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Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006

Alberto Fichera, Rosaria Volpe *, Emanuele Cutore

Department of Electrical, Electronics and Computer Engineering, University of Catania, Viale Andrea Doria 6, 95125, Catania, Italy

A R T I C L E I N F O

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A B S T R A C T

The International Standards ISO 50001 and ISO 50006 can be easily transferred to organizations, which outputs consist of tangible products. However, it is equally important to build an energy management system tailored to public organizations, whose outputs are often immaterial goods and in which buildings highly affect the overall energy performances. Commonly, energy performances of buildings are assessed by comparison with sector-based benchmarks, whilst monitoring and control practises are often overlooked. Under these premises, this paper aims at proposing a common framework for an energy management system tailored to public organizations in which buildings play a pivotal role in targeting energy performance improvement. The proposed energy management system also relies on the effective exploitation of monitoring and control tools to promptly identify deviations from the expected energy performance values and to evaluate improvements over time.

1. Introduction

Over the last decades, energy performance assessment of any organization has become a topic of utmost importance, also in light of the urgent need for fostering the path towards energy sustainability. Earning a detailed understanding on how an organization performs is, however, a non-trivial task, being the definition and evaluation of energy performances strictly linked to the particular technology, system, process or plant under investigation. Moreover, even the strategic mission and nature of the organization, e.g. either manufacturing plants or organizations offering immaterial services, play a significant role in any performance assessment process.

Specifically, insights on the energy performances can be drawn by evaluating energy efficiency, energy use and energy consumption of any organization (May et al., 2015). To gain awareness on these topics, the International Standard ISO 50001 comes to the aid. It is a voluntary regulation setting up the guidelines for planning, implementing, monitoring and controlling the energy performances of the organization through the adoption of an energy management system (EMS) (ISO International Standard Organization, 2018). Essentially, an EMS consists of a systematic procedure for the continuous improvement of the energy performances inspired by the well-known Deming Cycle, i.e. "*plan-do--check-act*", and coordinated by an energy manager. The adoption of a standardized EMS is crucial not only to improve the energy performances but also to detect deviations from expected values of *ad hoc* defined Energy Performance Indexes (EnPIs) characterizing specific processes or plant's sections called cost centres (Li et al., 2017). After the ISO 50001 came into effect, the ISO 50006 has been released with the main aim of clarifying the aspects related to the choice and measurement of EnPIs as well as to correctly implement monitoring and control methods and, generally, to offer a guidance for obeying to the EMS principles (ISO International Standard Organization, 2014).

To ensure effective compliance with these regulations, however, each organization should develop an EMS strictly tailored to its own strategy, mission, processes or systems and, to this scope, the choice of representative EnPIs is fundamental. In this regard, when dealing with a manufacturing plant, an energy manager can easily correlate the energy performances to the output of production, i.e. to the units of products or goods. Moreover, in these cases, the energy manager is also conscious of the need to implement monitoring practises and control tools to detect deviations from expected values, being effective and repeatable measurements of product samples easily obtained. Vice versa, similar measurement methods and repeatability do not fit to organizations offering intangible services, such as universities, public administrations or governmental bodies. In this instance, the energy manager encounters the main difficulty to obtain real-time, reliable and effective data regarding the actual energy performances of the organization he/she

* Corresponding author.
E-mail address: rvolpe@dii.unict.it (R. Volpe).

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Nomenclature

EMS	Energy Management System
EnPI	Energy Performance Index
EnB	Energy Baseline
PDCA	Plan – Do – Check – Act
DD	Degree Days
HDD	Heating Degree Days
CDD	Cooling Degree Days
h_d	Hours of darkness $[h]$
UCL	Upper Control Limit
LCL	Lower Control Limit
n	Statistical population
$\overline{X}$	Mean of the energy consumption measurements
σ	Standard deviation
CUSUM	Cumulative sum of differences
s_i	Cumulative deviation at step i
e_{meas}	EnPI obtained by measurement
e_{mod}	EnPI resulting from the model
R^2	Coefficient of correlation

