

Research Article

# Energy Audit and Optimization Strategies for Electricity Consumption in University Buildings of the Sudano-Sahelian Zone: The Case of Norbert Zongo University

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## Abstract

University buildings in sub-Saharan Africa are major items of energy expenditure, yet their consumption remains rarely documented. This study reports the electrical audit of three groups of buildings of Norbert Zongo University in Koudougou (Burkina Faso) and assesses the savings potential that can be mobilized. The approach combines a bottom-up estimate, based on an exhaustive equipment inventory and on a usage survey of one hundred and twenty-three respondents, with the analysis of one hundred and eight monthly billing records covering the period 2021-2023 and supplied by SONABEL, the national electricity utility. The inventory attributes 41.4% of consumption to air conditioning, 30.7% to lighting, 21.9% to ventilation and 6.0% to other equipment. When compared with the metered records, this estimate overstates the energy actually billed by 32.1%, a gap attributable to out-of-service equipment and to the operating-time assumptions adopted. The monthly profiles reveal a marked seasonality, with maxima from March to June and minima in September and October, as well as a decoupling between temperature and consumption at the end of 2023. The demand recorded exceeds the subscribed power in 56.2% of the months observed, by up to a factor of 5.4 for the 1000-seat lecture hall; the corresponding penalties reach 13.4 million CFA francs over three years, i.e. 6.4% of the bill. The power factor complies with the regulatory threshold of 0.92 in only 9.4% of the months, no capacitor bank being installed. The effective unit cost stands at 159.7 FCFA/kWh, i.e. 2.5 times the normal-hours tariff. A smart-meter prototype is proposed to instrument the monitoring of consumption.

## Keywords

Energy Audit, Energy Efficiency, University Building, Power Factor, Burkina Faso

## 1. Introduction

Buildings have become the largest source of energy-efficiency potential worldwide. According to the report of the

United Nations Environment Programme on the status of buildings and construction, this sector accounted in 2022 for

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nearly 34% of global energy demand and 37% of carbon dioxide emissions [1]. The pressure is even stronger in sub-Saharan Africa, where annual demand grows by about 8% per year while supply does not keep pace: in 2023 the region had an electrification rate of 53%, compared with 48% in 2020, but still concentrated 86% of the global deficit in access to electricity. Recent decomposition analyses of energy supply and demand across forty-eight sub-Saharan countries confirm that this growth is driven primarily by economic activity while remaining constrained by ageing and inefficient infrastructure [25].

Burkina Faso illustrates this tension. The building sector accounted for 72% of national energy consumption in 2023 [2], so that demand-side management in hospitals, public administrations and higher-education institutions is a first-order issue. African universities occupy a particular place in this respect: growing student numbers and the modernization of teaching infrastructure make them large and growing consumers [3], without their energy uses being documented with any precision.

The literature devoted to campus audits is, in fact, scattered and heterogeneous. The available studies converge on the predominance of thermal-comfort systems: Opoku et al. [4] attribute 62% of consumption to air conditioners at Kwame Nkrumah University in Ghana; Alfaoyzan and Almasri [5] report 79% at Sulaiman Al-Rajhi University in Saudi Arabia; Beza and Attia [6] measure 77% on a North American campus. In the Sahelian zone, Gado et al. [7] show, for the site of the university institute of technology of Maradi in Niger, that consumption peaks during the hottest months. Other studies shift the focus to occupant behavior: Masoso and Grobler [8] establish, in the hot regions of Botswana and South Africa, that 56% of the energy is consumed outside working hours. Further work addresses the analysis of campus consumption profiles, the statistical treatment of metered data, simulation-based audits and audit methodology itself [9-13]. Two recent contributions frame the present work more directly. At the national scale, Nebie et al. [23] review energy efficiency in the Burkina Faso building sector and identify the absence of documented audits and of enforced efficiency standards as the main barriers, while confirming that the air-conditioning set points adopted at the design stage are not adapted to the local climate. At the campus scale, Bakkouche et al. [24] benchmark the consumption of the buildings of a North African university and couple it with an assessment of the photovoltaic potential, reporting a payback period of 3.91 years for an integrated installation; their approach, however, does not address the contractual terms of the supply, which the present study places at the centre of the diagnosis.

Two limitations emerge from this body of work. First, published audits most often confine themselves to the breakdown of consumption by end use, without confronting the bottom-up estimate derived from the inventory with the metered records, although this confrontation is the only available test of

the validity of the method. Second, the contractual and electrotechnical dimension of the bill (adequacy of the subscribed power, quality of the power factor, associated penalties) is rarely addressed, although it weighs heavily on the cost actually borne by the institution. No published study documents these aspects for a campus in Burkina Faso. A third limitation should be added to these two: the available audits propose optimization measures without coupling them to an on-site measurement arrangement capable of verifying the savings actually obtained, whereas the granularity of the utility meter monthly, and for a whole group of buildings makes any such verification impossible. The contribution of the present article is therefore threefold: it confronts the bottom-up estimate with the metered records, it quantifies the contractual and electrotechnical component of the bill, and it specifies the instrumentation required to monitor the measures proposed.

The present article aims to partially fill this gap. It reports the electrical audit of three groups of buildings of Norbert Zongo University (UNZ) in Koudougou, and pursues three objectives: to establish the structure of consumption by end use and to test the robustness of the bottom-up estimate by confronting it with the billing records; to characterize the temporal profiles of consumption and the adequacy of the supply contract; and to assess, on this basis, the savings potential that can be mobilized as well as the means of monitoring it.

