Dynamic Approach to the Energy Functioning of a Built Space and Associated Carbon Footprint: Application to a School Complex Located in Ouagadougou

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Abstract: We propose in this study a dynamic simulation of the energy functioning of a built space in order to deduce an evaluation of the associated carbon footprint. A simulation and modeling tool is implemented based on several methodological references. We first use a systemic approach to describe the structural and functional aspects of the systems that make up the built space and the energy flux that we observe. This simulation is done in particular in a hierarchical way to allow a relevant analysis of flux from adequate data processing. The tool is also based on a typological approach around the notions of typical days, typical structural and functional configurations at different scales and angles of observation. The main purpose of this study is to present the correlation or weighting functions that will enable us to move from typical days to months of the year. We present results at different scales of observation in time and space. These results are explained in terms of energy consumption and in terms of carbon footprint based on emission factors of the energy mix of the WAEMU territory, more specifically Burkina Faso.

Keywords: *Energy balance, carbon balance, built space, consumption item, systemic approach, typological approach.*

1. INTRODUCTION

The sustained growth in energy demand, the dependence on hydrocarbons and the fluctuation of their prices, as well as environmental and budgetary constraints have prompted many countries to promote energy efficiency [1]. The major challenge is to reduce energy consumption in the buildings and in particular the problems of greenhouse gas emissions in an environment of crisis and pollution which are getting worse and worse. To do this, our architectural practices, our equipment methods and our consumption habits must necessarily be reviewed. In France, the built-up space sector more particularly buildings, is the second most emitting sector of greenhouse gases (GHG) [2].

In this article we propose a detailed and dynamic approach for evaluating the energy consumption of a built space. We deduce the associated carbon footprint from the energy mix emission factors in a given country. For this we are developing a systemic and typological description tool of a built space. This tool will provide information on the structural and functional characteristics of the subsystems that make up the Built Space at different scales of observation. We consider on a typical day an operating scenario explaining the energy consumption by consumption item for each Functional Space. Then from the weighting

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coefficients, we determine the energy consumption at the scale of the month and the year. We also work on typical Functional Spaces according to their structural characteristics in order to develop our results at the level of the entire Built Space. Typological approaches will make it possible to implement data acquisition that is both detailed and the least tedious possible. The systemic approach will make it possible to conduct an analysis at different scales of observation in space and time [3]. It is observed that electrical energy is the most used in most built spaces. The evaluation of electrical energy consumption is complex [4]. Therefore, the application of systemic tools and models seems to be a relevant, even essential, approach to decision-making in such a complex system. Many works on the analysis of physical and environmental phenomena have been carried out using this new approach. We can cite: R. Cantin et al. [5] conducted studies on thermal comfort in buildings. They considered a systemic approach to thermal comfort for a new characterization of different adaptive factors and mechanisms observed in situ. This systemic approach allows the representation of the dynamics of comfort and an elaboration of the structural characteristics of a dynamic model. The results show how a systemic approach contributes to a new analysis of thermal comfort allowing modeling likely to give rise to a dynamic simulation, then Néria Isabelle Rakotonarivo [6] carried out a dynamic analysis of the carbon balance of the energy consumed in any built space. For this, it has designed a tool to assess, through a dynamic approach at different time scales and at different operating levels, the carbon footprint of the energy consumed by built spaces during their construction and operating phases. This evaluation is based on a systemic description of the different entities making up the built space and of the energy and material fluxes.

The typological approach, frequent in the modeling of the thermal behavior of the building, refers to the classification of the building according to various characteristics. Several works have been carried out using the topological approach for the description of energy consumption systems. We can cite: Kavgic et al. [7] who simulated the operation in dynamic thermal regime (STD: dynamic thermal simulation) of a representative building by a topological approach. Energy consumption can be estimated at the scale of a territory by multiplying the energy consumption of the representative building of a class by the number of buildings of this class listed on the territory studied, and this, for each class defined in the model. However, the hypotheses of modeling and definition of the typological classes (number, precision, availability of data, influence of the discriminating parameters on the model) are to be dealt with subsequently Swan et al. [8] carry out a modeling of the final energy consumption in the residential sector. In the energy field, they consider that this approach, based on the typological approach, allows the separation of consumption according to energy use.

Life Cycle Assessment (LCA) is a standardized method of assessing the environmental impact of a product, system or activity throughout its life cycle, from Cradle -to-Grave. It includes all the consecutive stages from resource extraction, through transformation and use, to end of life, possibly with recycling [9] . Several studies have been carried out using Life Cycle Analysis (LCA). For example: Marie-Lise Pannier et al. [10] Who investigated the identification of influential Life Cycle Assessment (LCA) uncertain parameters with buildings. This work, carried out with the LCA tool novaEQUER, has highlighted the influence of the building's lifespan, the electricity production mix and the major contributors to the energy efficiency of the envelope. The results show a better understanding of the effect of influential parameters which contributes to make the use of LCA more reliable for the energy performance of buildings. Clyde Zhengdao et al. [11] have shown for a Life Cycle Assessment (LCA) that a systematic and comprehensive assessment of the energy of buildings is essential to maintain the sustainability of projects. Life Cycle Assessment based on the energy of buildings is increasingly favored by researchers.

