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Definition and Implementation of an Energy Metering Plans for Energy Efficiency

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ABSTRACT: Fossil fuels are responsible for global warming (carbon emissions). Throughout the world, energy efficiency is deployed in an attempt to reduce this negative impact. Energy management is one lever of energy efficiency. An energy management can't be successful without a clear and robust metering/monitoring plan. An energy metering plan has two main goals. The first goal is to continuously improve the performance. The second goal is the reduction of carbon emissions and costs. A deep sub-metering permits to realize more energy savings. Estimates of energy savings have ranged from 1% to 20%, depending on the application of the metering systems. This paper contains 2 cases study of metering plan: one in an industrial and one in a residential building.

KEYWORDS: Energy metering; Energy monitoring; Energy efficiency

1. INTRODUCTION

Energy efficiency is key to reduce carbon footprint of residential, commercial, and industrial buildings. Hussain et al. (2020) indicate that with the growth of appliances, electrical machinery handling, and excessive usage of electricity in residential buildings and industrial sectors, the precise energy forecasting is emerging as a hot research problem.

One component of energy efficiency is the energy monitoring (O'Driscoll & O'Donnell, 2013; M'Baye, 2022a). Energy monitoring itself includes 2 elements: energy supervision and energy metering. An energy metering plan is crucial and linked to an energy supervision (a software).

As stated by O'Driscoll & O'Donnell (2013) an energy metering system is a systematic framework for continuously improving the energy performance of a site and can help industrial enterprises reduce energy costs and improve performance and productivity.

Before launching an energy metering plan or optimizing an existing one, the site context must be first deeply analyzed: carbon emissions reduction strategy, current energy supervision software in place (if applicable) etc.

The metering plan is made up of three parts:

1. An inventory of the existing: Energetics and Material (identify the number of meters already in place, the type of energy uses such as gas and electricity…).
2. An analysis of influential factors and relevant ratios to be integrated into future monitoring
3. A detailed and quantified metering plan

This metering plan must be based on a detailed on-site examination of the equipment, a technical study of documents and an overall work on the site's energy consumption aims to prepare the metering plan and a consultation to create the pages of the future or existing energy monitoring system (Zhai & Salazar, 2020; Andrea Ahmad et al., 2016).

Moreover, there will be exchanges with people involved (technicians, operators etc.), an assessment of the initial situation (rate of under metering, architecture, proper hardware operation) and a study and proposal of several scenarios.

The size of the metering plan will depend on the organization current situation toward metering.

According to ASHRAE, the savings realized by a metering program depend largely on the actions taken with the meter data. As seen in figure 1, estimates of energy savings have ranged from 1% to 20%, depending on the application of the metering systems.

Action	Observed Savings
Installation of Meters	**0% to 2%** The Hawthorne Effect
Bill Allocation Only	**2.5% to 5%** Improved Occupant Awareness
Building Tune-Up And Load Management	**5% to 15%** Improved Awareness, Identification of Simple Operations and Maintenance Improvements and Managing Demand Loads Per Electric Rate Schedules
Ongoing Commissioning	**15% to 45%** Improved Awareness, Ongoing Identification of Simple Operations and Maintenance Improvements and Continuing Management Attention

Figure 1: Expected energy savings from utility metering (Plourde, 2011)

This paper contains different successful case studies on energy metering plan.

2. METHODOLOGY

2.1 Entry documents

The first step is to gather relevant documents such as:

- The Low Voltage and High Voltage substation plan,
- The plans of the buildings,
- Lighting plan (interior and exterior),
- Chilled water production diagram
- etc.

Those documents will permit to make a first assessment.

2.2 Measurement

In order to complete, correct or verify the available data, a set measurement should be taken during the study either in the form of occasional measurements with clamp meters as represented in figure 2 or with portable measurement units as shown in figure 3 (O'Driscoll et al., 2012).

Figure 2. Chauvin Arnoux - Clamp Meter - Digiflex MA4000D

Figure 3. Portable Measurement Unit - Chauvin Arnoux – PEL 103

2.3 Deep analysis of current situation and action plan definition

This article contains different case studies on different kind of building and energy.

