Energy monitoring retrofit in a multi-building complex

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Abstract. The 2022 strain on Switzerland's electrical grid significantly heightened interest in electricity monitoring and optimization, reinforcing the growing trend of Building Energy Management System (BEMS) implementation. While BEMS are often installed as entirely new systems, this paper presents a case study of a *retrofit* of an electricity consumption monitoring infrastructure within an engineering school during the winter of 2022–2023. We developed and integrated a custom monitoring solution that provides electricity consumption data to users across campus and serve as an educational resource. Built on top of existing equipment, this case highlights the novel challenges encountered in dealing with old, poorly documented, and unmaintained infrastructure, while also showing the potential of retrofitted BEMS to promote sustainability. Our findings underscore the importance of integrating BEMS with facility management processes and highlight emerging challenges related to the interoperability and durability of smart building infrastructure.

Additional Key Words and Phrases: energy, sustainability, IOT, time series, monitoring

1. INTRODUCTION

In 2022 Switzerland consumed ~60 TWh of electricity in 2022 [1]. The canton of Fribourg uses around 2 TWh per year [2] of which 0.1% (~2GWh) are consumed by the school of engineering and architecture of Fribourg (HEIA-FR), part of the University of Applied Sciences and Arts Western Switzerland (HES-SO). Being service oriented (education, applied research), electricity cost is, in normal times, marginal and of minimal concern for the school management.

Yet, the sudden prospects of power shortages during the winter 2022-23 triggered in September 2022 the decision to monitor the school's electric consumption. The motivation was to determine the baseload consumption of each building and to identify which one was responsible for the highest consumption peaks. This information was primarily needed to support decision making in case of mandatory restrictions. Moreover, the crisis prospect had a sobering effect, highlighting that energy shortages could extend beyond the 2022–2023 winter and underscoring the broader energy transition challenges. Therefore, beyond supporting decision-making in the short term, the monitoring system should enable everyone on the campus to track building consumption over time and identify areas for improvement, on a longer-term.

The timescale was too short to initiate a full project and secure its funding, on top of that most Building Energy Monitoring Systems (BEMS) contractors were busy at the time. The school thus created an ad-hoc taskforce, mainly composed of the paper authors, to address the situation.

The taskforce discovered that sensing and monitoring infrastructure had previously been installed 12 years earlier, in the context of a similar project, but was left unused after the decommissioning of a server. An initial analysis concluded that the existing infrastructure could be reused, but a retrofit was necessary to address the immediate crisis and to prepare for the coming years, when energy will play a critical role—especially in an engineering school.

This paper describes the achievements and challenges the taskforce faced through this retrofitting effort. It compiles lessons learned during this endeavour and raises several important research questions: 1) how to decide if an existing BEMS should be wholly replaced or retrofitted 2) how-to maximise BEMS lifespan, to delay the need for retrofits or replacements in the future 3) What should be the minimal BEMS lifespan to ensure sustainability?

2. INFRASTRUCTURE BEFORE ENHANCEMENT

2.1. Electrical network

Electric power enters the campus from the city's grid and passes through two Medium/Low Voltage transformers, which supply electricity (3 phases) to the Force sector (blue) and the Light sector (orange), as shown in Fig. 1. The Light sector or a diesel generator supply the Backup sector (grey) and the Uninterruptible Power Supply (UPS) sector (green).

Each sector then supplies the buildings, designated by letters A to H, along with a few ad-hoc connections that serve dedicated consumption points, such as the kitchen and two specific Heating Ventilation and Air Conditioning (HVAC) systems. The Force sector splits into 15 individual branches. The Light (11), Backup (13) and UPS (9) sectors split into 33 branches in total.

