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RESEARCH ARTICLE

EVALUATION OF THE ENERGY NEEDS OF A TYPICAL HOUSE FOR THE DIFFERENT CLIMATIC ZONES OF CHAD

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Abstract

Ensuring thermal comfort for occupants throughout the year, starting from the building design phase, is a key challenge for all stakeholders. In Chad, temperatures are often very high for much of the year, leading to excessive use of air conditioning and ventilation systems. This phenomenon appears to be increasingly exacerbated by climate change. However, the energy demand, especially for cooling, is considerable across the entire national territory, while the country faces an energy access crisis. In this work, we aim to provide assistance to decision-makers and stakeholders at various levels to better understand and optimize buildings for different climate sites. Minimizing energy expenses while ensuring thermal comfort plays an essential role in social, environmental, and other aspects of well-being.

Introduction:-

In a context of rapid urban growth and increasing pressures on global energy resources, effective energy management in the building sector is of paramount importance. As highlighted by A. Athienitis and L. Santamouris, "buildings account for nearly 40% of global energy consumption and about a third of greenhouse gas emissions" (Guivarch, 2020). Thus, improving the energy efficiency of buildings is essential for reducing CO2 emissions and mitigating climate change (IEA (International Energy Agency), 2019). This importance is particularly relevant in large cities located in diverse climatic zones, where weather conditions significantly influence the energy needs of buildings. As emphasized by (Kim & Jeong, 2018; H. L. Lee & Tang, 2018), "regional climate variations affect the heating, cooling, and lighting requirements of buildings, necessitating adaptive approaches to maximize energy efficiency" (K. Lee et al., 2003).

Chad, a country in Central Africa, faces unique challenges in urban development and access to energy. With increasing urbanization and a young, dynamic population, major cities in Chad experience growing demand for housing, offices, and infrastructure. However, these developments often encounter energy constraints, particularly due to electricity supply instability and high costs of conventional energy sources (World Bank, 2018). With an area of 1,284,000 square kilometers, the country is the 5th largest in Africa and the 21st largest in the world. Situated at an average elevation of 543 meters above sea level, this vast country encompasses four distinct climatic zones:
- Saharan or desert zone (city of Faya)
- Sahelian-savanna zone (city of Abéché, N'Djamena)
- Sudanian zone (city of Moundou)
- Guinean zone (city of Sarh)

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However, the current pressing issues regarding energy management for well-being and thermal comfort in buildings necessitate precise knowledge of the climate context. In this context, it becomes imperative to accurately assess the energy needs of buildings in different climatic zones of the country to guide decisions regarding design and urban planning. This study aims to address this need by thoroughly examining the energy needs of buildings in major cities across various climatic zones in Chad. As emphasized by C. Kermanshahi et al., "accurate assessment of building energy needs is essential for designing efficient and economically viable design strategies" cited in (Dionne, 2015). The primary objective is to assess how varied climatic conditions influence the heating, cooling, and lighting requirements of buildings and how these factors can be accounted for in the design and construction of energy-efficient buildings. Therefore, we will focus on determining the energy needs for different scenarios, considering major cities as sites.

To achieve this objective, this study adopts a multidisciplinary approach that combines research methods in architecture, civil engineering, and environmental sciences. By adopting a multidisciplinary approach that integrates research methods in architecture, civil engineering, and environmental sciences, this study will help fill a significant gap in research on building energy efficiency in African urban contexts. By highlighting the importance of considering local climatic conditions in building design and planning, this research will provide accurate data and practical recommendations to promote a more sustainable and resilient built environment in Chad. The findings of this study will provide crucial information to policymakers, urban planners, architects, and civil engineers involved in building planning and design in Chad. By identifying specific energy needs of buildings in different climatic zones, this research will contribute to guiding efforts to promote sustainable construction and reduce dependence on fossil fuels. By providing accurate data and practical recommendations, this research will contribute to the promotion of a more sustainable and resilient built environment in Chad, while addressing global challenges of climate change and energy security.

