Energy and Power Engineering, 2024, 16, 197-215
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Analysis of the Energy and Environmental Sustainability of a Built Space System: The Case of Patte d'Oie University Campus in Ouagadougou

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How to cite this paper: Sawadogo, D., Coulibaly, O., Chesneau, X. and Zeghmati, B. (2024) Analysis of the Energy and Environmental Sustainability of a Built Space System: The Case of Patte d'Oie University Campus in Ouagadougou. *Energy and Power Engineering*, **16**, 197-215.
https://doi.org/10.4236/epe.2024.165010

Received: March 10, 2024
Accepted: May 26, 2024
Published: May 29, 2024

Abstract

The aim of this study was to carry out a dynamic simulation of the energy and environmental performance of a built space system, with a view to assessing its energy and environmental class. The use of a simulation and modeling tool, supported by various methodological references, formed the basis of our approach. Adopting a systemic perspective, we described the structural and functional aspects of the systems making up built spaces, as well as the associated energy flows. Our approach was also based on a typology, taking into account typical days, structural and functional configurations at different scales and angles of observation. The analysis tool we developed in Java was applied to the built space system of the Patte d'Oie university campus in Ouagadougou. Annual electricity consumption was measured at 124387.34 kWh, closely aligned with the average annual electricity bill (125224.31 kWh), with a maximum relative deviation of 1%, followed by a carbon emission balance of 58337.66 kg eq CO_2 per year. This validation confirmed the effectiveness of our tool. In addition, following the analysis of electricity consumption using our tool, the university campus was classified in energy class B and environmental class C. These results will be based on the emission factors of the energy mix of the West African Economic and Monetary Union (WAEMU) territory, with particular emphasis on Burkina Faso.

Keywords

Energy Function, Energy Class, Carbon Footprint, Built Space, Consumption Item, Systemic Approach, Typological Approach

1. Introduction

Sustained growth in energy demand, dependence on hydrocarbons and fluctuating hydrocarbon prices, as well as environmental and budgetary constraints, have prompted many countries to promote energy efficiency and the integration of renewable energies [1]. Reducing energy consumption involves reducing the total amount of energy used by a particular system, building or activity. The main aim of this approach is to improve energy efficiency by implementing measures and technologies to reduce energy requirements, optimise processes and cut losses. Reducing energy consumption is an essential strategy for promoting sustainable development and managing energy resources responsibly. It is particularly crucial in tackling challenges such as greenhouse gas emissions, against a backdrop of environmental crisis and increasing pollution.

In Burkina Faso, given the energy context, in particular the high cost per kWh, the continuing growth in demand, the dependence on imports and the shortfall in supply, energy efficiency represents a real opportunity for households, businesses and institutions alike [2]. Unfortunately, little is known about how this concept works in practice, and adoption is still very slow. There are still huge areas of energy wastage in public and private buildings, in terms of installations, equipment and consumption habits. Nevertheless, the ever-increasing cost of energy bills is prompting some consumers to become more aware.

This article presents an in-depth and dynamic approach to assessing the energy and environmental performance of the university campus, based on its annual energy consumption and calculating its carbon footprint using the emission factors of Burkina Faso's energy mix. To do this, we developed a systemic and typological description of the built environment, providing detailed information on the structural and functional characteristics of the subsystems at different scales of observation. Based on a scenario representative of a typical day, we analysed energy consumption by consumption item for each Functional Space. Using weighted correlation functions, we extrapolated this consumption to the monthly and annual scales. At the same time, our work focused on typical Functional Spaces, characterised by their structures, in order to extend our results to the Building Space system as a whole. The typological approach adopted facilitates data acquisition by providing a detailed view while minimising the complexity of the process. This methodology provides an in-depth understanding of energy consumption in a built space system, paving the way for more accurate analyses and optimisation solutions.

The systems approach to energy consumption in the built environment involves considering the entire system as an interconnected network, analysing the complex interactions between components such as equipment, heating, ventilation and air conditioning systems, and occupant behaviour. This holistic perspective makes it possible to understand the interrelationships and identify opportunities for optimisation to improve the energy efficiency of the built environment. Numerous studies on the analysis of physical and environmental phenomena have been carried out using this new approach. These include: H. Kreiner *et al.* [3] carried out a study of the sustainability performance of office buildings at the design stage. They applied a systems approach to the analysis of sustainability improvements in buildings, specifically a public office building in Graz, Austria. The main part of the study describes the important steps required for the systemic optimisation of building sustainability. The method applied makes it possible to quantify the relative influence and identify the individual optimisation potential of design options on each assessment criterion. The systemic approach proposed has demonstrated the potential of the building certification system that is currently the most developed, given the interdependence between the various criteria. M. P. Ranjaranimaro [4] in his thesis, examined the evaluation of the environmental quality and energy performance of built spaces. To achieve this objective, he chose to adopt a systems approach. As part of this approach, he developed specific analysis and description tools using the methodology of the systems approach in order to achieve significant and relevant results.

The typological approach to energy consumption in the built environment involves classifying structures into distinct types based on their specific characteristics. It allows built spaces to be grouped into homogeneous categories in terms of structure and function, thus facilitating the analysis of energy consumption by providing representative models. This approach helps to extrapolate results from one category to the entire built space system, simplifying data collection while providing an in-depth understanding of energy consumption trends. Several works have been carried out using the topology approach to describe energy consumption systems. These include: K. V. Berna [5] showed that the typological approach refers to the classification of buildings according to their main or specific characteristics. This distribution must preserve the heterogeneity of the systems studied while being efficient, *i.e.* aiming for a minimum of classes. Each class is defined by specific parameters that become input data for the modelling. The difference between the models lies in the databases used and the way in which building typologies are established. The available data determines the building typologies. P. Florio *et al.* [6] evaluated the energy performance certificate of a housing stock characterised by qualitative variables using a typological approach model. A conversion algorithm was developed to reference each of the housing units in the National Housing Survey (ENL) to a reference building and a reference HVAC (Heating, Ventilation and Air Conditioning) system in the European typological approach database for the energy assessment of the housing stock in France.