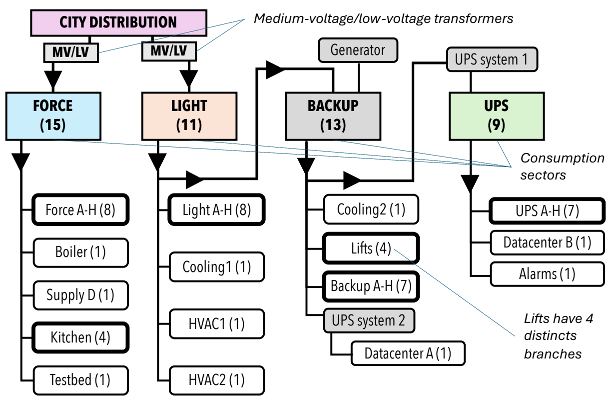

Fig. 1. Campus electric power distribution. Numbers in paratheses designate the number of electrical branches. Bold boxes indicate the 38 existing Measurement Points.

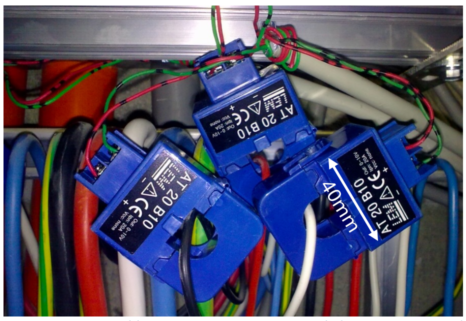

Fig. 2. Hall sensors on Building D Light.

2.2. Sensing and monitoring

In 2010 an array of Hall current sensors (LEM AT 150 B10, Fig. 2) was installed to measure effective Root Mean Square (RMS) currents. A few Rogowski probes (LEM RT 500) had also been installed for the high intensity branches. These sensors were deployed across 38 Measurement Points (MP) – bold boxes in Fig. 1 - each covering three phases. These 38 MPs spanned the Force (8 MPs), Light (8 MPs), Backup (7 MPs) and UPS (7 MPs) electrical branches for buildings A through H (building G has no Backup nor UPS), as well as the kitchen (4 MPs) and lift systems (4 MPs). All sensors were interfaced with a programmable logic controller (PLC), specifically the Saia PCD3.M5540 model, referred to as the "Gathering PLC" (Fig. 3). Phase angles were not recorded. According to the available documentation, the PLC estimated power consumption by applying a fixed computation to the measured current values. This process involved multiplying the individual phase currents by constant factors representing the power factor (0.99), nominal voltage (235V), and a correction factor (1.2857) to compensate for impedance mismatches between the Hall sensor outputs and the PLC input ports. The resulting power estimates were subsequently summed to yield the total power. However, no documentation was found regarding the Rogowski coils signal processing, even though these probes *do not* provide RMS measurement. Following the undocumented decommissioning of a data collection server, the sensors and associated PLC infrastructure were left unutilized, yet electrically connected.

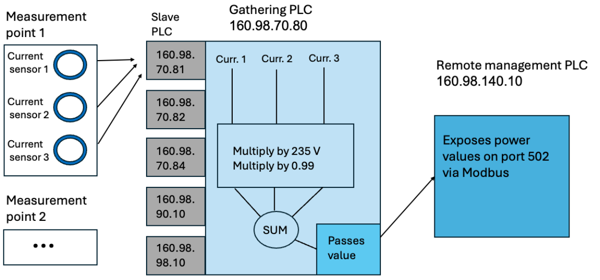

Fig. 3. Existing power measurement infrastructure.

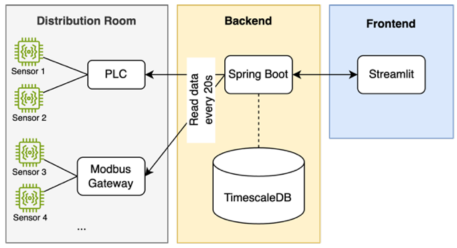

Fig. 4. Application added to the infrastructure.

3. NEW INFRASTRUCTURE

3.1. Accessing the legacy equipment

The initial objective of this work was to re-establish access to the 2007 legacy "Gathering PLC". A contractor specializing in Measurement, Control, and Regulation (MCR), included in the taskforce, successfully accessed the PLC and exposed its measurement data via the Modbus-TCP protocol. These data were subsequently redirected to another PLC associated with the Building Management System (BMS), hereafter referred to as the “Remote Management PLC” (see Fig. 3).