Theoretical context

The assessment of energy needs in buildings within similar climatic zones has been extensively studied in the scientific literature, with a particular focus on optimizing the energy performance of buildings in specific climatic contexts.

Previous research has shown that regional climatic characteristics play a crucial role in the energy needs of buildings. For instance, in their study on the influence of climatic conditions on the energy consumption of residential buildings in Europe, (Vorger, 2014) demonstrated that heating and cooling needs vary significantly depending on geographical location and climate. Advanced computer simulation models have been developed to predict and evaluate the energy needs of buildings in different climatic zones. For example, EnergyPlus, a widely used energy simulation software, integrates specific climatic data to calculate heating, cooling, and lighting loads of buildings in diverse geographical contexts (Deru et al., 2011). Integrated approaches, such as bioclimatic design and passive construction techniques, have been developed to maximize energy efficiency of buildings in similar climatic zones. Bioclimatic design, for example, aims to leverage local climatic conditions to minimize building energy needs by optimizing building orientation, layout, and envelope characteristics (Oussama, 2014). Empirical studies have also been conducted to evaluate the effectiveness of different energy design strategies in similar climatic contexts. For instance, in their analysis of energy performance of commercial buildings in Asia, (Alexeeva & Roche, 2015) identified effective measures such as the use of high-energy-efficiency materials, optimization of natural ventilation, and installation of low-consumption lighting systems.

The analysis of existing literature on energy needs assessment in similar climatic zones highlights the importance of considering local climatic conditions in building design and planning. Integrated approaches, based on advanced simulation models and bioclimatic design strategies, are essential for optimizing the energy performance of buildings and reducing their environmental footprint in a context of increasing climate change.

Methodology:-

This section of our research highlights the approaches and tools adopted to assess the energy performance of the experimental building under various meteorological data. The chosen building represents the most common type of housing in the country. However, the selection and validation of simulation tools constitute the first essential steps of our methodology.

Simulation Challenges and Tool Validation

Today, thermodynamic simulation appears to be an effective approach for evaluating heating and/or cooling energy needs. Although there are numerous digital tools on the market, careful selection and mastery are necessary. This led us to choose two digital tools renowned for their efficiency and ability to conduct complex thermodynamic simulations, namely Ecotect Analysis 2011 and Design Builder with EnergyPlus interface. These two tools have obtained international certifications, particularly from the European Union, regarding their use and exploitation of obtained results.

The Figure 1shows the approach adopted for each case associated with the meteorological file of each site.

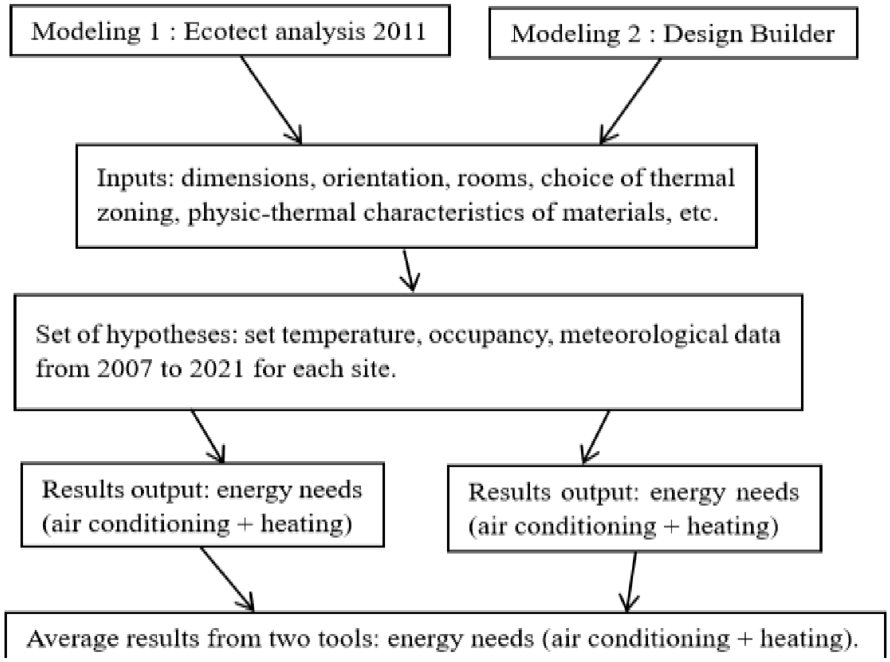

Figure 1:- Thermodynamic Simulation Operation Applied in Our Case.