2. METHODOLOGICAL APPROACH

2.1. Systemic approach

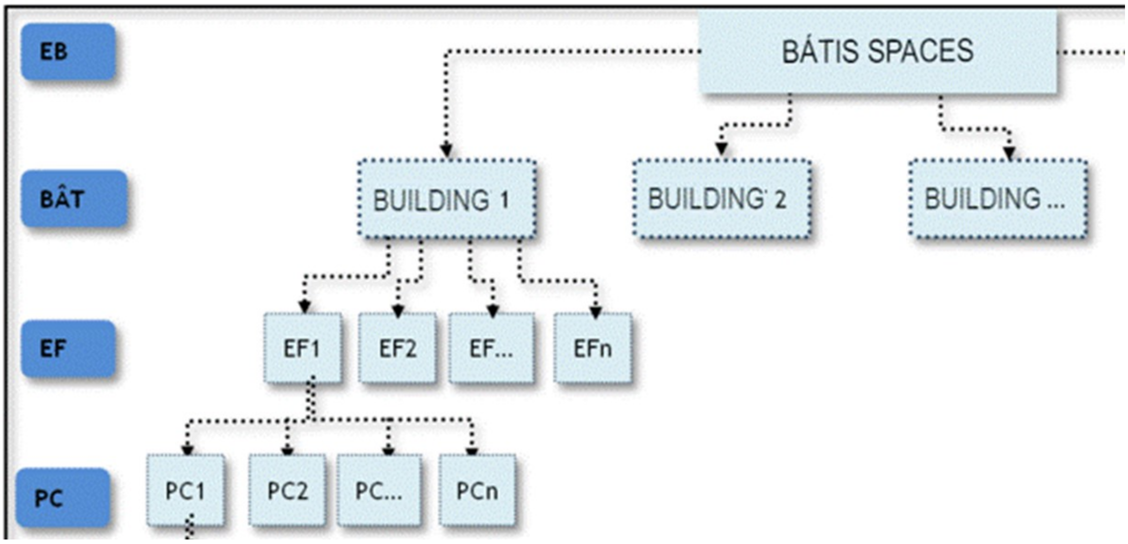

Fig. 1. Systemic description of a built space

The systemic approach allows us to implement a hierarchical and organic description of the different subsystems constituting the Built Spaces (EB) and the energy fluxes associated with them around entities that we will call: Buildings (BÂT), Functional Spaces (EF), consumer station (PC) and components (C). The explanation of the energy fluxes will be done at the level of each of these sub-systems which will constitute as many scales of observation [12,13].

2.2. Typological Approach

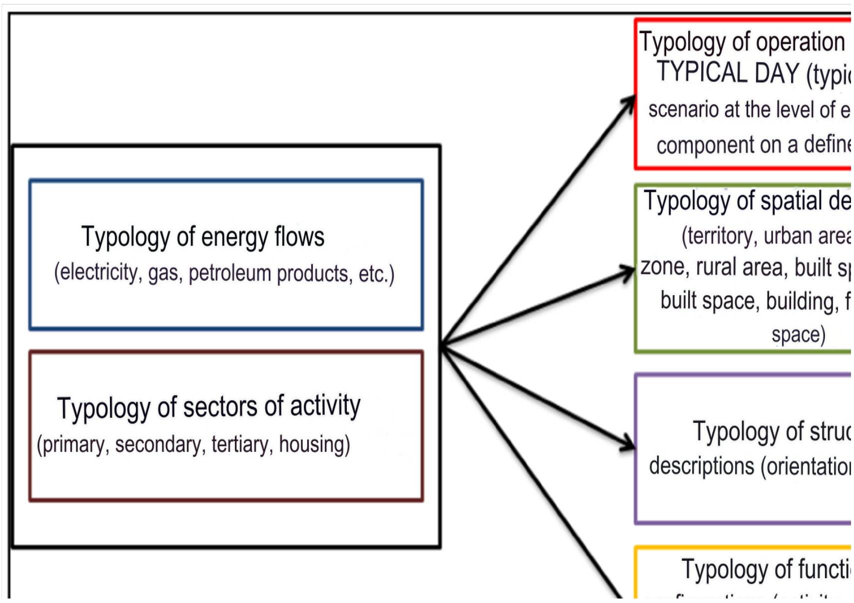

Fig. 2. Typological approach

The typological approach will be considered in relation to several descriptive indicators: energy typologies, activity sector typologies, built space typologies and associated subsystems, spatial, structural and functional configuration typologies the types of reference observation day. These typological approaches will in particular make it possible to deduce detailed energy consumption fluxes from reduced data [14].

2.3. Normative Framework

Our approach will also be based on ISO standards around Life Cycle Assessment considerations, particularly concerning the assessment of carbon footprints.