2.3.1 Case study #1: Analysis of electrical consumption and meters architecture in an administrative building and action plan definition

Current situation

There are two existing systems linked to different counters. A Chauvin Arnoux system is used and has been commissioned in the sense of energy monitoring (experimental and educational installation). There is also a building monitoring system (BMS) but not dedicated at 100% to energy monitoring.

Below the settings of the Chauvin Arnoux System:

- 35 meters
- Commissioned in 2012

The equipment in place includes:

1) Measurement units,
2) Control units + concentrator with display as represented in 4,
3) Control units + concentrator without display as represented in figure 5,
4) Electricity meters which are read by the measuring stations.

The control units are connected to a switch connected to an RJ45 socket.

Figure 4. Measurement units (in the middle) and Control units + concentrator with display (on the right and on the left)

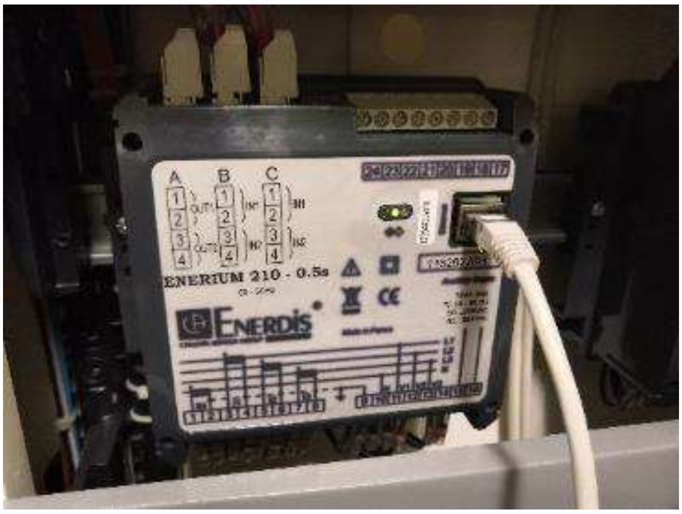

Figure 5.Control units + concentrator without display

Output of the analysis

Several elements have to be taken into account in view of the existing Chauvin Arnoux system.

The reuse of this system does not seem possible because:

- No data consistency checks possible at this stage because data are not recorded (no history available),
- 9 out of services counters including 1 of the generals,
- 12 indexes that do not evolve in the software
- Communication with the meters not always operational (cable problem?); wiring of the meters on a switch with a single RJ socket mounted in the info bay

The implementation of new meters presents many constraints:

- Not enough spaces in electrical cabinets,
- Costs,
- Cable pulling to be planned to recover the data (because there is no RJ 45 socket available)

Moreover, two new meters should be implemented to measure large consumer: Chillers and Steam boiler room.

Actions plan identified

3 possible actions plan have been identified for the meters:

- Replace all the counters in several cabinets (and change cabinets also where there is not enough spaces)
- Deploy a new system at key points and keep the existing one when it works
- Keep all the existing ones and just replace the out of services meters with the same reliability of the system and durability

The best solution is to replace all the counters because long-term environmental and financial savings will be done.

2.3.2 Case study #2: Analysis of gas consumption and meters architecture in an Industrial Building and action plan definition

Current situation

The site's natural gas consumption amounts to 13200 MWh for the year 2019 as show in figure 6. The invoice amounts to 594 k€. Natural gas is used for heating, Domestic Hot Water, catering, and the process.