However, the validation of Design Builder (EnergyPlus) from other research work is presented in Figure 2 below. Comparing its results with those of other tools ensures the reliability and accuracy of our analyses.

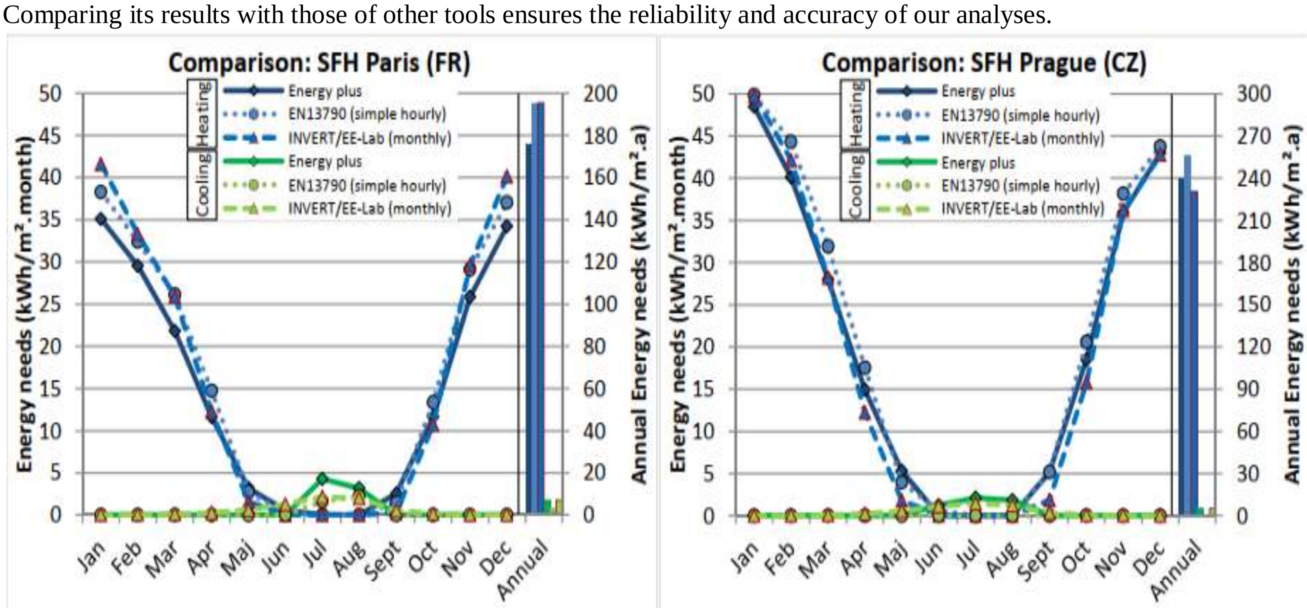

Figure 2:- Comparison of monthly energy needs for heating and cooling (only sensible component) between Energy Plus, EN13790 and INVERT/EE-Lab calculations for single house, Paris and Prague. (Paolo Zangher, et alt., 2014)

The building

From an architectural point of view, the building is designed as follows, as shown in Figure 6, with the room surfaces and thermal zones presented in Table 1.