The carbon footprint, also known as the greenhouse gas (GHG) emissions inventory, is an assessment method that quantifies the greenhouse gas emissions associated with an activity, product, organisation or territory. The main objective of the carbon footprint is to measure climate impact in terms of greenhouse gas emissions, in particular carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other gases that contribute to global warming. M. Karimpour *et al.*

[7] carried out a study of the energy performance of buildings based on Life Cycle Assessment. This study, designed to minimise energy consumption, showed that in milder regions, embodied energy can account for up to 25% of total energy. The time value of carbon is generally ignored in energy life cycle analysis studies, but in a national study when energy consumption is reduced, it can become an important factor. Applying net present value principles, the impact of embodied and operational energy was analysed in the context of greenhouse gas emissions. It has been shown that embodied energy can account for 35% of a building's carbon emissions in a mild climate.

It is crucial to note that a significant proportion of energy consumption in the WAEMU region comes from buildings. In order to achieve significant energy savings, it is essential to establish an accurate energy balance for these structures. To meet this challenge, it is necessary to develop a specific energy code for buildings in the WAEMU region. In the following, we will focus on the design and creation of a simulation tool to assess the energy consumption of buildings in this area. This crucial step will enable us to put our knowledge into practice and propose tangible solutions for improving the energy efficiency of buildings in the region. Once we've developed the tool that will provide us with data specific to the university campus, we'll move on to the application of energy and environmental class standards.

2. Methodological Approach

2.1. Systemic Approach

The systems approach enables us to implement a hierarchical and organic description of the various sub-systems making up the Built Spaces (BS) and the energy flows associated with them around entities that we will call: Buildings (BÂT), Functional Spaces (EF), Consumption Stations (PC) and Components (C). The energy flows will be explained at the level of each of these sub-systems, which will constitute the same observation scales [8] [9]. The description in **Figure 1** is:

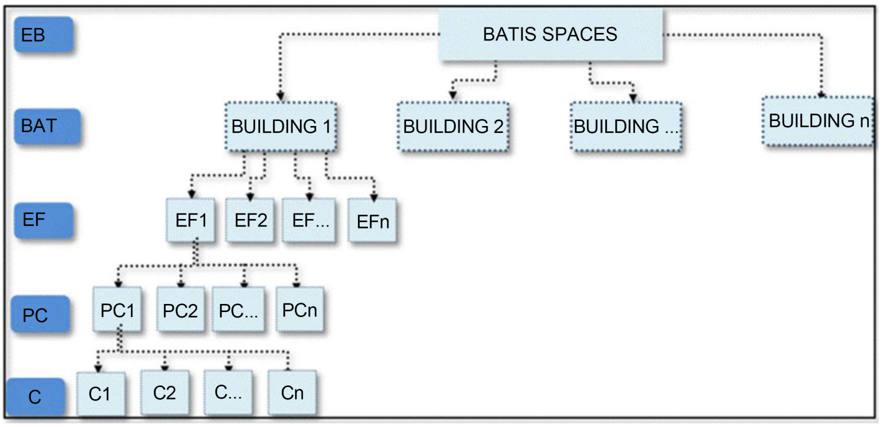


Figure 1. Systemic description of a built space.

- ✓ a component belongs to a consumption item; a consumption item may contain several components;
- ✓ a consumption item belongs to a functional space; a functional space may contain several consumption items;
- ✓ a functional space belongs to a building; a building may contain several functional spaces;
- ✓ a building belongs to a built space; a built space can contain several buildings.

2.2. Typological Approach

The typological approach will be considered in relation to several description indicators: energy typologies, activity sector typologies, built space and associated sub-system typologies, spatial, structural and functional configuration typologies and reference observation day typologies. In particular, these typological approaches will enable us to infer detailed energy consumption flows from succinct data, as illustrated in **Figure 2** [10]. Our approach will also be based on ISO standards relating to Life Cycle Assessment considerations, particularly concerning the evaluation of carbon footprints. We also take into account a set of regulatory documents, referenced for the territory of application of the tool implemented: WAEMU Regional Energy Efficiency Code for Buildings (CEEB) [11] [12].

3. Tool for Simulating the Functioning of the Built Environment

3.1. Architecture of the Simulation Tool

The tool will be produced using a **Java programming language that** controls navigation in each of the sub-systems of the Built Space in several phases:

- A phase describing the study setting and the built environment;
- A phase in which the sub-systems observed are described;
- A data acquisition phase;
- An energy consumption calculation phase;
- A phase of analysis and presentation of the results.

In this article, we will illustrate the implementation of the simulation tool on the "University Campus" type built space system located on the territory of the West African Economic and Monetary Union (UEMOA), more precisely in Burkina Faso in the city of Ouagadougou at Patte d'Oie.

3.1.1. Description of the Study Site and the Built Environment

The first step will be to specify the types of energy considered, the sectors of activity and the environment of the built environment according to different scales of observation of the territory considered in a systemic approach. In our case study (university campus), we will limit ourselves exclusively to electrical energy. This energy is the most significant at the level of built spaces. It is complex to study and evaluate, in that it depends on a number of factors. For example, there are human factors (presence or absence of people), natural factors (night-time) and meteorological factors (rain/sun).

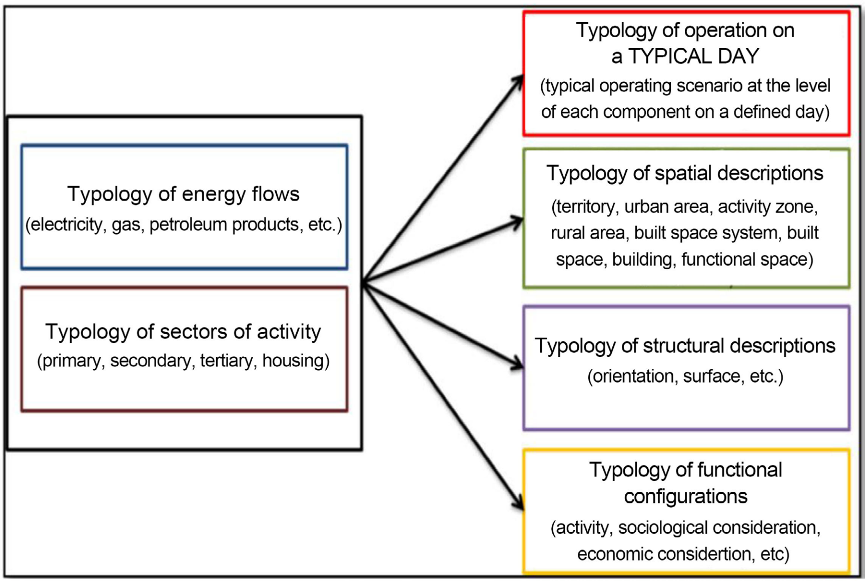


Figure 2. Typological approach.