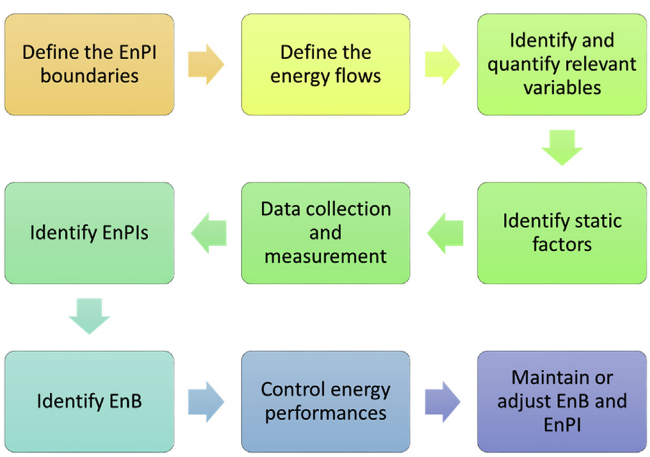


Fig. 1. The EMS procedure for buildings.

manages (O'Donnell et al., 2013). In addition, monitoring and control stages are often overlooked, being performances usually compared to sector-based benchmarks.

From this depicted background, it emerges the need to provide intangible service organizations with a tailored EMS. In particular, the definition of proper EnPIs is crucial to raise the energy manager awareness on the energy performance of the organization. As a further and most important issue, the EMS for these organizations needs to implement practical and standardized tools including real-time monitoring and control processes in order to determine the trend of the energy performances over time.

2. Literature review

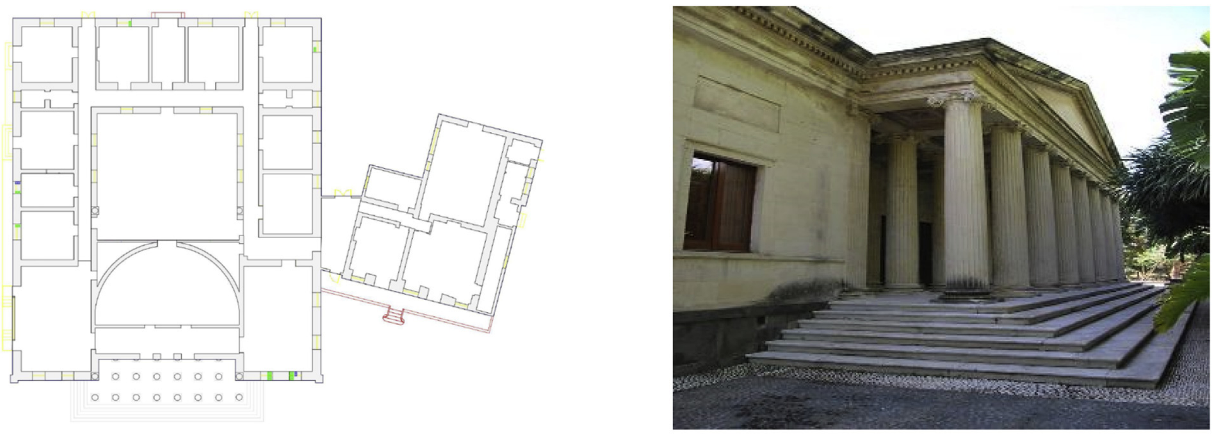
It is unquestionable that the release of the two International Standards ISO 50001 and ISO 50006 increased the awareness on the benefits that can arise from the application of a well-structured EMS within any organization. In this sense, it should be paid tribute to the Standards for having both established the concept of continuous improvement of energy performances and indicated the route to pursuit this goal. Through the implementation of the EMS, each organization clearly defines its energy policy as well as the energy objectives linked to this policy; the achievement of these objectives can be assessed by means of proper indicators, as said called energy performance indexes (EnPI).

The Standards' principles are deliberately general; it is the task of the energy manager to align these indications to the organization. In general, the energy manager is supported by personal experience as well as expertise deriving from the industry sector in which the organization operates (O'Donnell et al., 2013). However, besides the specific industrial knowledge, there is agreement within the scientific community on the need for defining standardized practises and EnPIs that can fit independently of the goods produced by the organization and facilitate the energy performances assessment process.

The Standards' principles can be more easily transferred to industrial companies or manufacturing plants, i.e. to those organizations, which output consists in a product or a good (Richert, 2017). Moreover, in these cases, the recognition of systems, processes and technologies (the cost centres) is immediate and intuitive. Thus, it should not be surprising that the majority of research papers focuses on industrial cases (Sola and Mota, 2019) and, specifically, is devoted to the definition of energy benchmarking methods to be included within the EMS (Swiatek and Imbault, 2017). For instance, Jemmad et al. (2019) suggest the use of an aggregated indicator for energy benchmarking when dealing with the need of measuring the performances of industrial and service sectors. Similarly, Siebert et al. (2014) define energy efficiency indicators tailored to the EMS of industrial organizations. Beyond the evaluation of proper benchmarks or indexes, Benedetti et al. (2017) develop an energy management scheme to support the decision-making process at any hierarchical level of an industrial company. To pursue this scope, the authors propose a performance control matrix and control charts, able to highlight deviations over time.