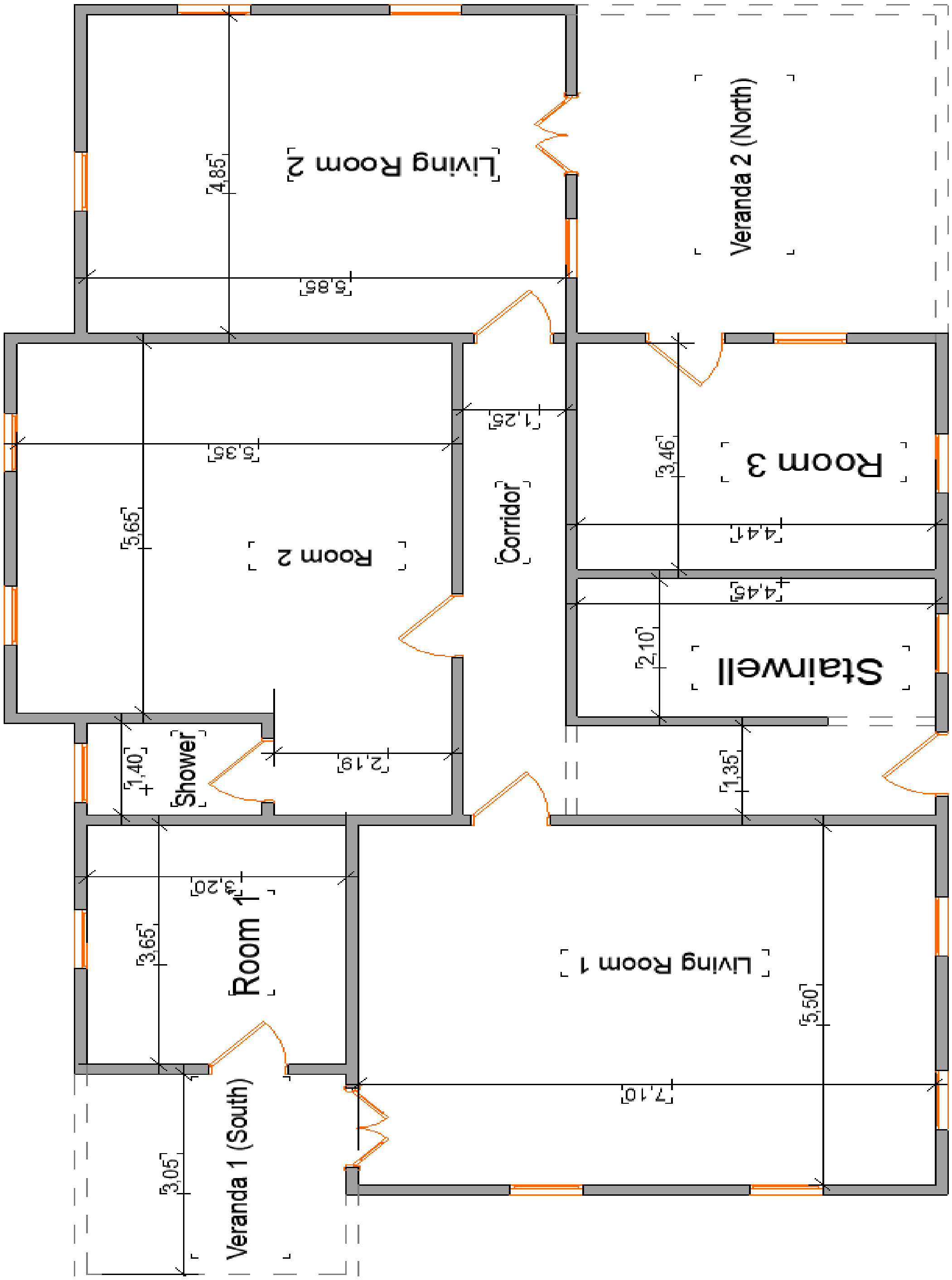

Figure 3:- Plan of the experimental thermal building.

In this study we have taken into account the different zones that allow us to consider the appropriate configurations from a thermal point of view, as shown in Table 1.

Table 1:- Parts and zoning.