- Series of ISO standards 14040 to 14044: specifies the principles and the framework applicable to carrying out life cycle assessments.
- Series of ISO 14000 standards which designates all the standards relating to environmental management.
- ISO 14001 standard: defines a series of specific requirements for the implementation of an environmental management system within an organization, regardless of its size and field of activity.
- ISO 9001 standard: the ISO 9001 standard defines a series of requirements concerning the implementation of a quality management system in an organization, whatever its size and sector of activity. Its application is complementary to the ISO 14001 standards.

We also take into account a set of regulatory documents, referenced for the territory of application of the tool implemented: Regional Code for Energy Efficiency in Buildings (CEEB) of UEMOA [15,16].

3. BUILT SPACE FUNCTIONING SIMULATION TOOL

3.1. Architecture of the Simulation Tool

The tool is produced within the framework of a Java programming language controlling the navigation in each subsystem of the Built Space around several phases:

- A phase of description of the study framework and the environment of the Built Space;
- A phase of description of the observed subsystems;
- A data acquisition phase;
- A phase of energy consumption calculation;
- A phase of analysis and presentation of results.

In this article, we have illustrated the implementation of the simulation tool on the built space type "School complex" located on the territory of the West African Economic and Monetary Union (WAEMU) more precisely in Burkina Faso in the city of Ouagadougou in Saaba.

3.1.1. Description of the study framework and the environment of the Built Space

It will initially be a question of specifying the types of energy considered, the sectors of activity and the environment of the Built Space according to various scales of observation of the territory considered in a systemic approach.

Identification of the type of energy: fuel, electricity, heat, or a combination of these sources. With the aim of influencing energy consumption and greenhouse gas emissions.

Identification of Sector of Activity: Residential, Commercial, Industrial, Agricultural. With the aim of affecting energy demand, equipment and system requirements.

Territory Identification: Urban or Rural areas. With the aim of affecting climate, weather conditions and building regulations.

Identification of the Urban or Rural Agglomeration: to influence population density, traffic and available infrastructures.

Identification of the Activity Zone: Residential, Commercial, Industrial, Agricultural. The objective is to determine how the building is to be used, and what equipment and systems are required.

Building Space System Identification: encompasses the building structure, its mechanical and electrical systems, and its equipment. The aim is to determine the building's maintenance and repair requirements.

Building Space Subsystem Identification: This is a set of building space system components that work together for a specific function. With the importance of assigning specific maintenance and repair requirements to each subsystem.

This description provides a clear visualization of the building identification process, enabling effective communication with stakeholders and guaranteeing correct follow-up of all stages.

3.1.2. Spatial description of the Built Space

We identify in this description phase, the subsystems constituting the Built Space, as well as the components of each energy consumption item:

1. Identification of the built space subsystem;
2. Identification of the building;
3. Identification of the functional space;
4. Identification of consumption items;
5. Component identification.

Before the official result of our school complex is published, we will present the validation of our study model.

We have chosen to validate ('in situ' validation) our simulation tool for analysing energy flows, i.e. we are going to compare the response of our systems analysis application with the annual results of the electricity bills of a university campus. The design of our systemic model stems from a typological model that should be validated beforehand to avoid modeling errors.

In view of the figure above, the University residence of Patte d'Oie has an electricity consumption of 124,387 kWh per year. It is close to the average annual value indicated by the electricity bills, which is 125,224 kWh with a maximum relative difference observed which does not exceed 1%. This discrepancy can be attributed to the lack of fictitious loads that enter and leave the site (mobile phones, PCs, etc.) brought by students who come to study or eat in the city. This assessment, depending on the rate of equipment, the time of use and the

type of device, is therefore linked to the level of income of the residents. The distribution can be deduced from the Fig. 3:

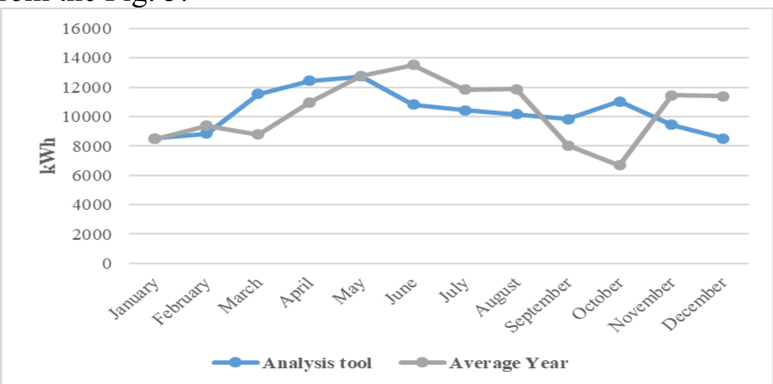

Fig. 3. Annual electricity consumption of the analysis tool and the three-year average electricity consumption of the University City of Patte d'Oie

The pages of the tool providing these two description phases are presented more concretely around navigation sequences.