3.1.2. Data Acquisition Phase

This description stage leads us, on the basis of a usage scenario, to specify the operating characteristics of each component of the set of consumption items for all the Functional Spaces of the Buildings and then the Built Spaces making up the Built Space System under study [13].

Several data acquisition strategies can be used to populate the simulation and analysis tool. We can proceed according to the following possibilities:

- Reference to statistical databases;
- Online data acquisition from BMS or Smart Grid devices;
- Use of experimental databases;
- Introduction of simulated databases from thermal or physical building behaviour software;
- Reference to relevant databases.

The choices made depend on the context of the study. In the present study we will rely on a priori data acquisition and the use of an experimental database.

3.1.3. Calculation Phase

Calculation for a typical day

We use the systemic approach calculation method to deduce the energy consumption associated with the hourly usage profiles of the appliances in the context of observation on a typical day:

$$DUTJ = \sum_{1}^{24} D_{ij} \tag{1}$$

$$CTHC_{ij} = D_{ij} \times P_{ij} \tag{2}$$

$$CTJ = \sum_{h=1}^{24} D_{ijh} \times P_{ij} \tag{3}$$

With,

DUTJ: total daily operating time;

Dij: duration of use of the appliance at each hour of the day;

CTHCij: total hourly consumption of a component;

Pij: installed capacity of the appliance defined in the previous phase;

CTJ: total daily consumption.

These calculations are carried out at component and consumption item level directly during the first data acquisition stage.

Calculation over one month and one year

During the second stage of data acquisition, by integrating the monthly usage scenarios and the weighting coefficients enabling us to move from a typical day for a given month to typical days for all the months of the year, we continue the calculation for the other time scales over the year. We deduce monthly and annual consumption from the following chart (Figure 3).

Energy signature

Energy Signatures (*SE*) are used to observe Energy Consumption (*CE*) by Consumption Point (*PC*), by Functional Space (*EF*) and by Building (*Bât*) in the Built Space (*EB*). These calculations are carried out at Functional Space, Building and Building Area level. They can be found from the following calculations carried out on an hourly, daily, monthly and annual basis.

$$CE_{PC} = \sum Consumption\ Cj \tag{4}$$

$$SE_{EF} = \sum Consumption\ Cn \tag{5}$$

$$SE_{B\hat{a}t} = \sum FE_I \tag*{(6)}$$

$$SE_{EB} = \sum Consumption\ B\hat{a}t_u \tag{7}$$

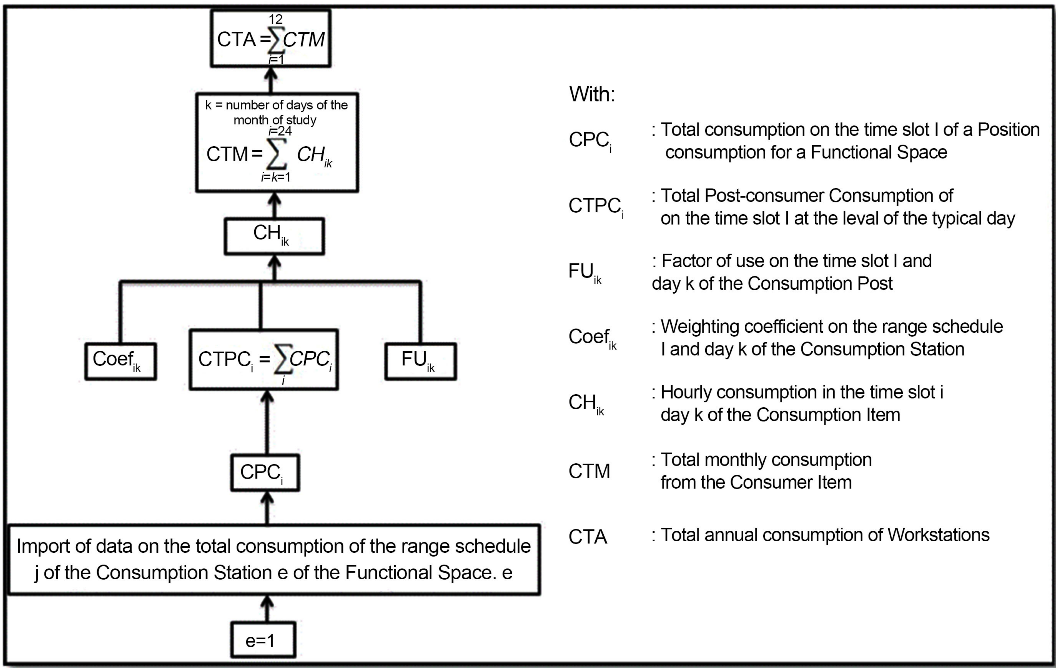


Figure 3. Flow chart for calculating consumption on a monthly and annual basis.

Carbon footprint

Carbon balances will be deduced from energy consumption using emission factors for the energy mix produced in a given location.