Despite more diffused, the implementation of the Standards' principles are crucial not only for organizations of industrial sectors, but also for those offering intangible services, such as governmental bodies (European Commission), universities and research centres (ISO 50001 and Sustainable Energy Planning, 2017) or even municipalities (Dzene et al.,

Fig. 2. Typical graphical output for a control chart.



(a) (b)

Fig. 3. Building A: (a) plant view; (b) image.

(a) (b)

Fig. 4. Building B: (a) first floor and (b) second floor.

2015). In these organizations, buildings rather than processes or technologies play a pivotal role for the improvement of the energy performances and can be reasonably identified as major cost centres. The identification of buildings as cost centres paved the way to a significant number of research papers linked to the assessment of energy performance indicators properly tailored for buildings. Among these, Castrillon-Mendoza et al. (Castrillòn Mendoza et al., 2019) apply the procedures of the ISO 50001 in order to evaluate the energy, economic and carbon savings obtained by substituting the traditional heating system fuelled with natural gas with district heating by biomass in an educational building in Spain. Keeping the attention to educational institutions, Ocampo Battle et al. (Ocampo Battle et al., 2019) apply the ISO 50001 in order to establish which variable may influence the electricity consumption of buildings in higher education campuses. Li et al. (2017) aim at detecting stakeholders and energy performance indexes for the EMS at both the district and building level. On the same topic, but investigating the impact of information and communication technologies (ICT) on the energy performances, Janez Moran et al. (Janez Moran et al., 2016) evaluate the energy savings that may derive from both private and public buildings. Differently from these listed papers mainly focusing on EnPI definition and benchmarking methods, Dermentzis et al. (2019) demonstrate the effectiveness of other management tools, and particularly audits, to assess the energy savings obtained by retrofitting buildings. Recently, Dall'O' et al. (Dall'O' et al., 2020) developed a methodology compliant with the ISO 50001 Standards to plan energy retrofit interventions aiming at reducing the heating load of a building stock.

Thus, from the literature reported so far, it emerges that the most investigated aspects concern the development of methods for the analysis and classification of the energy performances (usually by benchmarking) of industrial organizations. Nonetheless, significant contributions have been devoted also to the definition of EnPI for the measurement of the performances of those organizations operating in the tertiary sector or, generally, of public bodies and educational institutions. In these cases, it is common to focus the attention on the analysis of the energy performances of buildings through *ad hoc* defined indicators (Castrillòn Mendoza et al., 2019) and, generally, to evaluate any improvements after renovation or retrofitting actions (Dall'O' et al., 2020).

However, according to the principles of the EMS proposed by the Standards, cost centres should be analysed by not only measuring performances through EnPIs, but also guaranteeing control over time and defining corrections from unexpected deviations. In other words, the