This identification phase lists precisely the data reduced to the different scales of observation presented. These are structural data around in particular the dimensions and capacities linked to the subsystems of the Built Space and global functional data around in particular the sociological and economic characteristics [17].

At the level of the components or devices of a consumption station, the reduced data are their number and their power.

The consumption items are clearly specified for a given Built Space in relation to the activities carried out there.

The components are very variable; it is practical to define them in a drop-down menu which will allow them to be identified a priori.

Two scenarios can be programmed at the level of the Functional Spaces. We can, either consider a detailed data acquisition, or consider a reduced data acquisition by having previously defined typical Functional Spaces.

3.1.3. Data acquisition phase

This stage of description leads us, starting from scenario of use, to specify the characteristics of operation of each component of the whole of the stations of consumption for all the Functional Spaces of the Buildings constituting the Built Space studied [18].

The pages of the tool providing this description phase for a typical day of operation, around the durations of use of the devices linked to the consumption item described, allowing the calculation of energy consumption for each hour of the typical day. Then we will define the weighting coefficients making it possible to deduce the consumption for each month of the year and their summary on the scale of the year.

Several data acquisition strategies can be implemented to inform 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 device;
- Use of experimental database;
- Introduction of simulated databases from building thermal or physical behavior software;
- Reference to seemingly relevant databases.

The choices that will be made depend on the study contexts. In the present study we will rely on a priori data acquisitions and the use of experimental databases.

3.1.4. Calculation phase

Calculation on a typical day

We use the systemic approach calculation method to deduce the energy consumption associated with the hourly use profiles of the devices as part of an 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 duration of use;*
D_{ij}: *duration of use of the device at each hour of the day;*
$CTHC_{ij}$: *total hourly consumption of a component;*
P_{ij}: *installed power of the device defined in the previous phase;*
CTJ: *total daily consumption.*

These calculations are carried out at the level of components and consumer items directly during the first stage of data acquisition.

Calculation over a month and a year

During the second stage of data acquisition, by integrating the monthly usage scenarios and the weighting coefficients making it possible to go 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 the monthly and annual consumption from the following chart:

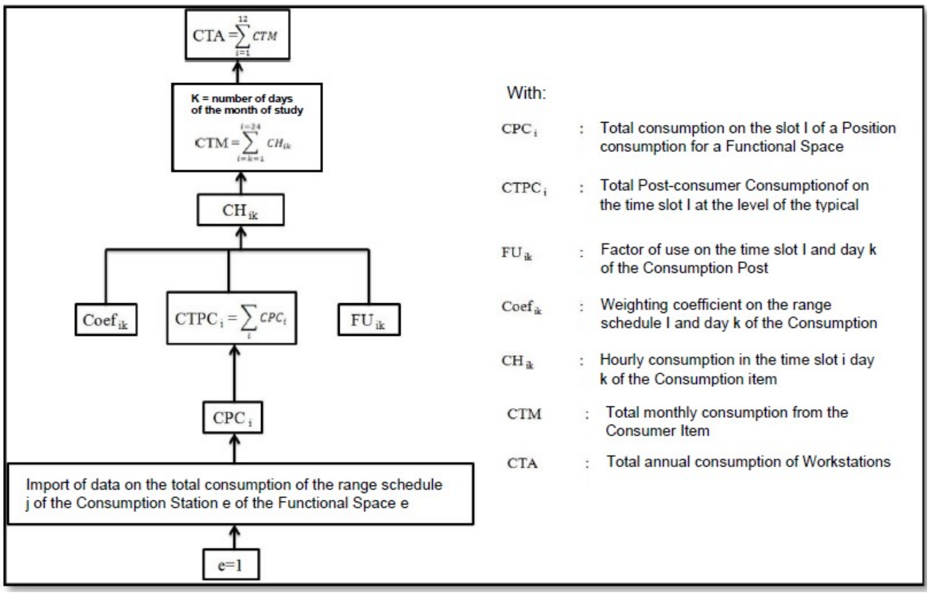

Fig. 4. Flowchart for calculating consumption on a monthly and annual scale

Energy signature

The Energy Signatures (ES) make it possible to observe Energy Consumption (EC) by Consumption Item (PC), by Functional Space (EF) and by Building in the Built Space (EB). These calculations are made at the level of Functional Spaces, Buildings and Built Space.

They are found from the following calculations carried out on the scale of the hour, the day, the month and the year.

$$CE_{PC} = \sum_{j=1}^{n} Consumption\ C_{ij} \tag{4}$$

$$SE_{EF} = \sum_{i} Consumption\ C_{n} \tag{5}$$

$$SE_{Bât} = \sum_{u} EF_{i} \tag{6}$$

$$SE_{EB} = \sum_{v} Consumption\ Bât_u \tag{7}$$

Carbon footprint

The carbon balances will be deduced from the energy consumption based on the emission factors of the energy mix produced in a given place.