## 2. Materials and Methods

### 2.1. Study Site

Norbert Zongo University, established by decree no. 2005-460/PRES/PM/MESSRS/MFB of 31 August 2005 following the transformation of the Higher Teacher Training School (ENS) of Koudougou, is a multidisciplinary institution located in Koudougou, in a Sudano-Sahelian climate characterized by a rainy season from June to September and a dry season from October to May, with temperatures frequently exceeding 40 °C at the end of the dry season.

The study covers the three medium-voltage metering points through which SONABEL (the national electricity utility of Burkina Faso) supplies the campus, designated according to the utility's nomenclature: Koudougou University I (new 1000-seat lecture hall and Toguyeni lecture hall), Koudougou University II (Wendpenga, PSUT, ENS workshop, CP1 classrooms) and the group referred to as the "1000-seat lecture hall" (pavilion, building C, central library, ENS administration). The three subscriptions are taken out at medium voltage, on transformers of 160, 400 and 630 kVA respectively, for initial subscribed powers of 30, 60 and 40 kW. None of the three contracts includes a capacitor bank: the compensated reactive power is zero.

## 2.2. General Approach

A mixed methodology was adopted. The quantitative component is based on the equipment inventory and on the billing records; the qualitative component is based on field observations and on a questionnaire survey of users. The former provides an objective assessment of performance, the latter sheds light on the practices and behaviors that determine it.

## 2.3. Equipment Inventory and Bottom-Up Estimation

An exhaustive inventory of functional equipment was drawn up through a systematic visit of the classrooms, offices, libraries and laboratories of the selected buildings. Four categories were distinguished: air conditioning, lighting, ventilation and other equipment, the last category comprising desktop computers and printers. Users' personal equipment (laptops and mobile phones) was excluded from the scope.

Operating times were established from a questionnaire ad-

ministered on site to staff and through an online form to students. One hundred and twenty-three responses were collected: 105 students, 15 administrative and technical staff, and 3 teachers. Respondents from the administrative services report an average use of air conditioning of five hours per day, at a set point of 22 to 24 °C, with a highly season-dependent need, 95% during the hot period, 70% in the intermediate period and 15% in the cool period. Among students, 64.4% consider that the lighting of the lecture halls is switched on permanently, which the night-time visits confirmed.

The annual consumption of each category was estimated by Equation (1):

$$E = n \times P_n \times t \quad (1)$$

where  $E$  is the energy consumed (kWh),  $n$  the number of items of equipment,  $P_n$  the unit rated power (kW) and  $t$  the corrected annual operating time (h). This corrected time is obtained by applying to the gross operating time a utilization factor and a simultaneity factor, following the values recommended by Modu et al. [14] (Table 1).

**Table 1.** Operating times and correction factors adopted.

| Load category              | Gross operating time (h/yr) | Utilization factor | Simultaneity factor | Corrected operating time (h/yr) |
|----------------------------|-----------------------------|--------------------|---------------------|---------------------------------|
| Individual air conditioner | 891                         | 0.9                | 0.8                 | 641.5                           |
| Ceiling fan                | 3278                        | 0.9                | 0.8                 | 2360                            |
| Luminaire (LED T8, 18 W)   | 7128                        | 1.0                | 0.8                 | 5702                            |
| Other equipment            | 2079                        | 0.8                | 0.75                | 1247                            |

The assumptions underlying this estimate call for three justifications. The gross operating times were not postulated but reconstructed from the daily durations declared in the survey and from the number of annual operating days of each category, taken from the academic and administrative calendar of the university; for luminaires, the value adopted corresponds to the quasi-permanent lighting of the lecture halls which 64.4% of the student respondents reported and which the night-time visits confirmed. The utilization and simultaneity factors were taken from Modu et al. [14], whose study concerns a university building situated in the Sahelian zone of northern Nigeria, that is in a climatic and operational context comparable to that of Koudougou; no factor was adjusted so as to bring the estimate closer to the metered records, precisely so that the confrontation presented in Section 3.2 would remain a genuine test of the method. The survey, finally, rests on a convenience sample of 123 respondents and is therefore not statistically representative of a population exceeding forty thousand students [17]; it was used to establish usage hypotheses and not to produce population estimates, the quantitative weight of the

analysis being borne by the exhaustive equipment inventory and by the billing records. This choice is restated among the limitations of the study in Section 3.9.

## 2.4. Billing Analysis

SONABEL monthly records were obtained for the three metering points for the years 2021, 2022 and 2023, i.e. 108 monthly observations. Each record reports the active energy (kWh), the reactive energy (kvarh), the maximum recorded demand (kW), the subscribed power (kW), the power factor and the amount billed in FCFA (franc of the African Financial Community). The tariff in force distinguishes normal hours (0:00-10:00, 14:00-17:00, 19:00-0:00) billed at 64 FCFA/kWh from peak hours (10:00-14:00, 17:00-19:00) billed at 139 FCFA/kWh, to which are added a fixed premium, meter rental and maintenance, taxes and, where applicable, penalties [15].