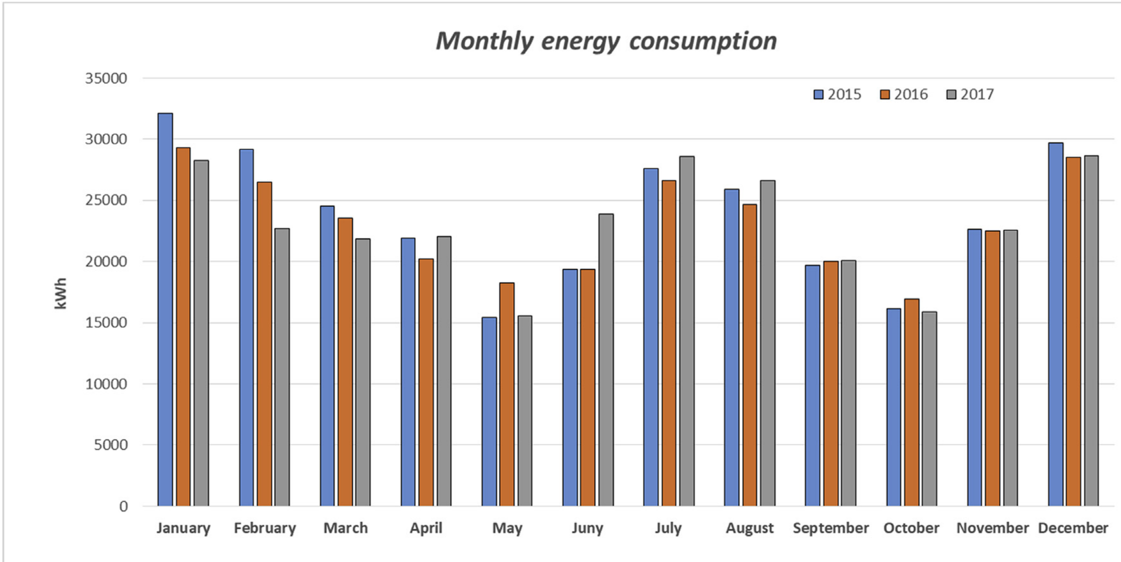


Fig. 5. Trends of the monthly energy consumption for the period 2015–2017 for *Building A*.

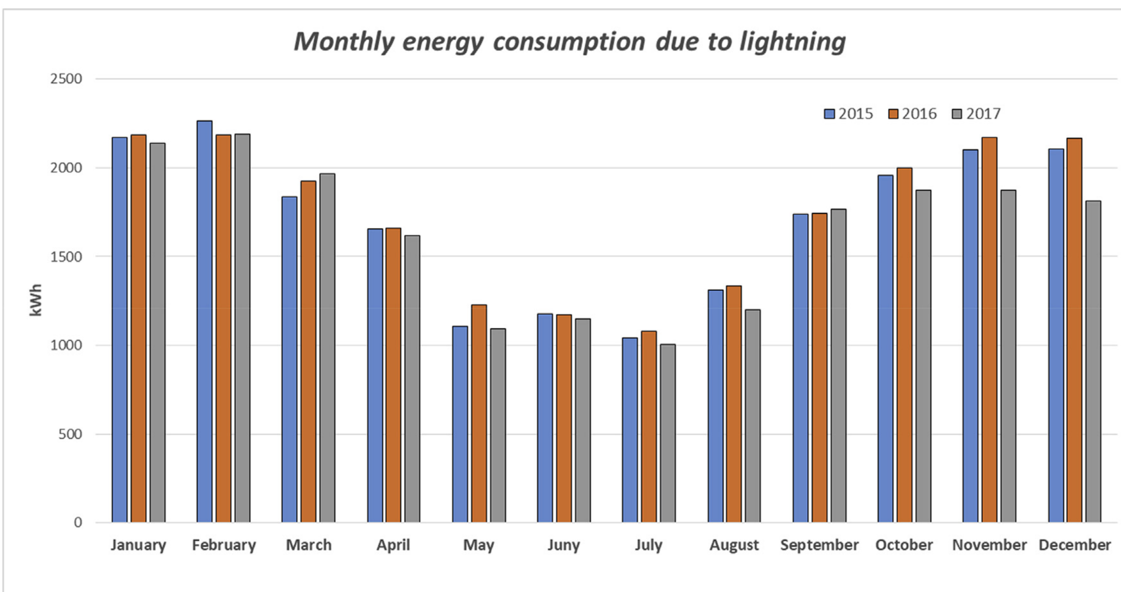


Fig. 6. Trends of the energy consumption for the period 2015–2017 due to lightning for *Building B*.

EMS has to cover the entire Deming Cycle of *"plan-do-check-act"*. According to this principle, buildings of service organizations make no exception and should be treated as cost centres as well. The need to include monitoring and control processes in the EMS even when buildings are identified as cost centres for the energy performance assessment is also stated by the current literature. In this direction, Borgstein et al. (2016) stress the importance of control management for buildings, Royapoor et al. (2018) study the current state-of-art of control systems implemented within buildings, starting from physical devices (sensors) to computational tools, and confirm the need to establish practical guidelines for building control management.