The carbon footprint (BC) of the built space will therefore be determined using the following formula:

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

with:

BC: Carbon footprint expressed in kg eq CO_2

CE: Energy Consumption expressed in kWh

EF: Emission factor expressed in kg eq CO_2 */kWh*

The energy consumption here represents the consumption of each building constituting the built space. Burkina Faso's emission factor is **0.469 kg eq** $\mathbf{CO_2}$ **/kWh**. **[19].**

3.2. Presentation of results and analyzes

3.2.1. Description of the built space

We have chosen to carry out our calculations on a school complex with a typical construction using the materials most used in construction in Ouagadougou. It is a multi-zone structure of 490 m². This site was modeled to determine the weighting coefficients. We were led to define 14 thermal zones within the complex.

3.2.2. Determination of weighting coefficients

The 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 different locations do not respect the recommended average illuminance level. Nevertheless, the LED tubes used have a good luminous efficiency compared with the best current values which are between 80 and 150 lm/W. However, there are possible improvements with respect to lamp management. From all the above, we will take the monthly weighting coefficient for **lighting equal 1**. For certain consumption items, it is possible to obtain the weighting coefficients at the level of the consumption items by similarity for example. We also note that for some consumption items, the weighting coefficient is equal to 1.

Table 1. Illuminance evaluation results

Typical place	Mean illuminance measured (lux)	Theoretical average illumination (lux)	Luminous efficacy (lm/W)
Bedrooms	186.2	243	92
Study rooms	193.5	174	92
Offices	432.6	464	92

The weighting coefficients for the air conditioning are taken from the doctoral thesis of Coulibaly [20]. The graph shows the sensible loads obtained in the building. This study was carried out by taking the materials most used in construction in the UEMOA zone, followed by meteorological data for the city of Ouagadougou over a full year in hourly time steps. These metrological data include in particular temperature, humility, radiation, wind.

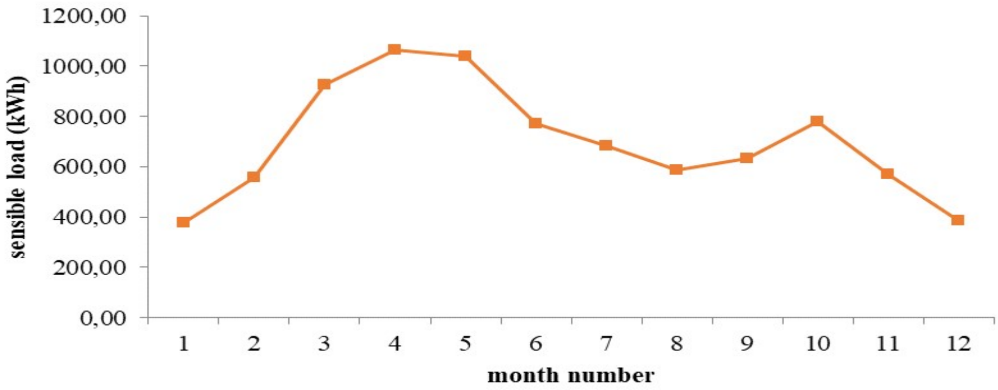

Fig. 5. The sensitive loads of a building

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 by considering the month of April as the reference month are presented in Table ***2***:

Table 2. Weighting coefficients by item of consumption in the year

Month/PC	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jul*	*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	1.00	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

These correlations or weighting coefficients are then integrated into our Java simulation tool at the level of the corresponding consumption items mentioned above. Then, we release the numerical and graphical results which will be presented following this publication. The graphical results will be given with the Excel tool.

3.2.3. Output of results from the Simulation Tool

Our simulation tool allows several digital outputs presenting consumption curves at the scale of the day, month or year at the level of components and consumption items, energy signatures per consumption item at the level of Functional Spaces, Buildings and Built Space, energy signatures by Consumption Item and by Functional Space at the level of Buildings and Built Spaces. We have chosen some of its digital outputs followed by the plotting of possible curves in the following figures.

3.2.3.1. Energy flux by consumption item

The energy fluxes by consumption item are observed at the level of a Functional Space, a Building or the Built Space. At this stage we can have daily (hour by hour) or annual (month by month) consumption curves for each component and each consumption item of the Built Space. We then deduce for a given functional space, a first level of energy signature by Consumption Station on the scale of the day, the month or the year. Table 3 shows the daily and monthly energy balance for January 2022 for the 6th classroom.

Table 3. Electricity consumption by consumption item for the "6th class" functional area.

	Daily consumption (kWh)	Monthly consumption (kWh)	Monthly carbon footprint (kWh)
Lighting	2.60	67.60	31.70
Air conditioning	3.37	31.59	14.82
Office automatique	1.62	42.12	19.75

Sécurité	0.24	7.44	3.49
Total	7.83	148.75	69.76

Table 3 shows that the daily consumption of the "Air conditioning" consumption item in the "6th Class" functional area is higher than that of the other consumption items. This is justified by its power and operating time, the monthly consumption of the "Lighting" consumption item outweighs that of the other consumption items in the same functional area. This is justified by its wattage, usage factor and weighting coefficient and the "Lighting" consumption item ejects a higher monthly carbon footprint than the other consumption items. This is justified by the fact that the "Lighting" consumption item admits a higher monthly consumption than the other consumption items.