Exceeding the subscribed power is penalized according to Equation (2):

$$\text{Penalty} = 30 \times (P_{\text{app}} - P_s) \times T_{\text{NH}} \quad (2)$$

where  $P_{\text{app}}$  is the maximum demand recorded in the month,  $P_s$  the subscribed power and  $T_{\text{NH}}$  the normal-hours tariff. The contract also imposes a guaranteed annual consumption (CAG), given by Equation (3):

$$\text{CAG} = 1000 \times P_s \quad (3)$$

any under-consumption being penalized to the extent of half of the difference valued at the normal-hours tariff. The power factor is finally derived from the ratio of reactive to active energy, Equation (4):

$$\tan\varphi = \frac{E_{\text{reactive}}}{E_{\text{active}}} \quad (4)$$

the reference value set by the utility being  $\cos\varphi = 0.92$ .

## 2.5. Computed Indicators

Four indicators were constructed from these data. The effective unit cost relates the total amount billed to the active energy consumed, and thus measures the gap between the posted price of the kilowatt-hour and the price actually borne. The exceedance rate is the share of months in which the recorded demand exceeds the subscribed power; the corresponding penalties were recalculated by means of Equation (2), the procedure having been validated by comparison with the amounts appearing in the records. The power-factor compliance rate is the share of months in which  $\cos\varphi \geq 0.92$ . The gap between the bottom-up estimate and the billing records, finally, relates the consumption estimated from the inventory to the average of the amounts of energy billed over the three years.

The sizing of the reactive-energy compensation was established month by month according to Equation (5):

$$Q_c = P_a \times (\tan\varphi - \tan\varphi') \quad (5)$$

where  $P_a$  is the active power demand,  $\varphi$  the angle corresponding to the recorded power factor and  $\varphi'$  that of the target power factor, the rating of the capacitor bank being set by the most unfavorable month.

## 2.6. Smart Meter Prototype

A prototype of a communicating electricity meter was built in order to instrument the monitoring of consumption. It combines an ESP32 microcontroller, with built-in Wi-Fi and Bluetooth interfaces, with a PZEM-004T measurement module

that returns voltage, current, power and energy. A  $16 \times 2$  liquid-crystal display (LCD) on an inter-integrated circuit (I2C) link provides local reading, a 5 V relay module allows a feeder to be switched remotely, and a DHT22 sensor monitors the temperature of the enclosure. The measured quantities are transmitted to the Blynk platform, which provides remote visualization. The PZEM-004T module specifies a measurement accuracy of 0.5% for voltage, current, active power and active energy, and of 1% for the power factor [27]; these are manufacturer figures and have not, at this stage, been verified against a calibrated reference instrument. Comparable low-cost architectures built on the same microcontroller have recently been described in the literature [26]. A metrological comparison with a class-1 reference meter, carried out over at least one full billing month and on a load representative of a campus feeder, is therefore regarded here as a prerequisite to any deployment beyond the prototype stage; this point is restated among the limitations in Section 3.9.

## 2.7. Data Processing and Limitations of the Database

Three monthly records show zero active energy: December 2023 for Koudougou University I, and July and August 2023 for Koudougou University II. These observations correspond to metering failures and not to an absence of consumption; they were excluded from the calculation of the indicators, which therefore cover 105 valid months. Two records of Koudougou University I, in July and August 2023, do not report a power factor and were excluded from the compliance calculation alone, which was carried out on 106 values. The two denominators used in the following sections consequently differ, and are stated here to remove any ambiguity: the indicators relating to energy, to cost and to exceedance are computed on the 105 months reporting a non-zero active energy, whereas the power-factor compliance rate is computed on the 106 months for which the utility reports a power factor.

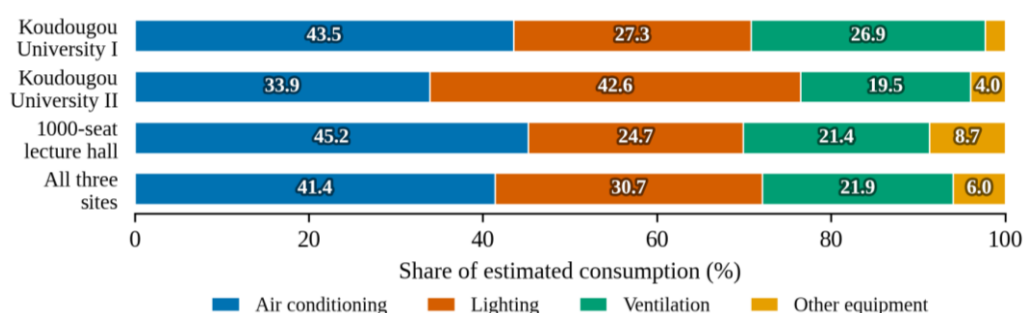
# 3. Results and Discussion

## 3.1. Structure of Consumption by End Use

The bottom-up estimate leads to an annual consumption of 575,139 kWh for the three sites taken together, distributed between air conditioning (41.4%), lighting (30.7%), ventilation (21.9%) and other equipment (6.0%) (Table 2, Figure 1). Thermal-comfort systems, air conditioning and ventilation combined, thus account for 63.3% of the estimated consumption.