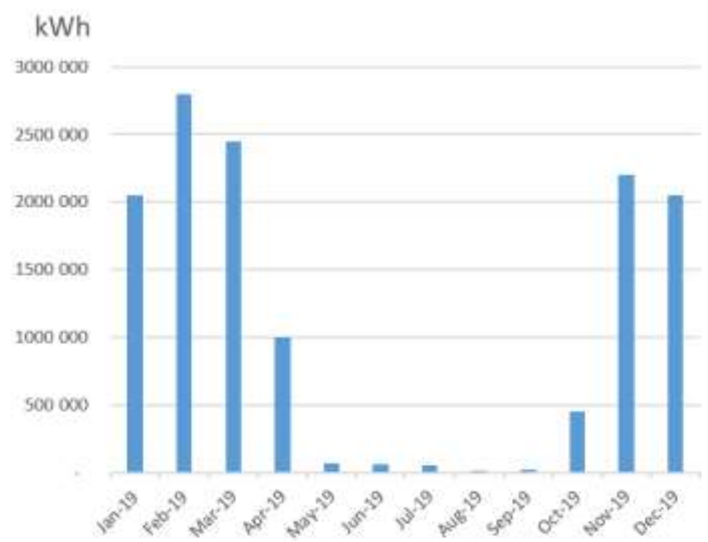

Figure 6: Monthly gas consumption

Based on weekly manual readings done by utilities technicians, the site's gas consumption cand be break down as shown in figure 7:

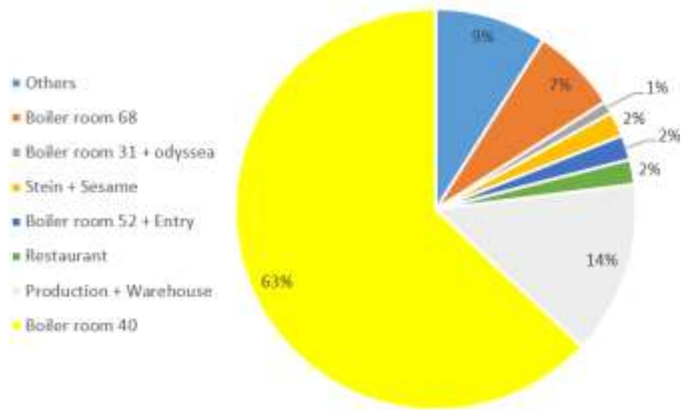

Figure 7: Gas consumptions repartition

The steam boiler room is the largest consumer on the site with 63 % of total consumption. The two boilers (5.5 MW) are used exclusively for heating 8 areas (production, testing, store, offices etc.).

The second consumption item is the production building and the store (excluding heating): gas oven, stripping machine, welding equipment, etc.

Boiler room N°68 is the third consumer item. It supplies the heating circuits for the Universal building with a surface area of 6300 m².

The restaurant is the fourth largest consumer on the site, in particular with the ovens and cooking fires and the Domestic Hot Water.

The other consumption items are mainly boiler rooms in small-area buildings.

Metering

27 meters are now present on the entire site (different brand such Elster type BK-G6 and Actaris type fluxi G650):

- 8 meters are totally out of services.
- 2 meters display 0
- Only 4 meters are linked to the BMS (Building Monitoring Systems)

Counting analysis

Available data have been analyzed (namely from April to November 2019). There is a discrepancy between the invoices and the general site meter during the summer period. The monitoring file only contains meter readings from the month of April, but we can notice that the lower the consumption, the greater the difference between the theoretical consumption calculated using the general meter readings and the consumption indicated on the invoice the greater the error. This is explained by the differences in reading dates and the range of accuracy of the meters.

Over the full year, there is a difference of 4% between the consumption shown on the bill and that recorded by the site's general meter.

The same exercise between the site's sub-meters and the general meter shows a very significant difference when the site's consumption is low, mainly in summer.

Over the year, a difference of 8% is recorded between the sub-meters and the general gas meter. However, the difference between the total of the sub-meters and the consumption shown on the bill is very small.

Proposed metering plan

At the level of the main gas consumption items, it is important to track data from the following counters: General website; Steam boiler room; Production and store; Oven TTH; Pickling boiler; General MP; Boiler room 68; Restaurant (building 35); Boiler room 52; Stein & Sesame; Boiler room 31; Boiler room 30 and Boiler room 14.

With this metering plan, it will be possible to monitor approximately 93% of consumption precisely. The part not counted represents only 7% and can be treated in a second time.