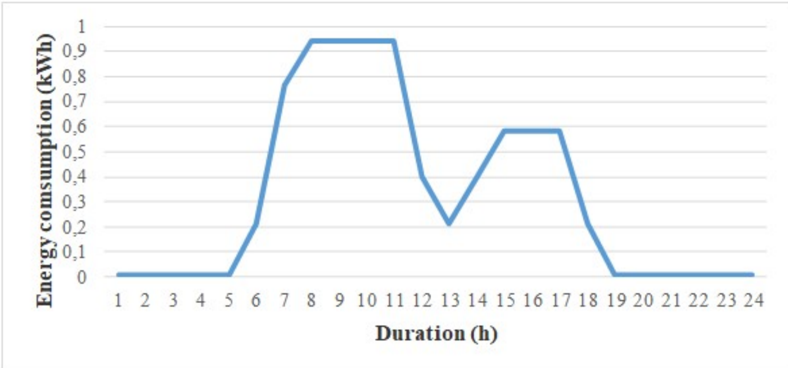

Fig. 6. Daily consumption (hour by hour) of the "6th grade" functional space

Fig. 6 shows a peak in power consumption from 8 pm to 12 pm followed by a constant until 11 a.m. around 12 noon. Electricity consumption falls until 1pm, then rises until 2 pm and remains constant until 6 pm. This can be explained by the fact that the teaching courses started at 8 am. and 3 pm. and all the equipment was switched on, and by the fact that the students went downstairs to have lunch. For constant consumption from 1 am. to 6 pm. and 7 pm. to midnight, it's the safety device that's on only.

3.2.3.2. Energy flow by functional space

The same types of graphic outputs can be produced by Functional Space at the level of each Building or the Built Space at the scale of the month or the year. By way of illustration, we present for example the signature of the monthly energy consumption for the month April 2022 by Functional Space, from which we deduce the daily and monthly consumption curves (Fig. 7) and (Fig. 8).

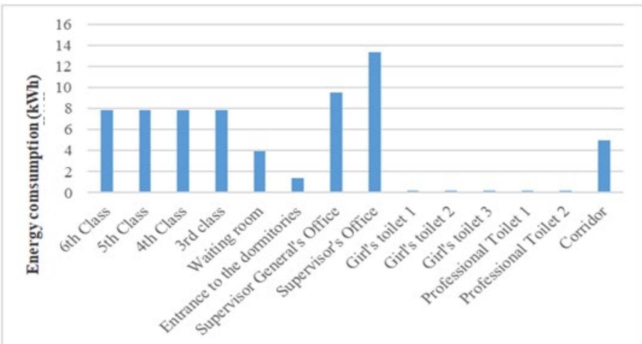

Fig. 7. Daily consumption per functional space in the "Education" building

Fig. 8. Monthly consumption per functional space in the “Education” building

The daily consumption of the "Education" building is 65.48 kWh. ***Fig.*** *7* shows the results obtained with the analysis tool.

Fig. 8 shows consumption trends for the "Education" building over the month of April. We remind you that it is evaluated on the basis of usage coefficients and monthly weighting factors. Monthly consumption was 1743.15 kW. High consumption is observed in the "Supervisors' office" functional area. This consumption is responsible for the emission of 817.54 kg eq CO_2.

3.2.3.3. Energy flux per building in the built-up area

We can also present signatures of energy consumption or greenhouse gas emissions within the Built Space by Building also at different time scales Fig. 9, 10 and 11 and an annual consumption curve for Built Space (Fig. 12).

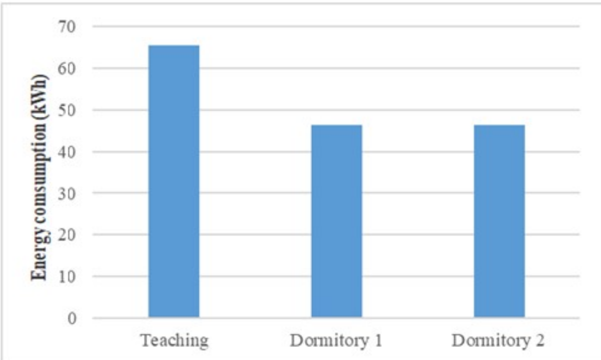

Fig. 9. Daily consumption per building of built space "Level R+2"