**Table 2.** Estimated annual consumption by site and by end use (kWh/yr).

| End use          | Koudougou University I | Koudougou University II | 1000-seat lecture hall | Total  | Share |
|------------------|------------------------|-------------------------|------------------------|--------|-------|
| Air conditioning | 50253                  | 59930                   | 127680                 | 237863 | 41.4% |
| Lighting         | 31509                  | 75335                   | 69792                  | 176636 | 30.7% |
| Ventilation      | 31117                  | 34574                   | 60532                  | 126223 | 21.9% |
| Other equipment  | 2619                   | 7108                    | 24690                  | 34417  | 6.0%  |
| Total            | 115498                 | 176947                  | 282694                 | 575139 | 100%  |

**Figure 1.** Breakdown of the estimated consumption by end use and by site.

The structure differs appreciably from one site to another. Air conditioning dominates at the 1000-seat lecture hall (45.2%) and at Koudougou University I (43.5%), which is explained by the density of offices, by the central library and, for the former site, by a stock of fifty-seven air conditioners of 3.5 kW. At Koudougou University II, by contrast, lighting becomes the leading category (42.6%), this site having 734 luminaires compared with 307 at Koudougou University I.

Compared with the literature, these results place the UNZ below the air-conditioning shares usually reported: 62% at Kwame Nkrumah University [4], 77% on the campus studied by Beza and Attia [6], and 79% at Sulaiman Al-Rajhi University [5]. Two factors explain this difference. First, three to four years ago the UNZ substituted 18 W light-emitting diode (LED) tubes for 36 and 40 W fluorescent tubes, which reduced the lighting category without the relative share of air conditioning increasing accordingly, because of the second factor: the lighting of the lecture halls is kept on twenty-four hours a

day, six days a week, which inflates the lighting category to an unusual level. The contrast with Ouattara [16], who finds 45% for lighting and 32% for air conditioning and ventilation together over a wider scope including laboratories and student residences, confirms that the structure of consumption depends closely on the scope adopted.

### 3.2. Confrontation of the Bottom-Up Estimate with the Metered Records

Comparing the bottom-up estimate with the average of the amounts of energy billed over three years reveals a systematic overestimation, from 25.7% to 46.7% depending on the site, and of 32.1% for the whole (Table 3). This confrontation, rarely carried out in published audits, is instructive on two counts.

**Table 3.** Bottom-up estimate and average billed consumption (kWh/yr).

| Site                    | Estimate from inventory | Average billing 2021-2023 | Gap    |
|-------------------------|-------------------------|---------------------------|--------|
| Koudougou University I  | 115498                  | 89867                     | +28.5% |
| Koudougou University II | 176947                  | 120595                    | +46.7% |
| 1000-seat lecture hall  | 282694                  | 224896                    | +25.7% |
| All three sites         | 575139                  | 435358                    | +32.1% |

It indicates first that the inventory, although it retained only the equipment declared functional, still includes a share of inoperative material: the visits established that many air conditioners are out of order or have become inefficient, that many lamps no longer light up and that a significant number of ceiling fans, particularly in the lecture halls, no longer work. It suggests next that the assumption of continuous operation of the lighting, although corroborated by the night-time observations, does not hold uniformly for the whole stock which is consistent with the fact that the gap is largest at Koudougou University II, precisely the site where lighting weighs the most.

Methodologically, this gap invites the bottom-up estimate to be regarded as an upper bound on consumption, useful for ranking the end uses but unsuitable for sizing purposes. The

ranking of end uses, on the other hand, is not affected: it rests on ratios of installed powers, which the overestimation of operating times affects homothetically.

### 3.3. Monthly Profiles and Seasonality

The billing records total 1,306,073 kWh over three years, for an amount of 208,536,612 FCFA (Table 4). The monthly profiles (Figure 2) show a clear and reproducible seasonality: consumption rises sharply from March, peaks in May or June, and then decreases until the minima of September and October. The 1000-seat lecture hall reaches its maximum in June 2023 with 31,010 kWh, compared with 10,336 kWh in September of the same year, i.e. a ratio of three.

**Table 4.** Summary of billing and indicators, 2021-2023.

| Indicator                            | Koudougou University I | Koudougou University II | 1000-seat lecture hall | All three sites |
|--------------------------------------|------------------------|-------------------------|------------------------|-----------------|
| Active energy, 3 years (kWh)         | 269600                 | 361785                  | 674688                 | 1306073         |
| Amount billed, 3 years (FCFA)        | 42579661               | 57856156                | 108100795              | 208536612       |
| Effective unit cost (FCFA/kWh)       | 157.9                  | 159.9                   | 160.2                  | 159.7           |
| Months exceeding subscribed power    | 4 / 35                 | 20 / 34                 | 35 / 36                | 59 / 105        |
| Exceedance penalties (FCFA)          | 66720                  | 1659660                 | 11701020               | 13427400        |
| Share of penalties in the bill       | 0.2%                   | 2.9%                    | 10.8%                  | 6.4%            |
| Months with $\cos \varphi \geq 0.92$ | 3 / 34                 | 7 / 36                  | 0 / 36                 | 10 / 106        |