The monitoring of these sub-meters will make it possible to know the distribution of gas consumption on the site. The monitoring of the general meter allows to have a global vision and to control any drifts on certain consumption items not specifically counted.

Other meters

In order to monitor the energy performance of the site and in particular the utilities, other meters or parameters to be monitored are proposed in the metering plan.

They are detailed below:

- **Condensates from Steam boiler room:**
  - A steam flow meter will be installed in the boiler room as well as a temperature sensor at the outlet of the condensate tank.
- **Chilled water production:**
  - To monitor the thermal energy produced, it is proposed to install a thermal meter (ultrasound type) on the chilled water outlet.
- **Compressed air:**
  - To monitor the compressed air flow, it is proposed to install a communicating flow meter at the output of the centralized production. In order to monitor the thermal energy recovered from the compressors, it is proposed to install a thermal meter on the recovery circuit. It is proposed to install an ultrasonic meter brand Diehl Metering reference Sharky 775.
- ***Outside temperature**:*
  - It is proposed to have an outside temperature sensor to calculate the DJU and monitor the influence of this quantity on the site's gas consumption.
- ***Production**:*
  - For several processes, it would be relevant to be able to monitor production automatically.

Investment

Electric metering

For each substation, the investment includes the installation of meters and the wired connection to the nearest information Technology (IT) cabinet. Total cost = 125 000 euros (91 meters)

Gas metering

For the general site, a wireless solution is proposed to recover the data namely:

- Provision of the pulse output by gas supplier,
- ATEX pulse transmitter to be provided,
- Data reception gateway,
- Connection to the IP network.

For unconnected meters, gateways to the IP (Internet Protocol) network are provided.

For the two arrivals without meters, the supply, installation, and connection of the meter to the IP network is provided.

Total cost estimated = 26 000 euros

Others metering

Table 1 contains a summary of the investment for other meter

Table 1

Number	Type of Energie/Fluid	What	Costs ($)
1	Steam boiler	Steam flowmer and implementation	13 000
2	Chilled water production	Thermal meter and implementation	12 000
2b	Heat recovery on Chilled water installation	RS485 bus connection from existing meter	
3a	Compressed Air production	Compressed air flowmer and implementation	10 000
3b	Heat recovery on Compressed Air installation	Thermal meter and implementation	
4	Others	External temperature sensor	1 000
5	Others	Production information	2 000
6	Others	2 electrical meters and implementation	2 000
TOTAL			40 000

Investments synthesis:

- Electrical meters = 65%; $125 000
- Gas meters = 14%; $26 000
- Other meters = 21%; $40 000

Total cost = $191 000

1. Energy ratio

Another crucial step in the metering plans is the definition of the ratios to follow. This section contains, the study done to define the ratios in the case study #2.

Energy Performance Indicator (EnPI) is a measure of energy intensity used to measure the effectiveness of the energy management in place (M’Baye, 2022b; Cooremans & Schönenberger, 2019).

Gas ratio

Site ratio

The outside temperature is the factor that seems to have the most influence with respect to the site gas consumption. The proposed ratio will therefore be the corrected gas consumption climatic severity in $kWh_{LVH}/DD/m^3$ or m² (DD = degree days; LVH = Lower Heating Value).

For industrial sites with buildings with great height under ceiling, the ratio per m^3 is preferred, to compare with other sites.

For following the evolution of consumption, the ratio per m² should be chosen.

Ratio per area

Boiler Steam

To monitor the performance of the steam boiler room, the following indicators should be followed: Boilers room specific production energy and then boilers efficiencies.

The specific production energy of the boiler room is calculated as follow:

$EnPI1_{\text{boiler room\_steam}}$ = Gas consumption (kWh_{LVH})/ Quantity of steam produced (tons)

The useful efficiency of the boilers will be calculated as follow:

$EnPI2_{\text{boiler room\_steam}}$ = Thermal production (kWh) / Gas consumption (kWh_{LVH})

Tertiary buildings

The evolution of consumption can also be monitored by a ratio in kWh_{LVH}/DD/m².