The Carbon Footprint (BC) of the built-up area will therefore be determined using the following formula:

$$BC = CE \times FE \tag{8}$$

With:

BC: Bilan Carbone expressed in kgeqCO_2

CE: Energy consumption expressed in kWh

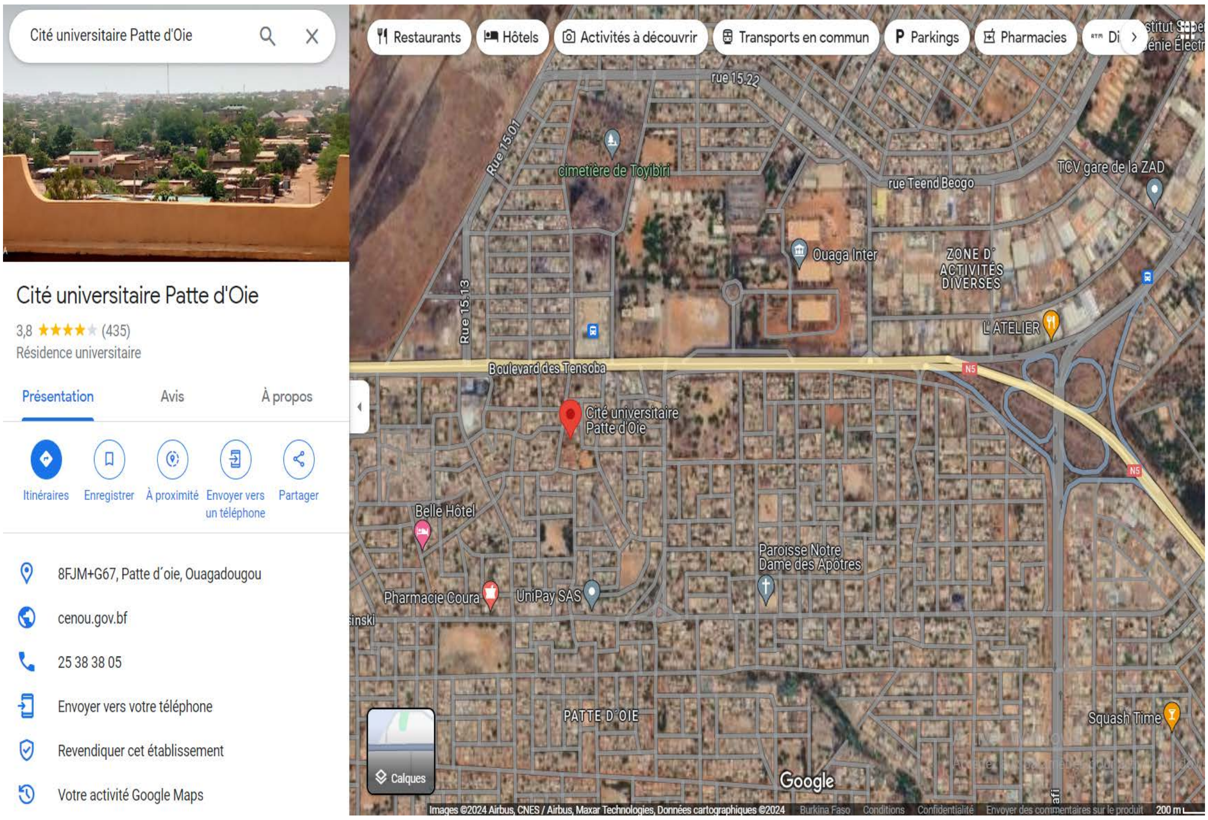
EF: Emission Factor expressed in $\text{kgeqCO}_2\text{/kWh}$

Energy consumption here represents the consumption of each building making up the built area. The emission factor for Burkina Faso is **0.469** $\mathbf{kgeqCO_2/kWh}$ [14].

3.2. Presentation of Results and Analyses

3.2.1. Description of the Built Environment System

The University Campus of the Patte d'Oie (Figure 4) is located in the UEMOA zone, in sector 15 of the city of Ouagadougou in the Bogodogo district. It has been in operation since the start of the 1995-1996 academic year and officially has a capacity of 231 student rooms, but the conversion of some single rooms into double rooms has increased this capacity to 259 student rooms.



Cité universitaire Patte d'Oie

3,8 ★★★★☆ (435)

Résidence universitaire

8FJM+G67, Patte d´oie, Ouagadougou

cenou.gov.bf

25 38 38 05

Figure 4. Map and location of the Patte d'Oie university campus in Ouagadougou.

The university residence comprises a central building housing the students' rooms and is divided into two (02) pavilions A and B. Pavilion A has a total of one hundred and seventyone (171) rooms, while pavilion B has eighty-eight (88) rooms. The ground floor of pavilion B houses the administration of the Centre Régional des Œuvres Universitaires. It comprises 12 offices. In addition to the building housing the student rooms and administration, the campus also has a university restaurant. The result shows that the building has a floor area of 500 m^2 per level, *i.e.* 5500 m^2 for all eleven levels (buildings) of the building. The aim of this work is to highlight the consumption and the energy and environmental signature of the university campus in order to better manage its energy management. In this work, we have presented the campus in detail, as well as the various buildings that make it up, so that we can carry out a complete electrical analysis of the site.

3.2.2. Determination of Weighting Coefficients

Illuminance is measured using a luxmeter. **Table 1** shows the average measured and calculated illuminance values for some typical locations.

The average illuminance values in the various locations do not comply with the recommended average illuminance level. Nevertheless, the LED tubes used have a good luminous efficacy, compared with the best current values of between 80 and 150 lm/W. However, there is still room for improvement in terms of lamp management. From all the above, we will take the monthly weighting coefficient for lighting to be 1. For some consumption items, it is possible to obtain the weighting coefficients for the consumption items by similarity, for example. We also note that for some consumption items, the weighting coefficient is equal to 1.

The weighting coefficients for air conditioning are taken from the doctoral thesis by **O. Coulibaly** [15]. **Figure 5** shows the sensitive loads obtained in the building. This study was carried out using the materials most commonly used in construction in the UEMOA zone, followed by meteorological data for the city of Ouagadougou over a full year with an hourly time step. These metrological data include temperature, humidity, radiation and wind.

After determining the building loads, we deduce the correlation coefficients for the "Air conditioning or comfort" consumption item. The correlation coefficients in relation to the sensitive loads are given for each month of the year. The results obtained using April as the reference month are presented in **Table 2**:

Table 1. Illuminance assessment results.

Typical location	Average illuminance measured (lux)	Theoretical average illuminance (lux)	Luminous efficacy (lm/W)
Rooms	186.2	243	92
Study rooms	193.5	174	92
Offices	432.6	464	92

Table 2. Weighting coefficients by consumption item over the year.