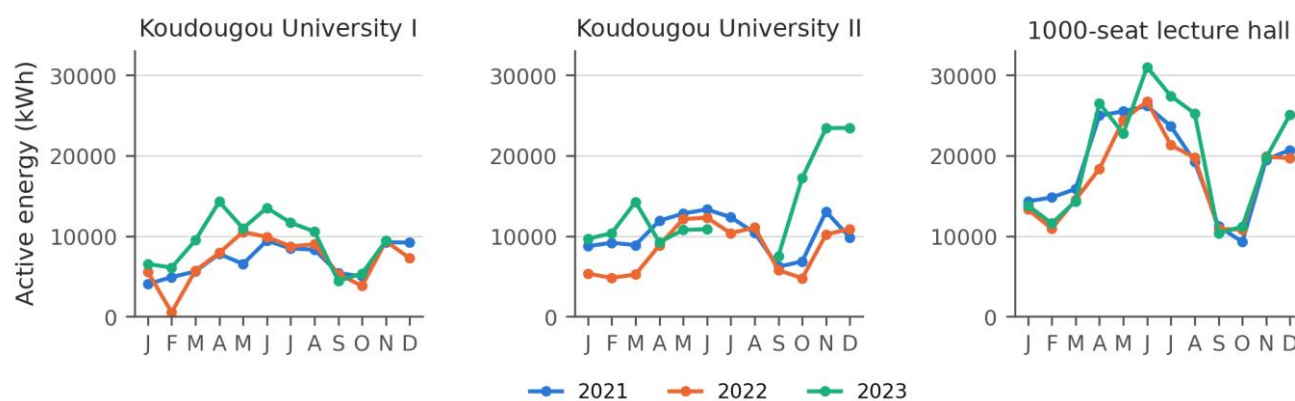


**Figure 2.** Monthly profiles of active energy consumption, 2021-2023.

This seasonality matches the thermal regime of the site: March to June are the hottest months in Burkina Faso, where the outdoor temperature frequently exceeds 40 °C, while September and October mark the end of the rainy season and coincide with the university holidays. The result is consistent with that of Gado et al. [7] for the Maradi site, in the same climatic zone, who attribute the April and May maxima to the

intensive use of air conditioners in offices and administrative buildings.

One profile nevertheless departs from this pattern. At Koudougou University II, the months of November and December 2023 record 23,415 and 23,443 kWh, i.e. more than twice the consumption of the same months in 2021 and 2022, although

these months are among the coolest of the year. This decoupling between temperature and consumption cannot be explained by thermal-comfort needs alone. The growth in student numbers (more than 40,000 students enrolled in 2022-2023 [17]) and usage practices are more plausible explanations, consistent with the results of Masoso and Grobler [8], for whom 56% of the energy of the buildings they study is consumed outside working hours. This finding shifts part of the savings potential from the technical to the organizational domain. Two hypotheses may be put forward for the specific case of November and December 2023, both of which concern administrative rather than thermal activity. The first is the concentration, over these two months, of the end-of-year academic workload (processing of examination marks, deliberations, preparation of degree certificates and enrolment for the following year) which extends the occupancy of the offices, and therefore the use of lighting and office equipment, well

beyond teaching hours. The second is the catching-up of the academic calendar after the interruption of July and August 2023, which shifted part of the teaching activity towards the end of the year. Neither hypothesis can be tested on monthly data aggregated over a whole group of buildings; separating them requires the hourly, per-feeder measurement that the device described in Section 3.8 is intended to provide.

### 3.4. Adequacy of the Subscribed Power

The most striking result of the contractual analysis is the widespread under-estimation of the subscribed power. Of the 105 usable months, 59 show an exceedance, i.e. 56.2% (Figure 3, Table 4). The situation of the 1000-seat lecture hall is extreme: the demand exceeds the 40 kW subscribed in 35 of the 36 months, with a maximum of 215 kW in June 2023, i.e. 5.4 times the contractual power.

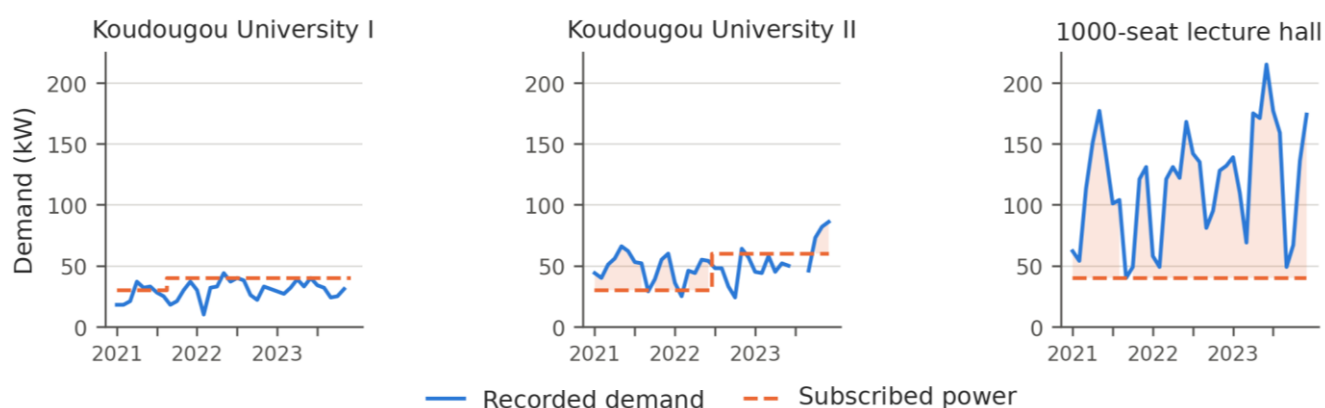


**Figure 3.** Maximum recorded demand and subscribed power, 2021-2023. The shaded areas indicate the months in exceedance.