Parts of the building	Area (m2)	Thermal zones
Veranda 1 (main South entrance)	9.76	Non thermal
Room 1	11.68	Thermal
Living room 1	39.05	Thermal
Shower	3.23	Thermal
Room 2	35.03	Thermal
Corridor	14.50	Non thermal
Stairwell	11.13	Non thermal
Room 3	15.13	Thermal
Living room 2	28.37	Thermal
Veranda 2 (North entrance)	21.58	Non thermal

a. Physic and thermal characteristics of materials

The physic and thermal characteristics used in the modelling for this study are presented in Table 2 (see also Table 1 in the Appendix).And in order to optimize energy consumption while ensuring thermal comfort, we have considered the setpoint temperature for HVAC ranging from 24^o (Lower band) to 26^o (Upper band).

Table 2:- Physic and thermal characteristics of materials.

Materials	Width(cm)	Admittance (W/m^2. K)	Weight (kg)	U-value (W/m^2. K)
Walls in Ep15 terracotta, density 2000 Kg/m3, rendering with plaster on 2 sides	18	5.190	349.500	2.560
16+4 floor with plastered sub-slab	22	5.260	253.302	3.040

b. Occupancy assumptions and thermal comfort parameters

In the modelling, we considered an occupancy rate with reference to the daily and cultural life of the inhabitants; then we took into account the set temperatures and the desired indoor conditions to ensure thermal comfort in the building. These data are shown in the appendix (see tables 1 and 2 in the appendix).

Results and Discussion:-

After simulating the model using the various climatic data, we present the results obtained from each numerical tool in Figure 4 below. This will make it possible to calculate the average results for each site directly and thus make comparisons.

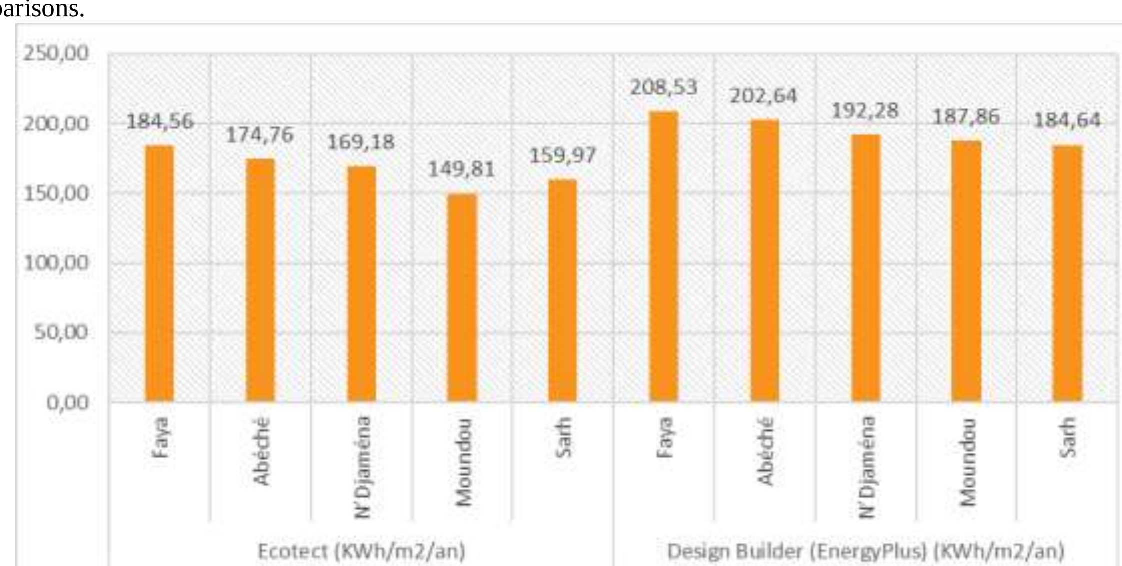

Figure 4:- Energy results in kWh/m2/year for each climate zone.

It is important for professionals to categorize energy requirements and the periodic variations in these over the year. For this reason, we present Figure 5 showing the monthly heating and cooling demand for each site. We note that air conditioning requirements are too high, particularly during the months of March, April and May for the sites, whereas heating requirements are too low. The weather conditions at the Faya site create greater demand for air conditioning than all the other sites in the months of May to the end of September.