Month/PC	Jan	Feb	Mar	Apr	May	Jui	Jul	Aug	Sep	Oct	Nov	Dec
Lighting	1	1	1	1	1	1	1	1	1	1	1	1
Air conditioning	0.36	0.53	0.87	1	0.98	0.73	0.64	0.55	0.59	0.73	0.54	0.36
Office automation	1	1	1	1	1	1	1	1	1	1	1	1
Multimedia	1	1	1	1	1	1	1	1	1	1	1	1

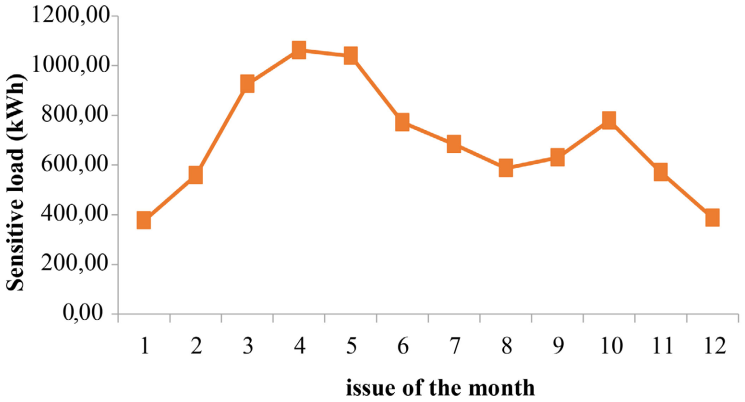


Figure 5. Sensitive loads in a building.

These correlations or weighting coefficients are then integrated into our Java simulation tool at the level of the corresponding consumption items mentioned above. We then output the numerical and graphical results, which will be presented later in this publication. The graphical results will be provided using Excel.

3.2.3. Output of Simulation Tool Results

Our simulation tool provides a number of digital outputs showing consumption curves on a daily, monthly or annual scale at component and consumption item level, energy signatures by consumption item at Functional Space, Building and Building Space level, energy signatures by Consumption Item and by Functional Space at Building and Building Space level. We have selected some of the digital outputs and plotted the possible curves in the figures below.

1) Energy flows by consumption item

Energy flows by consumption item can be observed at the level of a Functional Space, a Building or the Building Space. At this stage, we can obtain daily (hour by hour) or annual (month by month) consumption curves for each component and each consumption item in the Building Space. We can then deduce, for a given functional space, an initial level of energy signature per consumption item on a daily, monthly or annual scale.

Figure 6 shows the trend in electricity consumption for the Director's Office functional area over the month of April. It should be remembered that this is assessed using monthly weighting coefficients and usage factors. Based on this consumption, the associated carbon footprint is 234.61 kgeqCO_2.

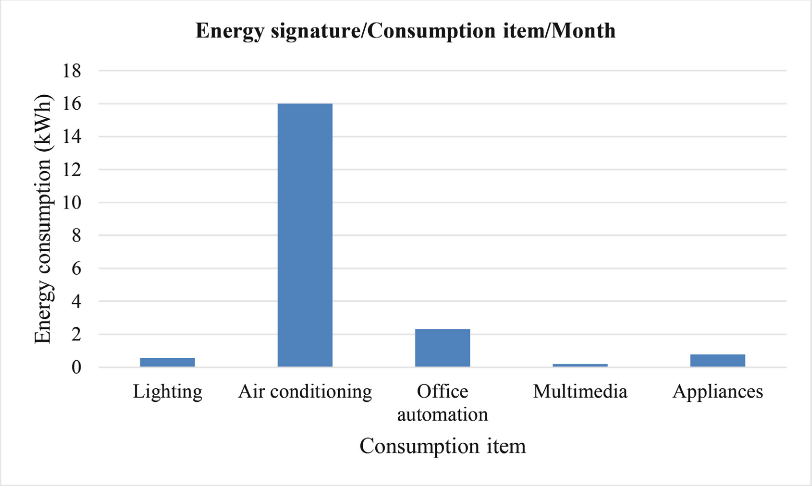


Figure 6. Monthly energy signature by consumption item.

2) Energy flows by functional area

The energy signature per functional area in the Administration building per month is shown in **Figure 7**. It can be seen that the Computer Room functional area consumes the most energy in the Administration building.

3) Energy flows by building

The energy signature per building in the Pavillon B building area per month is shown in **Figure 8**. Excessive consumption can be seen in the Administration building. Given the number of offices and the power installed in them, these functional areas alone account for 45% of the university campus' consumption.

The environmental signature for each building in Pavilion B is shown in **Figure 9**. This signature is correlated with energy consumption, so we see high emissions for the Administration building.

4) Energy flows by built area

As part of our study, we examined the energy signature of the University Campus, both on a daily (**Figure 10**) and monthly (**Figure 11**) basis. This analysis is essential for understanding the energy consumption of this built complex. One crucial aspect of ensuring that the electrical installations are working properly is phase balancing. Our flow analysis tool, specially developed for this research, incorporates this functionality, which enables the distribution of electrical loads to be visualised. The figure below shows this distribution for the University Campus building space system. In reduction, this text highlights the importance of phase balancing for the correct operation of electrical installations, by showing how our flow analysis tool helps to visualise the distribution of electrical loads, particularly for the University Campus studied.

The environmental signature per built space of the Cite Universitaire built space system is illustrated in **Figure 12**. This signature is associated with energy consumption, so we observe high emissions for the Pavilion B building space.

5) Energy flows by built space system

According to the figure above, Cite Universitaire de la Patte d'Oie annual electricity consumption is 124387.34 kWh. This value is very close to the annual

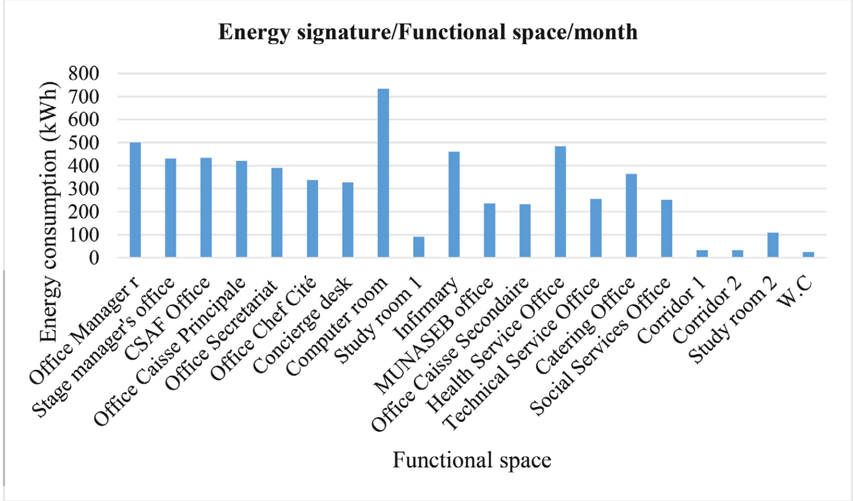


Figure 7. Energy signature for April by functional area.