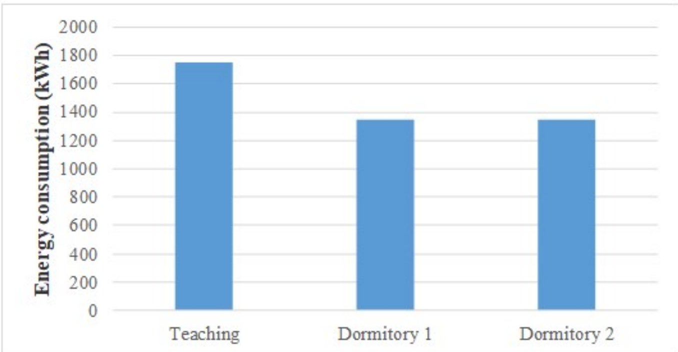

Fig. 10. Monthly consumption per building of built space "Level R+2"

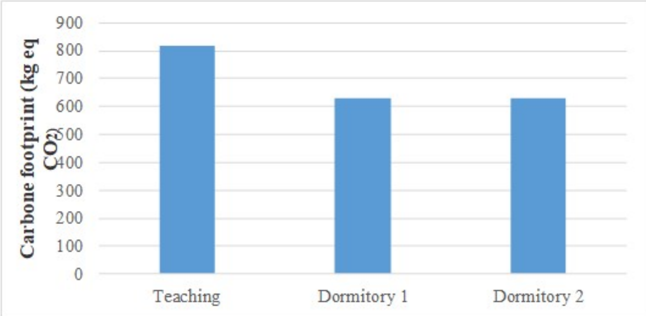

Fig. 11. Monthly carbon footprint per building of the “R+2 level” built space

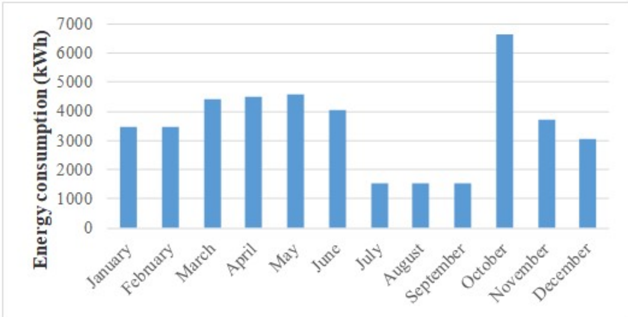

Fig. 12. Annual consumption of built space "Level R+2"

The tool shows the daily and monthly consumption of the "R+2 Level" building area. In all, the building space consumes a total of 158 kWh per day and 4435.07 kWh per month. The greenhouse gas (GHG) emission is 2080.05 kg eq CO2. In Fig. 9, 10 and 11, consumption in the "Education" building is higher than in the bedrooms of students. This is confirmed by the appliances and monthly usage factors.

We note that electricity consumption in the "R+2 Level" building area is higher in October than in the other months (Fig. 12). During the hottest months of the year (March, April and May), consumption is higher than in the other months. This is logical, as during theses months, the population uses more means to cool buildings, such as air-conditioning or fans; in addition, consumption drops sharply as school staff and students are on vacation during the month of July; August and September. Consumption peaks at around 4130.04 kWh in October. Electricity consumption then falls to around 3053.31 kWh in December.

CONCLUSION

At the end of our work, we have a tool for simulating and analysing detailed information at different scales of observation in time and space. Data acquisition is initially done in hourly time steps. This allows a fine dynamic approach to changes in energy fluxes over time. Successive integrations based on weighted correlation laws make it possible to visualize these fluxes at the scale of the month and the year. Beyond this dynamic representation, several types of signature can be observed. At this stage of our study, we must better refine our correlation functions in order to better control the data acquisitions. We will work for this with several tools for simulating the physical phenomena involved in the operation of the Buildings. We will also have to work on other representations of built space from all sectors of activity. We can implement specific tools characteristic of a type of activity or develop a generic tool that can process the consumption of any Built Space. We can also consider integrating consumption at larger scales of spatial observation, ultimately allowing us to scan a given territory. Finally, we must interface this tool with other Life Cycle analysis tools integrating broader scopes of study involving other impacts on greenhouse gas emissions.