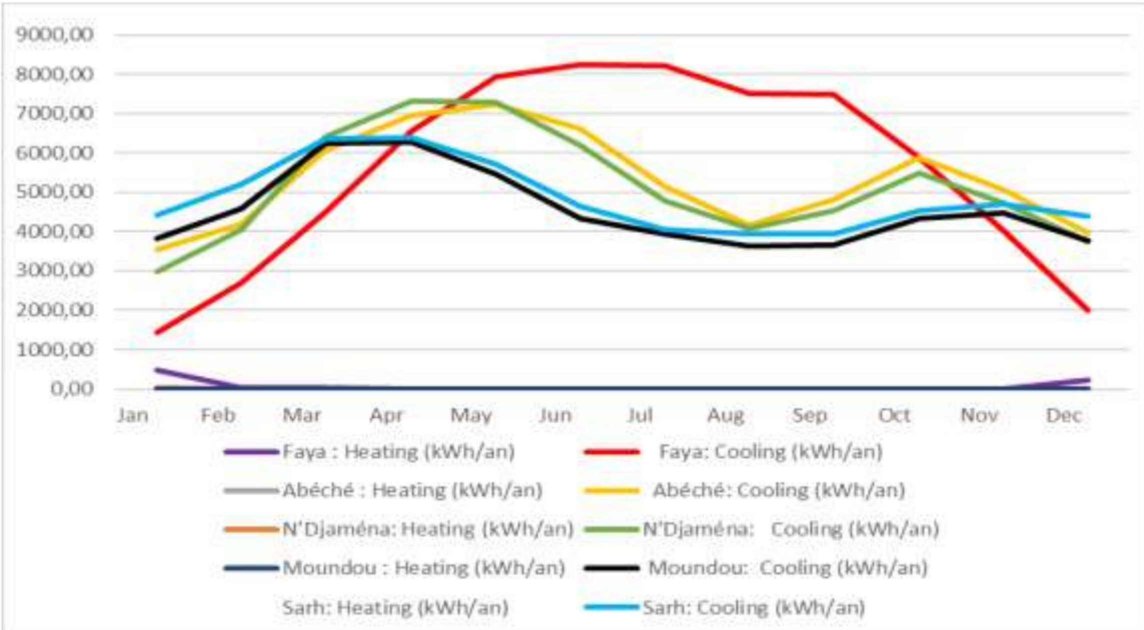

Figure 5:- Variation in energy requirements throughout the year.

In the building industry, it is very important to know the optimum orientation of any construction project right from the design phase. This is because it allows energy costs to be optimised by the free contribution of the site's climate. With this in mind, we have also studied the four orientations of the building, as shown in Figure 6.

The average results obtained by the two tools enabled us to highlight the effect of the building's orientation for each climatic zone. Thus, if we need to obtain the best building orientation for each site, the results from the four points considered in this study are sufficient to use interpolation.