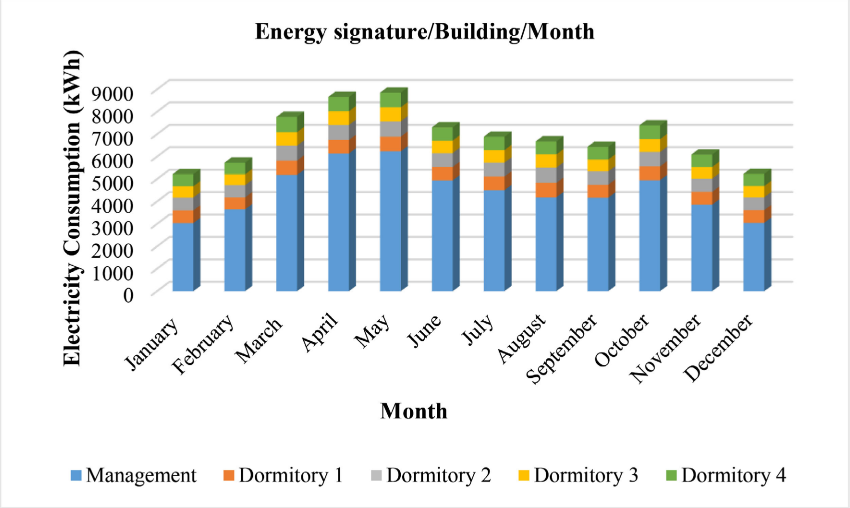


Figure 8. Monthly energy signature by building.

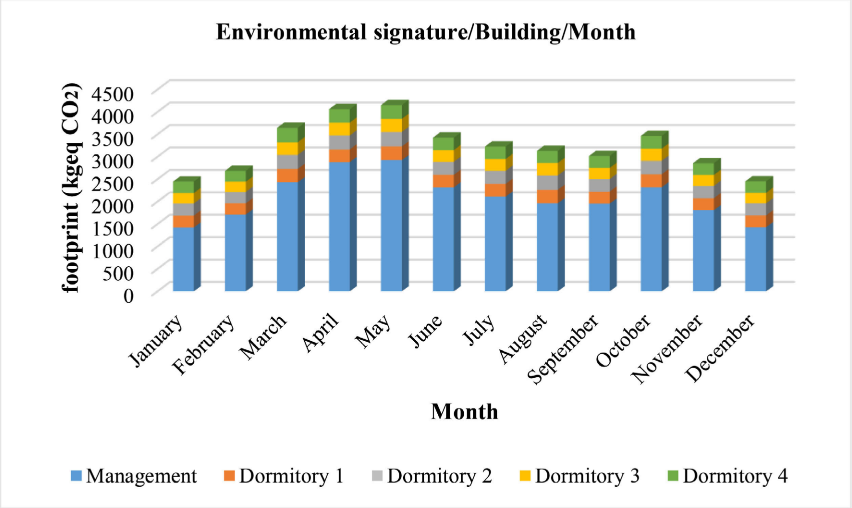


Figure 9. Monthly environmental signature by building.

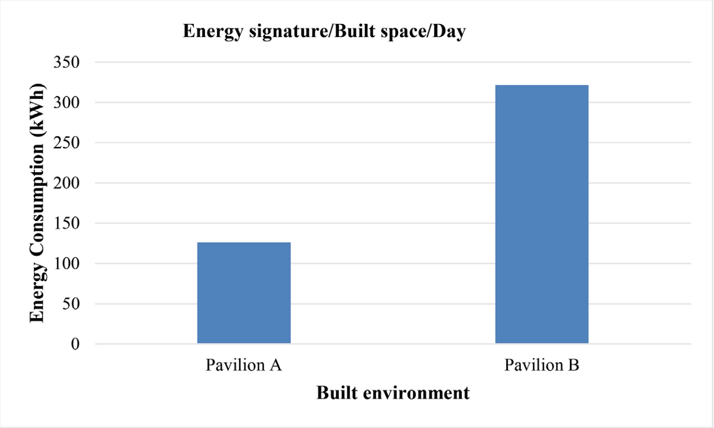


Figure 10. Daily energy signature by built area.

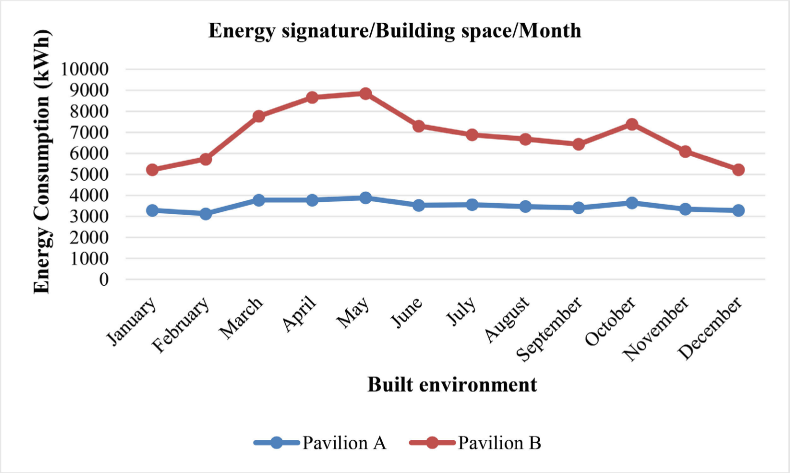


Figure 11. Monthly energy signature by built area.

