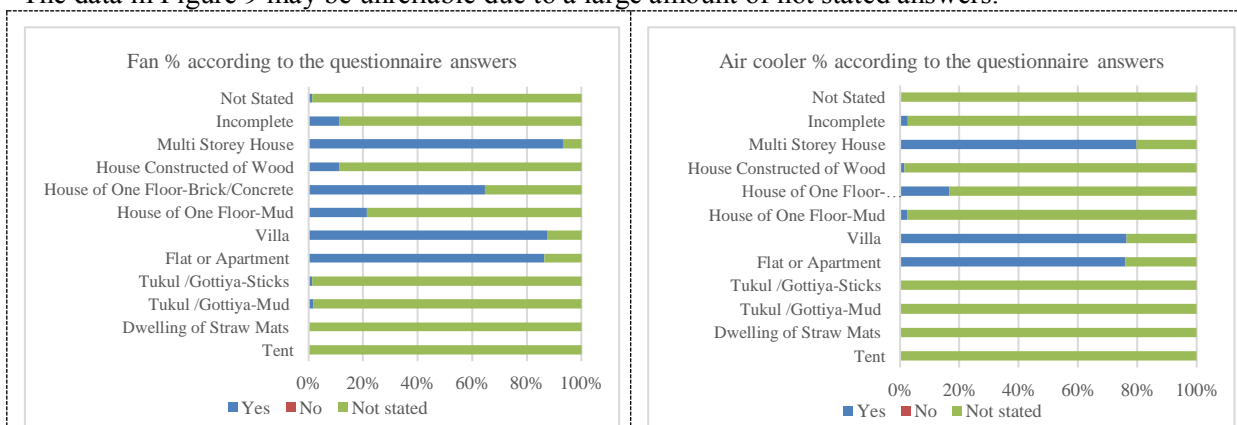


Figure 9. Percentage of fans and air coolers for different dwelling types according to the questionnaire answers, Source: Central Bureau of Statistics Census 2008 [13]














Table 1: Percentage of fans and air coolers of the total population

Item	Households%		
	Total %	Urban %	Rural %
Fan	18,17	40,22	9,3
Air Cooler	3,94	11,05	0,77

Source: Central Bureau of Statistics Census 2008 [13]

In temporary, old and traditional buildings fans and air coolers are rarely used, while they are more common in one-floor brick, concrete dwellings, single or multi-story houses and apartments (Figure 9). Most of the modern houses from reinforced concrete and bricks contain either simple or advanced cooling devices, due to the fact that concrete as a building material is not compatible with the Sudanese environment. Heating devices are not applicable in Sudan, except in a few houses in the northern part where electrical heaters are used for a few days in winter [13].

Table 2. Building typology table.

Construction Time	Temporary	Single Family Dwelling Detached			Multi-family Dwelling
		Climate Zone I (warm desert climate)	Climate Zone II (warm semi-arid climate)	Climate Zone III (tropical savanna climate)	
Very old (1900-1950) ^{1,2}		 House of One Floor Mud (Adapted)		 Tukul/Gottiya Mud	
Old (1956-2000) ³	 Tukul /Gottiya Sticks	 Tukul/ Gottiya Mud	 House of One Floor Brick/ Concrete	 Dwelling of Straw Mats	 Flat or Apartment
Modern (2000- till now) ⁴	 Tent  Tukul /Gottiya Sticks	 House of One Floor Mud	 Villa	 Wooden Dwelling	 Multi Storey House

¹ Early Colonial Architecture (1900–1920)

² Late Colonial Architecture (1921–1956)

³ The Post-Independence Era (1956–2000)

⁴ Architecture from 2000 onwards [19]

3. Results

The aim of the research was to present an overview and create the building typology of Sudan based on the data collected according to the different parameters: construction time, climate zone, construction materials, durability, tenant status of the dwelling and the building capacity.

From the collected data we could arrange the building typology table (Table 2) according to construction time, different climate zones, the durability of the material and the family size. A short description of each type is as follows:

The Tent is a very old, temporary and easy to move dwelling, which is used by nomads. It is made from the local materials. **Dwelling of Straw Mats**: a traditional dwelling which is made from pieces of mats connected together to form a room shape which is used as a shelter, it could be as a hut or a rectangle shape. **Tukul/ Gottiya of Mud**: a mud hut or house which is made essentially from the mud. (Tukul is a simple room made from traditional materials, some people use it as a place for cooking, while Gottiya is a single room with round walls and a conical roof.) **Tukul/ Gottiya of Sticks**: it's a temporary stick room, which is made essentially from sticks as supporters for the dwelling. **Flat or apartment**: made of modern buildings materials, such as bricks and reinforced concrete. **Villa**: includes a large amount of land and often barns, garages, or other outbuildings as well. **House of one floor, mud**: a traditional house with one or many rooms. It is made from mud as an essential material. **House of one floor, brick/ concrete**: a one family house with many rooms which is made from bricks and concrete. **House constructed of wood**: a single family house which is made from wooden elements. **Multi- Storey House**: a multi-family dwelling which is made from modern materials such as red bricks, reinforced concrete, cement block, and others.

4. Conclusions

The collected data from the country censuses, surveys, reports, and research papers had a lot of information about the climate, topography, building materials, and building technology of Sudan. A building typology table was prepared from the different collected data and with different parameters, such as construction time, the durability of the dwelling, and building capacity.

From the analysis the following points could be concluded:

- Climate change has a deep effect everywhere. In Sudan, the hot-arid areas have advanced southward, especially in the vulnerable areas surrounding Al Fashir and Nyala. This climate change caused a strong food scarcity, draught and affect the thermal comfort of buildings.
- The means of cooling and heating devices, such as air-conditioning is rarely used in Sudan because of the high cost of the operation, the price of the equipment and the low income of the majority of the urban population.
- The research on building typology was a starting point to better understand the features of Sudan's climate and to study and organize the building typology. These typology results should be improved and transferred into practical results.
- Data from Sudan's fifth population and housing census in 2008 were used, because it was the most recent, although there was some shortage of information on housing and building materials in the data. Due to this reason, some of the information applied in this paper is rather old but at least it was helpful in the classification and analysis procedure. Future research and updating the information will be much easier in the future.

5. Acknowledgment

Project FK 128663 has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the FK_18 funding scheme. The research reported in this paper was also supported by the FIKP grant of EMMI in the frame of BME-Water Sciences & Disaster Prevention (BME FIKP-VÍZ).

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