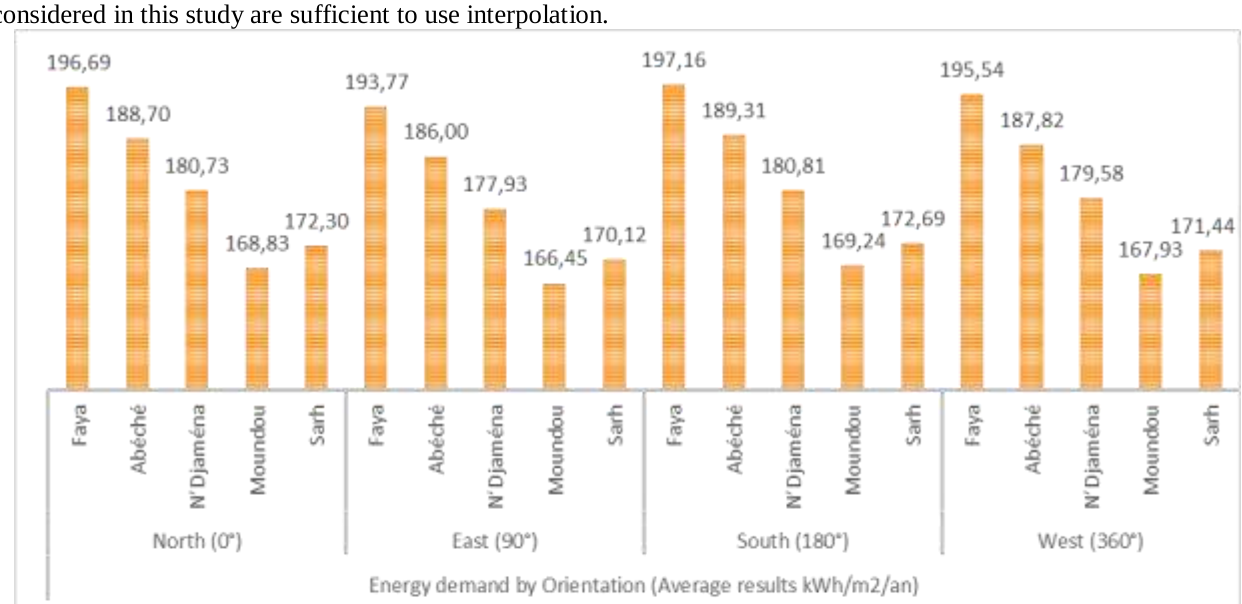

Figure 6:- Energy requirements in kWh/m2 for each climate zone according to orientation.

The results of our study confirm the importance of taking local climatic conditions into account in the design of buildings to optimise their energy efficiency. As pointed out by Santamouris et al (2001), regional climatic variations have a significant influence on the energy requirements of buildings, particularly for heating, cooling and lighting (Abdelkader, 2024). Our results show a significant correlation between the specific climatic conditions of the different zones of Chad and the energy requirements of buildings, which confirms the previous findings of several studies conducted in similar contexts (Crawley et al., 2009; Torcellini& Crawley, 2006). Furthermore, our results highlight the effectiveness of integrated approaches, such as bioclimatic design and passive building techniques, in reducing the energy requirements of buildings in similar climate zones. As previous research has shown (Santamouris et al., 2001), optimising the orientation, layout and characteristics of the building envelope can make a significant contribution to reducing the energy consumption of buildings while improving occupant comfort. Our results confirm this conclusion, demonstrating that buildings designed according to bioclimatic principles offer better energy performance than those that are not.

Finally, our results also highlight the importance of innovative construction technologies and practices in improving the energy efficiency of buildings in specific climatic contexts. As pointed out by Wang et al (2017), the use of energy-efficient materials, the optimisation of ventilation systems and the integration of renewable energy sources can significantly contribute to reducing the energy consumption of buildings cited by (Le Bars et al., 2010). Our results support these conclusions by highlighting the effectiveness of such measures in reducing the energy needs of buildings in Chad's different climatic zones.

Annexes

Table 1:-Physic and thermal characteristics of materials.

Materials	Width (cm)	Conductivity (W/m. K)	Density (Kg /m3)	Sp. Heat (J/Kg. K)	Resistance (m2.K/W)
Doors (Single Glazing and Wood Panel)					
Aluminum exterior doors 120x210 (in standard glazing)	0.40	1.046	2300.00	836.80	5.500
Interior doors 90x210 (based on wood from 700 to 850 Kg/m3)	4.00	0.240	675.00	1600.00	2.900
Windows (Single glazing)					
Windows 100x100 (standard glazing)	0.40	1.046	2300	836.80	5.500
Shower window 60x60 (standard glazing)	0.40	1.046	2300	836.80	5.500
Medium-thick slab on the ground					
Sand-cement plaster	2.00	1.30	1900.00	1000.00	2.640
Reinforced concrete	13.00	2.50	2500.00	1000.00	
Backfilling of the paving on the ground	20.00	1.50	1500	2000	
Plastering of walls and floor					
Current plaster-cement (internal-external application to walls)	1.50	1.30	1900.00	1000.00	0.012
Coating-cement (application to the subfloor)	1.50	1.30	1900.00	1000.00	0.012
Asphalt (applied only to the terrace for waterproofing)	0.50	1,15	1050	1000	0,004

Table 2:- Building hours and occupancy rates.