Process

For the three uses below, ratios based on production may be followed:

- “TTH” oven
- Stripping
- Welding n°56 and welding n °54

A ratio either by part or if the parts have characteristics very different from each other (weight in particular) a ratio per kg can be put in place: IPE = kWhPCS / number of parts or parts weight in kg

Electrical ratio

The site's electricity consumption is relatively stable in 2019. January is the month with the greatest consumption and the greatest difference to the average (+41%). This is explained by the significant consumption increase of several posts during tests (tests are part of the process). In addition, those posts have consumption relatively stable depending on the month.

For those posts, the min/max differences observed between the different months of year 2019 are the following:

Table 2

POST	Difference in consumption between the most consuming month and the least consuming month
POST 1	+470%
POST 2	+1048%
POST 3	+151%
POST 4	+124%
POST 5	+57%

From this analysis and the 2019's data, the best ratio is in kWh/days worked/m². For 2019, we would have the following ratios:

Table 3

Months	EnPI in kWh/days worked/m²		
	Site Ratio	Production Ratio	Tests Ratio
January	0,72	0,49	0,14
February	0,58	0,47	0,04
March	0,57	0,44	0,04
April	0,54	0,45	0,04
May	0,53	0,44	0,04
June	0,51	0,45	0,04
July	0,48	0,43	0,03
August	0,62	0,55	0,04
September	0,52	0,46	0,03
October	0,51	0,44	0,04
November	0,55	0,45	0,04
December	0,75	0,42	0,05
Average 2018	0,57	0,47	0,05

The "production" ratio includes the electricity consumption of all uses relatively constant.
The "tests" ratio corresponds to the uses in high demand during major tests.

Other ratios

Chilled water production

Performance monitoring of chilled water production can be done by monitoring the performance of the installation:

$EnPI_{chillers}$ (gross) = $E_{Thermal}$ / $E_{Electric\_compressors}$

$EnPI_{chillers}$ (Net included) = $E_{Thermal}$ / ($E_{Electric\_compressors}$ + $E_{Electric\_auxilliaries}$)

Influencing factor = outside temperature. Therefore, it is possible to follow together the evolution of the $EnPI_{chillers}$ and the average outside temperature.
Other information can be monitored at the chilled water production level and especially:

- Average load rate of the group
- Average daily power
- Maximum daily power

Compressed Air

The energy performance indicator proposed is:
$EnPI_{comprssed\ production\ room}$ = Electricity consumption [Wh] / Compressed air production [Nm^3]
Note: This indicator can be broken down by compressor. It seems necessary, however, mainly in power plants with many machines which is not the case here. A ratio to a production unit can also be tracked, for example Wh/kg of finished products (but necessary not in this case).
In addition, it is relevant to monitor the evolution of the average power, the average flow of compressed air required by the installation and the pressure at the exit of the installation (especially if pressure varies according to different time slots).

Water

This post contains water pumping. The ratio to follow would be the Wh/m^3 of pumped water (Mudumbe & Abu-Mahfouz, 2015; M'Baye, 2022c).
Given the short operating time of the pumps (50 to 800 h/year), automated the monitoring of this ratio does not present an issue for the site.

Others equipment

For other uses, in particular lighting and ventilation, it is relevant to also follow a ratio in kWh/day worked/m².

CONCLUSION

According to Ahmad et al., (2018), the increasing installation of energy meters and environmental monitoring sensors has acted as a catalyst towards the drive to reduce energy consumption and associated green gas emissions.
This paper demonstrates by case studies that the methodic and rigorous definition and deployment of a metering plan can lead to a significant carbon emission reduction and therefore financial costs savings.
An energy metering should be carried out before implementing an existing energy software supervision or to implement a new one.
Next step is to develop predictive consumption thanks to innovation and new technologies (Ahmad et al., 2018) and mean of communication such as Iot (Internet of Things) (Yaghmaee & Hejazi, 2018).

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