The reconfiguration process was carried out using SAIA’s PG5 software. This software, only available on Microsoft Windows, requires advanced technical expertise to operate without compromising the integrity of the existing PLC programs. Although several programming backups were available in the documentation, they lacked clear versioning, preventing unambiguous identification of the most recent and valid configuration. Consequently, any reprogramming attempt carried the risk of irreversible data loss. Furthermore, it was not possible to establish a direct Modbus-TCP connection to the original “Gathering PLC” limiting direct interaction.

Upon successful retrieval of the 38 current MP on the “Remote Management PLC” via Modbus-TCP, a series of functional validation tests were conducted. These involved monitoring the activation and deactivation of known electrical loads. Despite inherent limitations in the measurement methodology—namely the use of a constant power factor and absence of phase angle measurement—these preliminary tests indicated that the legacy system yielded power estimates within a ±10% margin of error.

Given these acceptable performance results, the operational constraints, and the high upfront costs associated with a wholly new BEMS [3], the decision was made to preserve the existing measurement infrastructure. A new software layer was then designed and implemented to facilitate data acquisition, long-term storage, and visualization, thereby extending the legacy hardware utility.

3.2. New software infrastructure

Fig. 4 offers a general picture of our new software architecture. Several Time Series Database (TSDB) systems have been considered for storage. TimescaleDB was selected due to our preference for the SQL ecosystem. The backend is built with Spring Boot. Streamlit.io visualization enables rapid deployment of intuitive interactive dashboards.

The backend consults the Remote Management PLC approximately every 20 seconds collecting power values for the different MP and inserting them into the database. These streams of measurements are called the “raw data”. Every 5min, the backend aggregates and aligns this raw data to obtain average power consumption for each MP and for each 5-min time slot, for instance, 9.00-9.05am.

3.3. Measurement coverage enhancement

As shown in Fig. 1, many electrical branches were left uncovered by these 38 existing MPs. To address gaps in measurement coverage, we explored ways to enhance data acquisition across the electrical infrastructure. First, we noticed that two industrial precision electric meters [4] had been placed at the Force and Light sectors entrance, displaying metrics on an LCD screen. These meters provide an unexploited ModBus interface. We acquired a ModBus gateway and tasked our Backend to interrogate it, resulting in two additional MP. We also found out that the two UPS power consumption and the Datacenter (A+B rails) could be obtained via the Simple Network Management Protocol (SNMP). One HVAC system also had a ModBus-TCP capability, so we tasked the Backend to periodically consult these devices.

3.4. System validation

With the data acquisition and storage systems successfully re-established, the project advanced to the validation phase.

In the UPS sector, we conducted an analysis by comparing two measurements: first, the UPS's internal consumption multiplied by its documented efficiency factor; and second, the combined consumption of Datacentre B and the seven Hall-effect-based "UPS A..H" measurement points (MPs). The calculated values converged within approximately 100W – a discrepancy that can be attributed to the alarm system – demonstrating that the Hall-effect-based measurement points (MPs) were reliable. Furthermore, the aggregated consumption measured by the two energy meters correlated with the official electric utility billing data, with a relative error of less than 1%, thereby confirming the internal measurements consistency and reliability.

In contrast, the Force sector presented more complex validation results. While general correlations were observed, significant discrepancies were also noted. The absence of measurements on several branches (boiler, testbed, supply D) contribute to an underestimation of actual consumption. However, and unexpectedly, overestimation events were also detected, predominantly associated with branches monitored using Rogowski coils. These errors were traced to the lack of signal integration hardware [5] and insufficient post-processing algorithms to convert the raw Rogowski signals into accurate current or power values. In summary, while the measurements from the Force sector are currently suboptimal, they remain sufficiently accurate for high-level analytical purposes, as discussed in Section 4.

In the Light and Backup sector, the cumulative power measured across all instrumented branches fell short of the value recorded at the main incoming meter by approximately 10kW. This discrepancy is attributable to several known "blind spots" in the monitoring architecture. Specifically, the Datacentre Liquid Cooling Package units ("Cooling2" in Fig. 1), typically draw 3-4 kW, and the unmonitored HVAC system, accounts for an additional 6kW. When these factors are considered, the observed measurement deficit is consistent with expectations. Overall, the Light sector yields consumption estimates within a few percentage points of the true values, which is considered acceptable for the intended application.