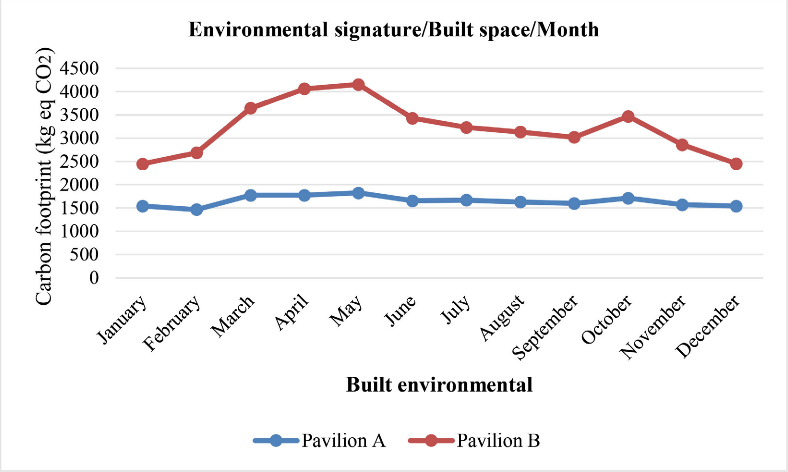


Figure 12. Monthly environmental signature by built area.

average indicated by the electricity bills, which is 125224.31 kWh, with a maximum relative difference of no more than 1%. This discrepancy can be attributed to the lack of fictitious charges associated with students coming to study or eat in the university halls of residence, such as mobile phones, laptops, etc. This consumption depends on the level of equipment, the duration of use and the type of equipment, and is therefore linked to the income level of residents. The details of this breakdown are presented in the following figures, allowing a more precise visualisation of the distribution of electricity consumption within the Cite Universitaire of the Patte d'Oie.

The breakdown in **Figure 13** shows that 2019 is the year with the highest energy consumption. **Figure 14** shows the breakdown of the annual consumption of our analysis tool and the average of the three years of electricity consumption of the university campus. Our analysis tool shows electricity consumption of 124387.34 kWh per year, followed by a carbon emissions balance of 58337.66 kgeqCO_2 per year, with an annual cost of 15050868.41 FCFA. Based on the study of the above curves, this breakdown shows that lighting and air conditioning are the most energy-consuming items in the estate, followed by ventilation.

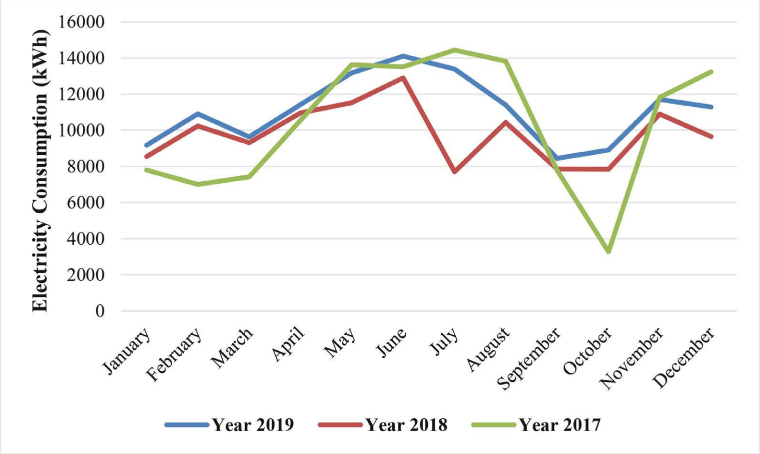


Figure 13. Three years of electricity consumption at the Cite Universitaire de la Patte d'Oie.

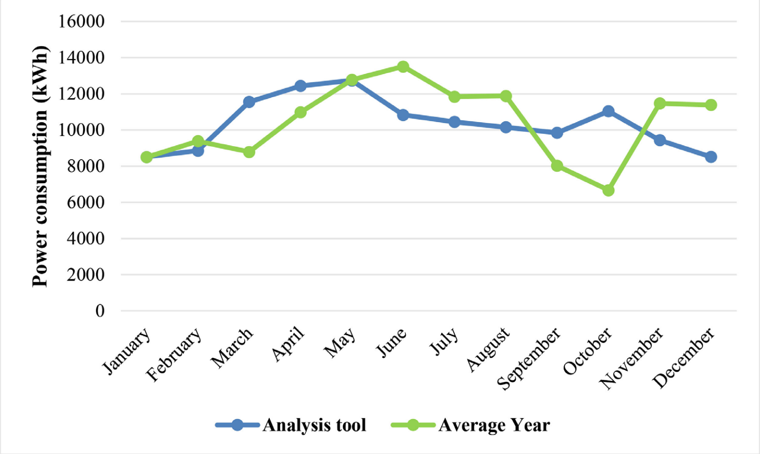


Figure 14. Annual electricity consumption of the analysis tool and average electricity consumption over three years at the Cite Universitaire of the Patte d'Oie.

In short, the power and energy balances carried out highlight important aspects of electrical energy consumption:

- ✓ The power demand of air conditioners and fans is very high. A way will have to be found to reduce them; this may involve replacing existing equipment with more efficient equipment;
- ✓ The installed power of occasionally-used appliances (irons and electric water heaters) is very high; this can lead to power overruns and unexpected bills;
- ✓ Energy demand from air conditioning, lighting and ventilation is high. This can be achieved by raising awareness and installing intelligent regulation and management systems.

Generally speaking, the city's electricity consumption fluctuates from year to year and according to the season. 2018 was particularly marked by a certain slowdown in activity. This can be seen in the behaviour of the red curve. The peak consumption season begins in April and ends in August. This is the most favourable period for awareness campaigns. March, April, May and June are the hottest months of the year in Burkina Faso. Fans and air conditioners, which consume a lot of electricity, are in great demand during this period. This is why the curves rise during this period. As for the period from July to August, this is the period when academic activities slow down, so most students stay in their classrooms all day. It is also the period when residents are most active in cultural activities and non-resident students are most frequented. This explains the high consumption during these months.

All three curves show low electricity consumption during the period from August to October. These months correspond to the winter period in Burkina, when it is relatively cold, so fans and air conditioners are used less. During these periods, many students go on holiday, and most of the equipment installed is out of order. Use of the campus resumes normally from November, when the holidays are back.