REFERENCES

1. Touria, B., (2019). *Un aperçu de la situation de l'efficacité énergétique des ménages au Maroc* [An overview of household energy efficiency in Morocco], [Online]. Available: https://ma.boell.org/fr/2020/06/02/un-apercu-de-la-situation-de-lefficacite-energetique-des-menages-au-maroc, [in French].
2. Olivier, P. (2020). *Enjeux carbones et secteur de la construction. Analyse de Cycle de Vie, bilan carbone, non classé* [Carbon issues and the construction sector. Life Cycle Assessment, Carbon Footprint, Uncategorized], [Online]. Available: http://www.e6-consulting.fr/enjeux-carbones-et-secteur-de-la-construction/, [in French].
3. Nidhoimi, E. A., Gatina, J. C., Praene, J. P., & Fakra, A. H. (2014). *Approche dynamique du fonctionnement énergétique d'un espace bâti et bilan carbone associé: Application sur un gîte rural situé à Mayotte* [Dynamics approach to the energy functioning of a built space and associated carbon balance: Application to a rural gîte in Mayotte], [Online]. Available: https://www.researchgate.net/publication/278807528, [in French].
4. McLoughlin, F., Duffy, A. & Conlon, M. (2012). Characterising domestic electricity consumption patterns by dwelling and occupant socio-economic variables: An Irish case study. *Energy and Buildings*, **48**, 240–248.
5. Cantin, R., Moujalled, B., HDR, G., Guarracino et. al. (2005). *Complexité du confort thermique dans les bâtiments* [The complexity of thermal comfort in buildings], *Proc. of congrès Européen de Science des Systèmes* (Paris, France), 1–10, [in French].
6. Rakotonarivo, N. I. (2013). Approche dynamique du bilan carbone de l'énergie consommée et de l'énergie grise dans un espace bâti [Dynamic approach to the carbon footprint of energy consumption and embodied energy in a built environment]. *Ph.D., thesis,* Université de La Reunion, [in French].
7. Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., et. al. (2010). A review of bottom-up building stock models for energy consumption in the residential sector, *Building and Environment*, **45**(7), 1683–1697.
8. Swan, L. G. & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: a review of modeling techniques. *Renew. Sustain. Energy Rev.*, **13**(8), 1820–1833.
9. Allacker, K. (2010). Duurzaam bouwen: ontwikkeling van een evaluatiemethode op gebouwniveau [Sustainable building – the development of an evaluation method]. *Ph.D. Thesis*, KU Leuven, [in Dutch].
10. Pannier, M., L., Schalbart, P., & Peuportier, B. (2016). Identification de paramètres incertains influents en analyse de cycle de vie des bâtiments [Identification of influential uncertain parameters in building life cycle analysis], *Proc. of Conférence IBPSA France 2016* (Champs-sur-Marne, France), [in French].
11. Li, C. Z., Lai, X., Xiao, B., Tam, W. V., Guo, S., et al. (2020). A holistic review on life cycle energy of buildings: An analysis from 2009 to 2019. *Renew. Sustain. Energy.*, **134**, 110372.
12. Jean-Louis Le Moigne (1977). La théorie du système général : Théorie de la modélisation [General system theory: Modeling theory]. Paris, France: Presses Universitaires de France, [in French].
13. Gracceva, F., & Zeniewsk, P. (2014). A systemic approach to assessing energy security in low-carbon EU energy system, *Applied Energy*, **123**(15), 335–348.
14. *Règlement thermique 2012* (2012), [Online]. Available: http://rt2012-leguide.com
15. Union Economique et Monetaire Ouest Africaine [West African Economic and Monetary Union] (2020) *Directive No. 04/2020/CM/UEMOA portant étiquetage énergétique des lampes*

électriques et des appareils électroménagers neufs dans les états membres de l'UEMOA [on the energy labelling of new electric lamps and household electrical appliances in WAEMU member states] [Online].Available: https://rise.esmap.org/data/files/library/niger/Renewable%20Energy/Niger_Electrical%20Appliances%20Standards_Directive%20NA%CC%82%C2%B004_2020_CM_UEMOA_2020.pdf, [in French].

16. Union Economique et Monetaire Ouest Africaine [West African Economic and Monetary Union] (2020) Directive No. 05/20207CM/UEMOA fixant des mesures d'efficacité énergétique dans la construction de batiments dans les états membres de l'Uemoa [laying down energy efficiency measures in the construction of buildings in WAEMU member states],[Online].Available:https://rise.esmap.org/data/files/library/niger/Energy%20Efficiency/Niger_%20Energy%20Efficiency%20in%20Buildings%20Construction_Directive%20NA%CC%82%C2%B005_2020_CM_UEMOA_2020.pdf, [in French].
17. Gatina, J. C. (2010). Description and systemic modeling of energy working built spaces, *Proc. of the 7th International Conference Indoor Air Quality, Ventilation and Energy Conservation in Buildings*, (Syracuse, New York).
18. Vorger, E. (2014). Étude de l'influence des occupants sur la performance énergétique des logements par le biais d'une modélisation stochastique globale [Study of the influence of occupants on the energy performance of dwellings using global stochastic modelling]. *Proc. of Conférence IBPSA France-Arras* (Paris, France), 33–50, [in French].
19. L'Agence Internationale de l'Energie (2013). Émissions de CO_2 dues à la combustion des carburants fournissant des données pour 2011210 [International Energy Agency (2013). CO2 emissions from fuel combustion providing data for 2011210] [Online]. Available: *https://fr.globalpetrolprices.com/,* [in French].
20. Coulibaly, O. (2011). Contribution à l'élaboration d'une réglementation thermique et énergétique des bâtiments au Burkina Faso : Données de base multiparamétriques et modélisation thermo-aéraulique sous CoDyBa et TRNSYS [Contribution to the development of thermal and energy regulations for buildings in Burkina Faso : multiparameter baseline data and thermo-aerodynamic modelling using CoDyBa and TRNSYS]. *Ph.D. Thesis*, Université Joseph KI-ZERBO, [in French].