4. EXAMPLES OF USE CASES

This section shows how our monitoring system has been used to perform high-level analyses.

4.1. Global energy consumption analysis

A consumption profile analysis during the Christmas Holiday period reveals a ribbon consumption of approximately 80kW. The Force sector dominates with ~55kW. The Building B 22kW and Building G 15kW force baseloads are mainly due to the chemistry department and its associated ventilation and safety systems. In contrast, the Building C 8kW constant load triggered investigations. It was also established that buildings G and H were responsible for intense power surges reaching 300kW. In the event of a power shortage [6], those buildings should be temporarily taken out of use as a priority.

4.2. Assessing effectiveness of energy directives

Monitoring the building's electricity consumption is essential to assess energy saving directives effectiveness. Our system permitted to quantify the automatic lights-off policy introduced in the energy crisis context: at specific times (lunch pause, end of workday...) the lights are automatically shut off, resulting in daily savings of ~65kWh (Fig. 5) or tens of thousands CHF/year.

4.3. User awareness

Comprehensive monitoring of electrical consumption enabled the active engagement of campus users, including students and staff. By providing open access to the monitoring interface, individuals are empowered to observe their actions direct impact on energy usage. As illustrated in Fig. 6, the user interface includes an interactive component displaying real-time electricity consumption for each building (consumptions of building B are currently on display in the black box), thereby enhancing spatial awareness of energy distribution across the campus. An additional widget presents daily consumption values in comparison to the average for the same weekday, incorporating statistical indicators such as historical means and extrema from previous weeks. This transparent approach not only fosters awareness but also promotes behavioural change. Elements of gamification [7] have been considered to further promote user engagement, for example, by introducing prompts that encourage occupants to maintain consumption within a predefined "green" efficiency zone throughout the day.

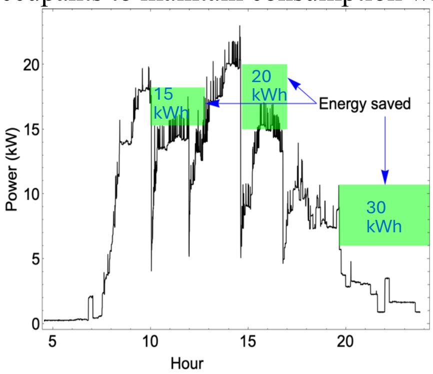

Fig. 5. Building D lighting consumption on 23.04.2023. Green rectangles saved energy.

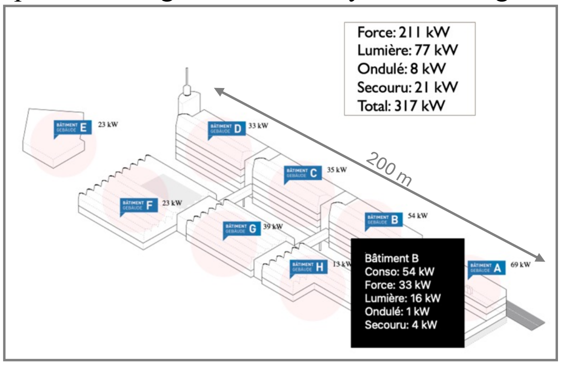

Fig. 6. Widget showing the complete actual electric consumption across the campus. The top box shows the school's total consumption, per sector and aggregated.

5. DISCUSSION

The task force ultimately succeeded in re-establishing a BEMS, and this with limited additional hardware, though it required a significant investment of time and effort. Here are our main take-aways:

- Existing system documentation was insufficient and scattered across different places, far from the Building Information Modelling (BIM) concept [3, 8], especially its usage "throughout the entire lifecycle of a built facility" [9]. The integration of BEMS with BIM is challenging for existing buildings [10]. In our particular case, there is no BIM software, and we had to create an ad-hoc documentation of the new system.
- Our investigation also revealed that the previous monitoring system had not been fully integrated into the facility management processes. Had it been institutionalized, the original frontend interface would likely have remained operational, or its decommissioning would have been documented. This observation underscores a critical requirement for the long-term viability of any BEMS: beyond being technically functional and validated, the system must also be actively adopted by facility management personnel [11]. For a BEMS to persist throughout the facility's lifecycle, it is also essential that its operation and maintenance be clearly assigned to responsible parties. All stakeholders must have full access to comprehensive system documentation to ensure proper usage, maintenance, and potential future upgrades.
- Although our primary focus was limited to monitoring electrical energy consumption, the implementation process required interfacing with a diverse set of technologies, including ModBus, PLCs, and SNMP. These systems spanned multiple domains of expertise, such as electrical engineering, HVAC systems, and information technology, underscoring the interdisciplinary nature of modern building energy management [12]. We further observed that both technologies and operational practices are evolving at a rapid pace. For instance, photovoltaic panels were recently installed on-site, and integration into the existing monitoring platform was possible thanks to the

availability of a ModBus interface on the inverters. However, this compatibility was more a fortunate coincidence than a deliberate design decision. As building get smarter, they also become more complex, with more cross-dependencies, requiring more skilled facility managers.

- The replicability of our "DIY approach" depends on different factors. In our case, a strong support and trust from the school management enabled the project. We can quote few prerequisites: management approval and the desire to support such initiatives, the availability of technical expertise (internal or external), and finally a governance flexibility. In larger infrastructure with rigid governance this type of retrofit may be more difficult to implement, indeed.

In the short term, we plan to install sensors on the remaining blind spots, add the energy (kWh) used by our district heating system, which can be up to 50% of the total energy consumption [15], and investigate air quality monitoring which can have significant a saving potential of 30-40% [16]. IT security aspects will also have to be considered, although they are not the primary focus of this work.

Looking further ahead, more "smart" devices will likely be deployed, which will create more backward compatibility challenges. Referring to the questions highlighted in the introduction:

1) how to decide if an existing BEMS should be wholly replaced or retrofitted?

The 2022-2023 crisis mandated the retrofit approach in our case, but the next evolution will likely be a replacement. To become a fully integrated energy management system, our monitoring system would require implementation of control mechanisms to approach BIM [8] and prepare for Fault Detection and Diagnostics (FDD) system [13]. Integrating such functionalities in a flexible way within a legacy, even retrofitted, infrastructure is probably too complex.

2) how-to maximise BEMS lifespan, to delay the need for retrofits or replacements in the future?

interoperability and extensibility appear to be key for supporting the integration of additional devices and/or functions. Yet the vast literature on BEMS, Energy Management and more generally smart building and cities gives little practical insights on to *durably* integrate multiple Smart Building System in an *interoperable* way. The nearest available guideline we found is a recommendation from Switzerland's Coordination Conference for Public Sector Construction and Property Services (KBOB) promoting BACnet as a universal platform [14]. Many comprehensive monitoring systems exist on the market, but they appear rather monolithic, and their integration with other systems might be challenging or simply unaffordable, especially for universities. In our case the full data-pipeline is visible, which has already proved useful to demonstrate concepts to students. But our do-it-yourself approach, while open, is clearly more challenging to maintain.

3) What should be the minimal BEMS lifespan to ensure sustainability?

We note first that our system is now 15 years old, which is significant but still far less than the building lifespan. At the same time, it remained unused for many years, providing no value during this period. Fortunately, no "dark-data" has been accumulated during the "off-period" [17], yet the system did consume some energy for nothing for a couple of years. Is our system amortized? Is it sustainable to replace a BEMS every 15 years? These are questions that should deserve attention in the future. While smart metering can aid the energy transition, evaluating its full lifecycle—from manufacturing to decommissioning—is crucial for understanding its true cost-benefit balance [18]. Incorporating approaches and results from the Lifecycle assessment community [19] is key to truly target eco-designed systems.