Recalculated by means of Equation (2), the exceedance penalties reach 13,427,400 FCFA over three years, i.e. 6.4% of the total amount billed. They are concentrated on the 1000-seat lecture hall, which bears 11,701,020 FCFA of them, i.e. 10.8% of its own bill. The calculation procedure was validated by comparison with the penalty amounts appearing in the records of this site, which it reproduces exactly; it was then extended to the two other metering points, for which the records did not itemize this component.

The case of Koudougou University I provides a useful quasi-experiment. The subscribed power there was raised from 30 to 40 kW as from September 2021; the number of exceedances then fell from three in 2021 to a single one in 2022, and to none in 2023, without consumption having decreased — on the contrary, it grew by 22% between 2022 and 2023. The same adjustment, carried out at Koudougou University II from 30 to 60 kW as from June 2022, reduced the exceedances from eleven months in 2021 to four months in

2023. Renegotiating the contract thus appears to be the most immediate and least costly lever, subject to a trade-off between the reduction of penalties and the correlative increase in the fixed premium.

### 3.5. Power Factor and Reactive-Energy Compensation

The power factor reaches the regulatory threshold of 0.92 in only 10 of the 106 documented months, i.e. 9.4% (Figure 4). The 1000-seat lecture hall never achieves it over the thirty-six months observed, although its annual average rises from 0.713 in 2021 to 0.821 in 2023. The lowest values — 0.58 in September 2021 for the lecture hall and 0.58 in February 2022 for Koudougou University I — reflect a predominance of poorly compensated inductive loads.

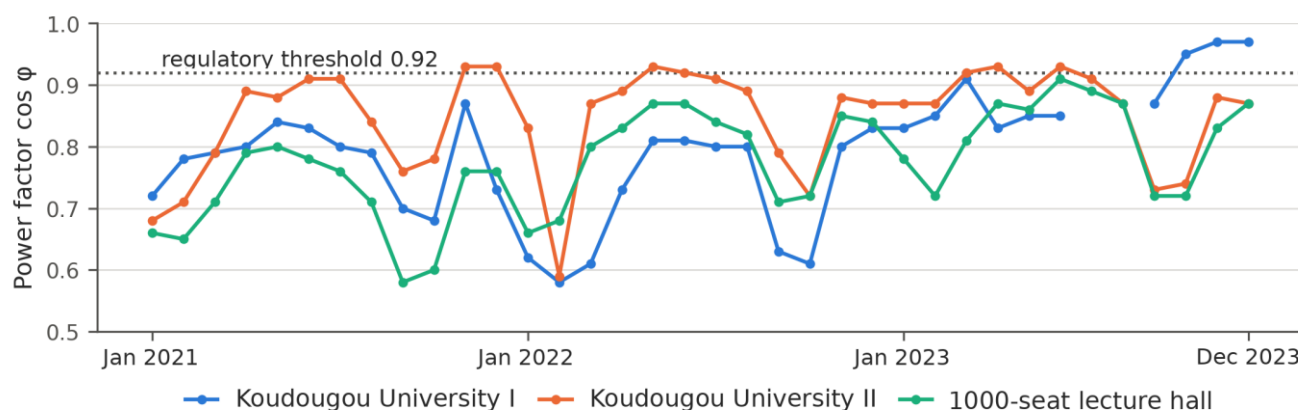


**Figure 4.** Monthly evolution of the power factor, 2021-2023.

This result follows directly from the configuration of the installations: the three contracts report a capacitor rating of zero. No compensation device is therefore installed, whereas the equipment stock is dominated by fan motors and by ageing air conditioners a maintenance technician indicates that most of them are more than ten years old. Ouattara [16] further reports a significant imbalance between phases on the transformers supplying the UNZ, some lines being overloaded while others remain under-used, which further degrades the overall power factor.

The sizing of a compensation by capacitor bank was established according to Equation (5), month by month, the rating adopted being that of the most unfavorable month (Table 5). Set against the annual saving of the order of 1,300,000 FCFA estimated by Ouattara [16] for the correction of the power factor at the scale of the university, these values place the pay-back time of the investment at a few years, without counting the indirect benefits reduction of the line current and of Joule losses, decrease in voltage drops, increase in the available capacity of the network and extension of equipment life.

**Table 5.** Sizing of the reactive-energy compensation (target  $\cos \varphi = 0.92$ ).

| Site                    | Sizing month | Demand (kW) | Recorded $\cos \varphi$ | Computed $Q_c$ (kvar) | Standard rating |
|-------------------------|--------------|-------------|-------------------------|-----------------------|-----------------|
| Koudougou University I  | March 2022   | 32          | 0.61                    | 27.9                  | 50 kvar         |
| Koudougou University II | October 2023 | 73          | 0.74                    | 35.3                  | 50 kvar         |
| 1000-seat lecture hall  | March 2021   | 113         | 0.71                    | 63.9                  | 75 kvar         |

### 3.6. Effective Unit Cost of Electricity

Related to the active energy consumed, the amount billed leads to an effective unit cost of 159.7 FCFA/kWh for the three sites taken together, remarkably stable from one metering point to another (157.9 to 160.2 FCFA/kWh) and from one year to another (155.3 to 163.3 FCFA/kWh). This cost represents 2.5 times the normal-hours tariff (64 FCFA/kWh) and 1.15 times the peak-hours tariff (139 FCFA/kWh).

This gap has a practical consequence. An energy-efficiency policy centered on the reduction of kilowatt-hours alone acts on only a fraction of the cost borne: the fixed premium, metering charges, taxes and penalties make up a substantial share

of it, of which the exceedance penalties alone represent 6.4%. Contractual optimization and reactive-energy compensation act on these terms and produce effects without heavy investment or behavioral change, which makes them first-rank measures in an action plan.