Thus, having demonstrated that energy performance measurement for buildings is a necessary but not sufficient condition to achieve a holistic evaluation of how organizations perform, this paper proposes a standardized approach including monitoring and control processes for buildings of organizations offering immaterial services (public bodies, educational institutions, municipalities and so on). The presented procedure applies the principles of both the ISO 50001 and the ISO 50006 systematically, by shaping each stage of the EMS for the analysis of the energy performances of buildings belonging to public or governmental organizations. In detail, a suitable EnPI is chosen and its suitability in describing energy performance in buildings is demonstrated. As a main and more remarkable contribution, this paper evidences the importance of putting into effect the monitoring and control processes of buildings' energy performance. In particular, the joint combination of control charts and CUSUM (Cumulative SUM of differences) is implemented to detect real-time deviations from expected values and to assess energy performance improvement over time.

3. Methodology

The control management contributes to targeting the objectives chosen by the organization for the enhancement of its energy performances and described within the energy policy. In particular, a control

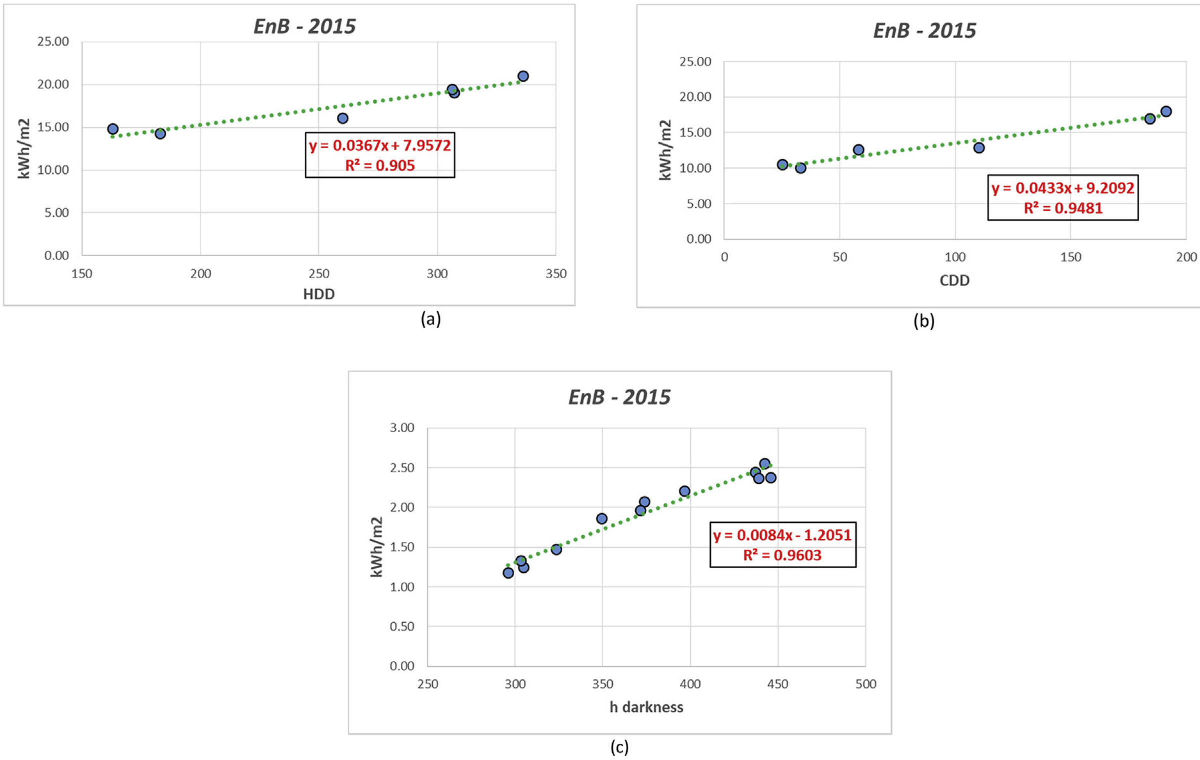


Fig. 7. Regression analysis for the EnB of building *A* choosing as relevant variables (a) HDD, (b) CDD and of building *B* choosing (c) h_d.