6. CONCLUSION

We highlight the inherent complexity of a retrofit of an existing power measurement infrastructure in a multi-building complex. We introduced a custom monitoring solution deployed above the preexisting infrastructure, displaying live electric consumption data within the campus for all users. We showed how our system has provided and still provides insights on the school of engineering energy and power consumption. Finally, we discuss several challenges we faced while performing the retrofit. Notably, we highlight the need to thoroughly document a Building Energy Management System (BEMS) once in place, ideally in the context of Building Information Modelling (BIM). We also exhibit the importance to integrate the BEMS within the facility management processes.

References

[1] Swiss federal office of energy. Electricity consumption down by 1.9% in 2022, 2023. URL https://www.admin.ch/gov/en/start/documentation/media-releases.msg-id-94437.html.

[2] Swiss federal office of statistics. Consommation d'énergie, 2024. URL https://www.fr.ch/deef/sstat/statistiques-par-themes/consommation-denergie.

[3] Digitemie, W. N., & Ekemezie, I. O. (2024). A comprehensive review of Building Energy Management Systems (BEMS) for improved efficiency. World Journal of Advanced Research and Reviews, 21(3), 829-841.

[4] Schneider Electric. PowerLogic PM5000 Serie: https://www.se.com/de/de/product-range/61281-powerlogic-pm5000-serie/, 2014.

[5] Samimi, M. H., Mahari, A., Farahnakian, M. A., & Mohseni, H. (2014). The Rogowski coil principles and applications: A review. *IEEE Sensors Journal*, *15*(2), 651-658

[6] Erb, Simon. "36 Power Shortage Situation: Active Management of Scheduled and Unscheduled Operational Disruptions". Handbook of Electrical Power Systems: Energy Technology and Management in Dialogue, edited by Oliver D. Doleski and Monika Freunek, Berlin, Boston: De Gruyter, 2024, pp. 715-732. https://doi.org/10.1515/9783111264271-036.

[7] Berger, V., & Koch, D. (2024). The climate wins!–how a gamification approach can foster sustainable consumption on university campuses and beyond. *International Journal of Sustainability in Higher Education*, *25*(8), 1646-1661.

[8] Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building Information Modeling (BIM): Now and beyond. The Australasian Journal of Construction Economics and Building, 12(4),

[9] Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). *Building information modeling: Why? what? how?* (pp. 1-24). Springer International Publishing.

[10] Kozlovska, M., Petkanic, S., Vranay, F., & Vranay, D. (2023). Enhancing energy efficiency and building performance through BEMS-BIM integration. Energies, 16(17), 6327.

[11] Sayed, K., & Gabbar, H. A. (2017). Building energy management systems (BEMS). Energy conservation in residential, commercial, and industrial facilities, 15-81.

[12] Marinakis, V. (2020). Big data for energy management and energy-efficient buildings. Energies, 13(7), 1555.

[13] Marco Pritoni, et al.: Digital and Interoperable: The future of building automation is on the horizon. What's in it for me? https://doi.org/10.20357/B76W3X.

[14] KBOB, Empfehlung BACnet Anwendung, v2, 2021, https://www.kbob.admin.ch/de/gebaeudetechnik-und-gebaeudeautomation (last accessed April 14th, 2025).

[15] Li, W.; Koo, C.; Hong, T.; Oh, J.; Cha, S.H.; Wang, S. A novel operation approach for the energy efficiency improvement of the HVAC system in office spaces through real-time big data analytics. Renew. Sustain. Energy Rev. 2020, 127, 109885. [CrossRef]

[16] Franco, A.; Crisostomi, E.; Leccese, F.; Mugnani, A.; Suin, S. Energy Savings in University Buildings: The Potential Role of Smart Monitoring and IoT Technologies. Sustainability 2025, 17, 111. https://doi.org/10.3390/su17010111.

[17] Gimpel, G. (2020). Bringing dark data into the light: Illuminating existing IoT data lost within your organization. Business Horizons, 63(4), 519-530.

[18] Louis, J. N., Calo, A., Leiviskä, K., & Pongrácz, E. (2015). Environmental impacts and benefits of smart home automation: Life cycle assessment of home energy management system. IFAC-PapersOnLine, 48(1), 880-885.

[19] Andrae, A. S. (2015). Life-Cycle Assessment of Consumer Electronics: A review of methodological approaches. IEEE consumer electronics magazine, 5(1), 51-60.