### 3.7. Possible Optimization Strategies

The preceding findings outline an action plan on three levels: the supply contract, the equipment and the building envelope, and behavior. Table 6 summarizes the measures identified and the orders of magnitude of savings reported in the literature.

**Table 6.** Optimization strategies identified and expected gains.

| Lever            | Measure                                                                                                                                                                                                          | Reported gain                                                 | Source        | Estimated payback at the UNZ                                                                            |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|---------------|---------------------------------------------------------------------------------------------------------|
| Contract         | Readjustment of the subscribed power on the basis of the recorded history                                                                                                                                        | Elimination of exceedance penalties (up to 10.8% of the bill) | Present study | Immediate; administrative cost only                                                                     |
| Contract         | Installation of capacitor banks                                                                                                                                                                                  | $\approx 1,300,000$ FCFA/yr at the scale of the UNZ           | [16]          | < 2 yr if the installed cost of the 175 kvar stays below 2.6 million FCFA ( $\approx 14,900$ FCFA/kvar) |
| Lighting         | Occupancy detection and dimming in the lecture halls; for the replacement of defective luminaires, LED drivers with a wide input range (90-300 V), the lecture halls and the central library being treated first | 20 to 30% on the lighting category                            | [18]          | Break-even at 2 yr for an installed cost $\leq 8.5$ -12.8 million FCFA                                  |
| Air conditioning | Set point raised from 20-22 °C to 26 °C                                                                                                                                                                          | 15 to 20% on air conditioning                                 | [19]          | Immediate; no investment                                                                                |
| Envelope         | Double glazing and reflective solar films; night ventilation and solar protection of the façades as passive measures preceding any increase in cooling capacity                                                  | 8 to 15%                                                      | [16]          | Requires a local quotation                                                                              |
| Materials        | Compressed earth blocks replacing hollow concrete blocks                                                                                                                                                         | Reduction of the duration of thermal discomfort               | [20]          | Not applicable; new construction only                                                                   |
| Computing        | Automatic standby outside working hours                                                                                                                                                                          | 15 to 25% on this category                                    | [21]          | < 1 yr; cost limited to configuration                                                                   |
| Generation       | Hybrid photovoltaic system with storage, with inverters qualified for a weak and fluctuating grid                                                                                                                | 32 to 52% of demand covered (7.8 MWp, KNUST)                  | [4]           | 3.91 yr reported for a comparable campus [24]; site-specific sizing required                            |
| Behavior         | Awareness raising, closing of the lecture halls outside teaching hours                                                                                                                                           | 56% of the energy consumed outside working hours              | [8]           | Immediate; no investment                                                                                |

Two clarifications must accompany this table. The gains in the third column are those reported by the studies cited; only the first line derives from the present investigation, where the elimination of the exceedance penalties is established directly from the billing records. Applying the reported percentages to the mean energy actually billed (435,358 kWh/yr) at the effective unit cost of 159.7 FCFA/kWh yields orders of magnitude for the UNZ, and not measured savings: approximately 4.3 to 6.4 million FCFA/yr for the lighting category, 4.3 to 5.8 million for air conditioning and 0.6 to 1.0 million for office equipment. The end-use shares used for this transposition are those of the bottom-up estimate, which Section 3.2 shows to overstate the absolute level of consumption by 32.1% while preserving the ranking of the categories; this is why they are applied to the energy billed and not to the estimate itself.

Two measures deserve to be highlighted for their suitability to the context. Raising the air-conditioning set point to 26 °C responds directly to the finding of Hema et al. [22], according

to which the 24 °C set point adopted at the design stage is not adapted to the Burkinabe context: as the difference between indoor and outdoor temperature governs consumption, reducing it produces an immediate gain without investment. The use of compressed earth blocks, next, relies on their thermal inertia being superior to that of the hollow cement blocks from which most of the campus buildings are built [20]; it concerns new construction only, however.

The payback periods given in the last column follow from the same reasoning. Two measures call for no investment and therefore pay for themselves immediately: the readjustment of the subscribed power, which avoids an average of 4.48 million FCFA of penalties per year, subject to the correlative increase in the fixed premium, and the raising of the air-conditioning set point. For reactive-energy compensation, the annual saving of 1,300,000 FCFA estimated by Ouattara [16] sets the break-even condition: a payback of less than two years requires the installed cost of the 175 kvar identified in Table 5

to remain below 2.6 million FCFA, that is about 14,900 FCFA/kvar, an order of magnitude that a local quotation will have to confirm. For the measures relating to equipment and to the envelope, the absence of local price references precludes stating any payback; the figure of 3.91 years reported by Bekkouche et al. [24] for an integrated photovoltaic installation on a university campus gives the order of magnitude to be expected for generation, in a context where the unit cost of electricity is comparable.

The photovoltaic potential, finally, is considerable in view of a mean irradiation of 5.5 kWh/m<sup>2</sup>/day. Transferring the order of magnitude obtained by Opoku et al. [4] to the UNZ must nevertheless be done with caution: the 7.8 MWp installation they study bears no comparison with the 1.3 GWh consumed in three years by the three sites considered here, and the question of sizing would require a specific study.