We also see low electricity consumption in January, February and December. These months correspond to the cooler months, so fans and air conditioners are used less. In 2017, there was a significant drop in consumption in October. This was due to a slow return of residents who had left on holiday, as the estate remained closed during the holidays. In 2018, the building's electricity consumption seemed to vary from period to period. There was an abnormal drop in consumption in July, the causes of which we do not know. In 2019, consumption did not fluctuate too much, except in September and October when it fell relatively (university holiday period).

Figure 14 shows that, generally speaking, the results obtained using the analysis tool are in line with the annual average.

4. Identification of the Energy and Environmental Class of E University Campus

4.1. Consumption Indexes He University Campus

As part of the assessment of the energy consumption of the built space system, we have collected some essential data. Firstly, the total surface area of our built space system, including two built spaces together, amounts to 5500 m^2 with 500 m^2 per level doc the whole gives eleven levels. Using the analysis tool, we recorded an annual consumption of 124387.34 kWh. However, to assess the environmental impact more accurately, we took into account the fact that 1 kWh of electrical energy is equivalent to 2.58 kWh of primary energy (this is the value currently accepted in France), taking into account losses during the transformation and transport of energy. So the equivalent primary energy consumption of our built environment is 320919.34 kWhep. The Energy Consumption Index (ECI) is a key parameter for assessing the energy efficiency of our built environment. It is calculated by dividing the annual primary energy consumption by the total surface area of the built space system, in accordance with Equation (9):

$$\text{ICE} = \frac{\text{Annual primary energy consumption in kWhep/year}}{\text{Living area in m}^2} \tag{9}$$

ICE = 58.35 kWhep/m^2/year

In this case, the energy consumption index is 58.35 kWhep/m^2/year. This value is essential for assessing how our built space system consumes energy per unit area. We also calculated the CO_2 emission index ($IRCO_2$) using data from SONABEL (Burkina Faso’s national electricity company) activity reports. Each kWh of electricity produced corresponds to a release of 0.72 kg of CO_2 into the atmosphere. The CO_2 emission index is therefore 16.28 kgeqCO_2/m^2/year. These indices provide us with valuable information for assessing both the energy efficiency of our built environment and its environmental impact in terms of CO_2 emissions. They will serve as a solid basis for making decisions to reduce our energy consumption and greenhouse gas emissions.

4.2. Energy and Environmental Class of the University Campus

Assessing the energy and environmental performance of the Patte d’Oie university campus is a crucial step towards promoting a sustainable educational environment in the cities of Burkina Faso. The aim of the assessment is to determine the energy performance and environmental impacts of university halls of residence, thereby contributing to a better understanding of the challenges and opportunities for sustainability in the education sector. This introduction will serve as a starting point for an in-depth exploration of the key aspects relating to the energy and environmental performance of buildings in Burkina Faso.

The European Union’s Diagnostic de Performance Energétique (DPE) ratings provide a basis for assessing the university campus’ performance in terms of energy and environmental efficiency, as well as guiding us towards future action to further reduce energy consumption and greenhouse gas emissions. According to Figure 15, the university campus has achieved a **class B** rating for energy consumption, underlining its relative efficiency compared with current standards. This classification reflects the fact that the university campus is more

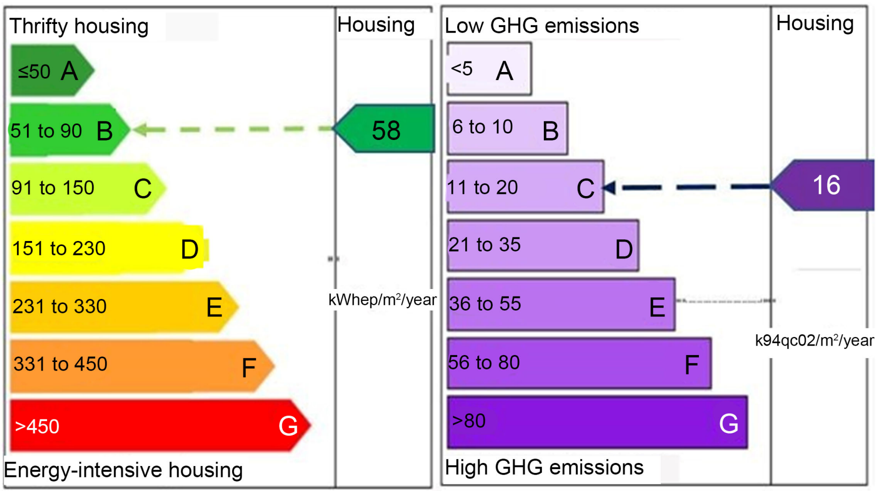


Figure 15. Energy and environmental performance indices for the university campus.

energy-efficient than many similar buildings, which is a commendable achievement. What's more, in terms of greenhouse gas emissions, the campus has been classified as **class C**. This indicates that greenhouse gas emissions are at a moderate level, but it also implies that there are opportunities to further reduce these emissions.

The performance indices we have obtained clearly indicate that the university campus' energy consumption can be further reduced. However, it is essential to interpret them with caution, as the label we use does not necessarily reflect the specific realities of our context. This means that although the indices suggest opportunities for energy savings, they should be considered as initial indicators. Further analysis is required to identify where energy is being wasted within the items we have identified. This detailed analysis will enable us to understand more precisely how electrical energy is used in the university campus and where specific improvements can be made. In other words, these performance indices are an important starting point for our energy efficiency objective, but we need to dig deeper to develop effective strategies for significantly reducing energy consumption.

5. Conclusion

In conclusion, our simulation and analysis tool offers an in-depth understanding of energy flows at different temporal and spatial scales, enabling a dynamic and detailed analysis of variations. To refine our data acquisition, we plan to collaborate with tools for simulating the physical phenomena associated with building operation, in order to improve our correlation functions. We also plan to explore various representations of the built space in different sectors of activity. This flexibility will enable us to develop tools adapted to specific or generic activities, capable of dealing with the consumption of any built space. An additional option would be to extend our spatial observation to cover an entire territory, thus offering a more holistic vision. Our study highlights the crucial importance of energy and environmental class for the energy efficiency of university halls of residence. These data can not only be used to characterise the ecological footprint of infrastructures, but also to guide decisions towards more sustainable practices. By considering integration with life cycle analysis tools on a larger scale, including greenhouse gas emissions, our approach aims to contribute to more responsible and global energy solutions.

Conflicts of Interest

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

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