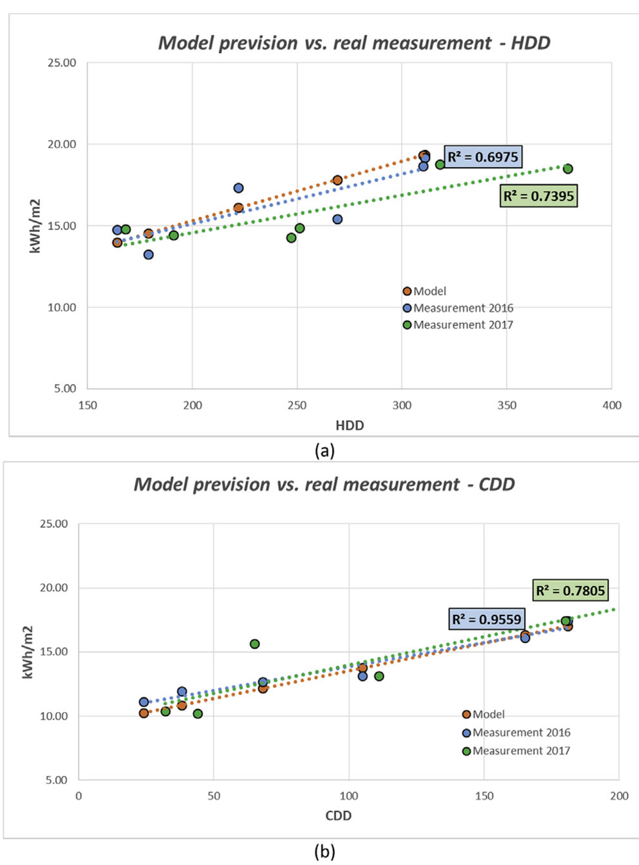


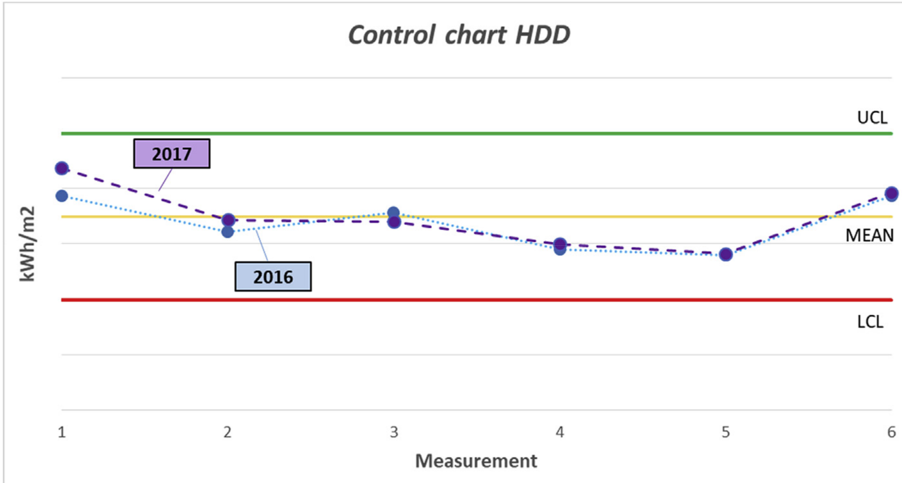
Fig. 8. Trends of the predicted and measured EnPI during the (a) heating period and (b) cooling period.

process consists of: *(i)* measuring the EnPI, *(ii)* comparing the measured value with the baseline and, eventually, *(iii)* suggesting corrections for the continuous improvement. The main steps of the EMS issued in this paper for buildings of public organizations are summarized in the flow-chart of Fig. 1 and are consistent with both the principles of the ISO 50001 (ISO International Standard Organization, 2018) and the guide-lines of the ISO 50006 (ISO International Standard Organization, 2014).