### 3.8. Instrumentation of the Monitoring

The weakness of the measurement arrangement is a structural limitation of the energy management of the campus: the only measurement point available is the utility's meter, at the granularity of three groups of heterogeneous buildings and on a monthly basis. The prototype smart meter built in this study addresses this need. Laboratory tests, carried out on a test load, validated the complete chain: acquisition by the PZEM-004T module, local display on the LCD screen, transmission to the Blynk platform and remote display of the measured quantities. The relay module additionally allows controlled load shedding, and the DHT22 sensor the thermal monitoring of the enclosure.

Such a device, deployed at the granularity of the building or of the feeder, would allow three advances: the identification of the most energy-intensive equipment and of consumption peaks, today only inferred from the inventory; the detection of electrical anomalies overvoltage, voltage drop, overcurrent; and above all the real-time monitoring of the demand, which would make an active management of exceedances possible rather than their a posteriori observation on the bill. The technical value of such a device nevertheless rests on an organizational condition. Real-time data produce savings only if someone is designated to act upon them: the deployment should therefore be accompanied by the designation, within the technical services, of an officer responsible for monitoring the demand, by a written procedure specifying the threshold at which an exceedance warning triggers a load-shedding action, and by the entry of a monthly review of the indicators on the agenda of the body responsible for the buildings. Without this human loop, the warning is recorded but not acted upon, and the penalty is incurred all the same.

### 3.9. Limitations of the Study

Four limitations must be recalled. The bottom-up estimate relies on declared operating times and on coefficients borrowed from the literature, as the 32.1% gap with the metered

records demonstrates. The scope does not cover the whole campus: the laboratories, whose demand is substantial, and the student residences are excluded from it, which limits the reach of comparisons with studies conducted over complete scopes. No dynamic thermal simulation software was used, owing to the number of buildings concerned, so that the gains expected from measures relating to the envelope remain borrowed orders of magnitude. The meter prototype, finally, has been validated only in the laboratory on a single load and does not yet constitute a deployable device. Two further limitations follow from the preceding sections. The survey, resting on a convenience sample of 123 respondents, is not statistically representative of the campus population, which confines the declared operating times to the establishment of hypotheses rather than to population estimates. The characterization of the prototype, moreover, relies solely on the accuracy specified by the manufacturer of its measurement module: the metrological comparison with a calibrated reference instrument announced in Section 2.6 remains to be carried out, and conditions any deployment.

Three minor discrepancies noted in the source data also call for mention: the annual total of reactive energy of the 1000-seat lecture hall for 2022, the sum of the amounts billed to Koudougou University I in 2023, and the power factor used as an example for the sizing of the compensation. The values recalculated from the monthly records have been adopted in the present article.

## 4. Conclusions

This study has established the energy diagnosis of three groups of buildings of Norbert Zongo University, by combining an exhaustive equipment inventory, a usage survey of one hundred and twenty-three respondents and three years of billing records.

Four results emerge. Consumption is dominated by thermal comfort, air conditioning and ventilation together accounting for 63.3% of the estimated consumption, lighting nevertheless becoming the leading category at the site where the stock of luminaires is the largest. The bottom-up estimate overstates the billed consumption by 32.1%, which disqualifies it as a basis for sizing while preserving its value for ranking end uses. Consumption follows a marked thermal seasonality, but decouples from it at the end of 2023 at Koudougou University II, signalling the weight of student numbers and usage practices. The subscribed power, finally, is structurally under-estimated: 56.2% of the months are in exceedance and the corresponding penalties reach 13.4 million FCFA over three years, while the power factor complies with the regulatory threshold in only 9.4% of the months, no compensation being installed.

A clear hierarchy of actions follows. The effective unit cost of 159.7 FCFA/kWh, i.e. two and a half times the normal-hours tariff, shows that the tariff and contractual lever precedes the technical one: readjusting the subscribed power and installing capacitor banks sized here between 50 and 75 kvar

depending on the site produce immediate savings without heavy investment. Next come the measures relating to equipment and to the envelope, and then behavioral actions, whose importance the decoupling observed at the end of 2023 serves to recall.

Deploying the proposed smart meter, at the granularity of the building, conditions the whole: without fine and continuous measurement, neither the verification of the savings achieved nor the active management of the demand is possible. Future work will address the integration of a global system for mobile communications (GSM) module in order to free the device from Wi-Fi coverage, the extension of the audit to the laboratories and student residences, and the dynamic thermal simulation of the most energy-intensive buildings.

## Abbreviations

|         |                                                    |
|---------|----------------------------------------------------|
| CAG     | Guaranteed Annual Consumption                      |
| FCFA    | Franc of the African Financial Community           |
| GSM     | Global System for Mobile Communications            |
| I2C     | Inter-Integrated Circuit                           |
| KNUST   | Kwame Nkrumah University of Science and Technology |
| LCD     | Liquid-Crystal Display                             |
| LED     | Light-Emitting Diode                               |
| SONABEL | National Electricity Utility of Burkina Faso       |
| UNEP    | United Nations Environment Programme               |
| UNZ     | Norbert Zongo University                           |
| WAEMU   | West African Economic and Monetary Union           |

## Author Contributions

**Moussa Tissologo:** Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing

**Idrissa Sourabie:** Methodology, Supervision, Validation, Writing – review & editing

**Seydou Ouedraogo:** Resources, Validation, Writing – review & editing

## Conflicts of Interest

The authors declare no conflicts of interest.

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