Days	Hours (H)	Occupation (%)	Hours (H)	Occupation (%)
Standard weekday	00h00 à 07h00 & 15h00 à 23h00	100	08h00 à 14h00	50
Standard Weekend	00h00 à 23h00	100	-	-
Public Holiday	00h00 à 23h00	100	-	-

Tableau 3:- Setpoint temperature and desired indoor conditions.

Températures de consigne (HVAC)		Internal design conditions				People and activity
Lower band (°)	Upper band (°)	Design level of Clothing worn: (clo)	Lighting level (lux)	Humidity (%)	Air speed (m/s)	Sedentary (W)
24	26	1.00 (Light business suit)	100 (Corridor/stairs)	60	1.00 (hair & papers move)	70

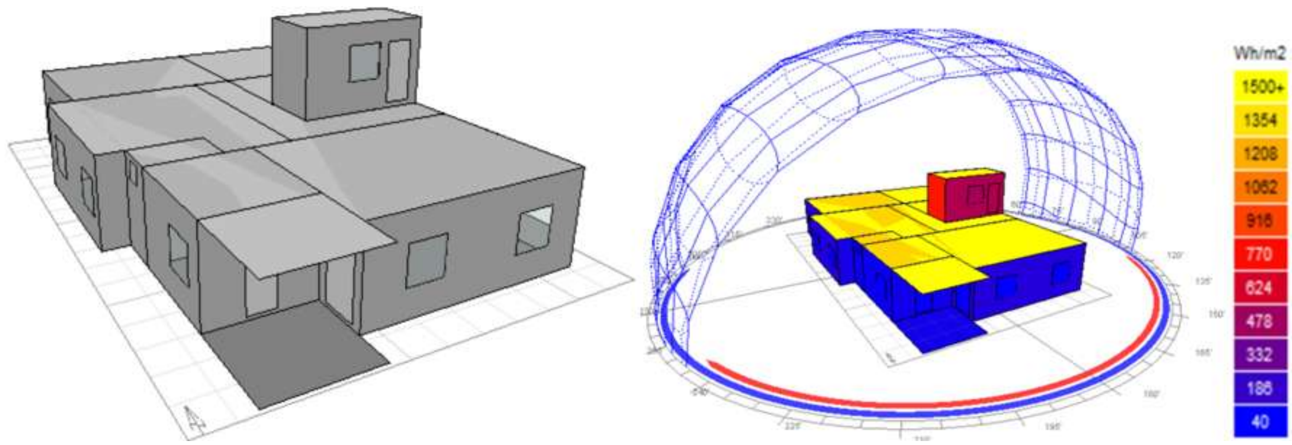

Figure1:- Example of the visualized model and solar radiance (by using weather data of N'Djamena).

Conclusion:-

This study focuses on determining the energy requirements needed to ensure the thermal comfort of users. It shows that the annual demand for air conditioning is too high compared with that for heating, which remains very low for all the sites. This is due to the country's particularly hot, dry climate. It is therefore important to look at short-term development in order to optimise or reduce energy consumption, with particular emphasis on air-conditioning needs.

However, it is necessary to adopt existing techniques to keep room temperatures stable, i.e. the use of local materials, large openings and shading of windows, appropriate orientation of the building, and so on. We also bear in mind that the introduction of positive energy and the use of renewable energies play an essential role. Thanks to the results in Table 9, the optimum orientation of the building at the design stage can be obtained directly by interpolation. Ultimately, our results confirm the importance of taking local climatic conditions into account in the design and planning of buildings to optimise their energy efficiency. By integrating integrated approaches, innovative technologies and sustainable construction practices, it is possible to design buildings that meet energy needs while reducing their environmental impact in a variety of climatic contexts.

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