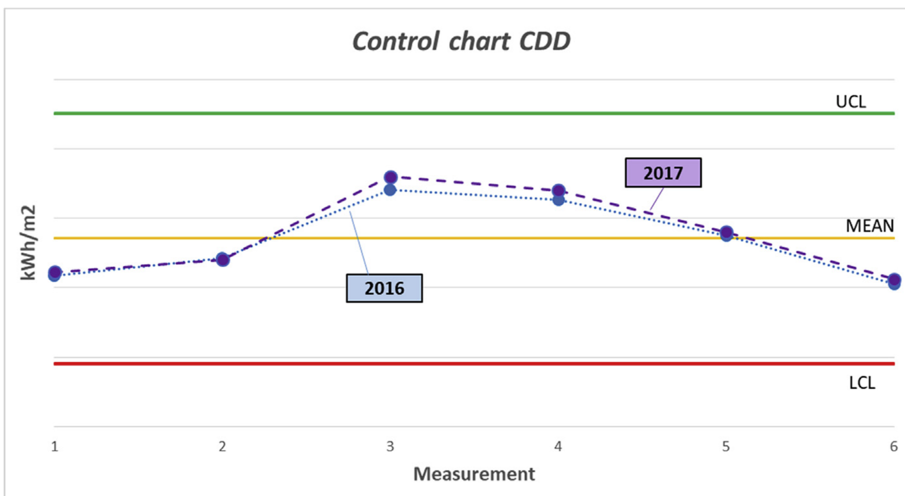
The first step consists in the definition of boundaries for the EnPI. Boundaries substantially determine the physical perimeter of the department, process or system that the organization aims to control. According to the Standards, when choosing the boundaries for each EnPI, the perimeter should be easily isolated. Moreover, particular care should be devoted during this stage, being fundamental to identify a boundary from not only the physical viewpoint, but also univocally identifying responsibilities and energy use. For the EMS here developed the boundary for the EnPI is the building in which an energy supervisor (coordinated by the energy manager of the organization) has been designed and in which the energy use has been clearly identified (illuminance, heating/cooling and similar). Subsequently to the boundaries definition, energy crossing the boundaries should be pointed out. With reference to this case study, electricity and natural gas flows are identified and dedicated sensoring points provide information on the amount of energy that flows across each boundaries, i.e. the energy consumed by each building (both electrical and thermal).

Having identified boundaries and flows, the subsequent step consists in quantifying which variables influence the energy consumptions of buildings. These variables should be able to highlight trends and deviations. To determine if the choice is consistent, the energy manager can plot the variable over time and see if it affects the trends of the energy consumption in a simple x-y diagram. Once the trends have been detected, it should be assessed if the correlation is significant; to this scope, linear regression can serve to the aid. Generally, the equation form resulting from this correlation process has the form:

$$y = mx + c \tag{3.1}$$



(a)



(b)

Fig. 9. Control charts for the EnPI measurements during the (a) heating period and (b) cooling period.

Table 1
CUSUM calculations for the energy performances of *Building A* during heating periods.

Month	HDD	Predicted	Measured	Difference	CUSUM
	[-]	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
JAN-15	336	21.03	21.03	0.00	0.00
FEB-15	307	19.10	19.10	0.00	0.00
MAR-15	260	16.07	16.07	0.00	0.00
APR-15	183	14.34	14.34	0.00	0.00
NOV-15	163	14.84	14.84	0.00	0.00
DEC-15	306	19.43	19.43	0.00	0.00
JAN-16	311	19.37	19.18	−0.19	−0.19
FEB-16	222	18.10	17.35	−0.75	−0.94
MAR-16	269	17.83	15.41	−2.42	−3.37
APR-16	179	14.53	13.24	−1.28	−4.65
NOV-16	164	13.98	14.75	0.78	−3.87
DEC-16	310	19.33	18.66	−0.67	−4.54
JAN-17	379	21.87	18.50	−3.36	−7.91
FEB-17	251	17.17	14.86	−2.30	−10.21
MAR-17	247	17.02	14.29	−2.73	−12.94
APR-17	191	14.97	14.44	−0.53	−13.47
NOV-17	168	15.12	14.78	−0.34	−13.82
DEC-17	318	19.63	18.76	−0.86	−14.68

Table 2
CUSUM calculations for the energy performances of *Building A* during cooling periods.

Month	CDD	Predicted	Measured	Difference	CUSUM
	[-]	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
MAY-15	33	10.10	10.10	0.00	0.00
JUN-15	58	12.66	12.66	0.00	0.00
JUL-15	191	18.07	18.07	0.00	0.00
AUG-15	184	16.96	16.96	0.00	0.00
SEP-15	110	12.90	12.90	0.00	0.00
OCT-15	25	10.58	10.58	0.00	0.00
MAY-16	38	10.85	11.96	1.11	1.11
JUN-16	68	12.15	12.68	0.53	1.64
JUL-16	181	17.05	17.45	0.40	2.04
AUG-16	165	16.05	16.13	0.08	2.11
SEP-16	105	12.76	13.13	0.37	2.49
OCT-16	24	10.25	11.11	0.86	3.35
MAY-17	44	11.11	12.19	1.08	4.43
JUN-17	65	12.02	15.65	3.63	8.05
JUL-17	203	18.00	18.73	0.74	8.79
AUG-17	180	17.00	17.43	0.43	9.22
SEP-17	111	14.02	13.14	−0.87	8.35
OCT-17	32	10.59	10.39	−0.20	8.14

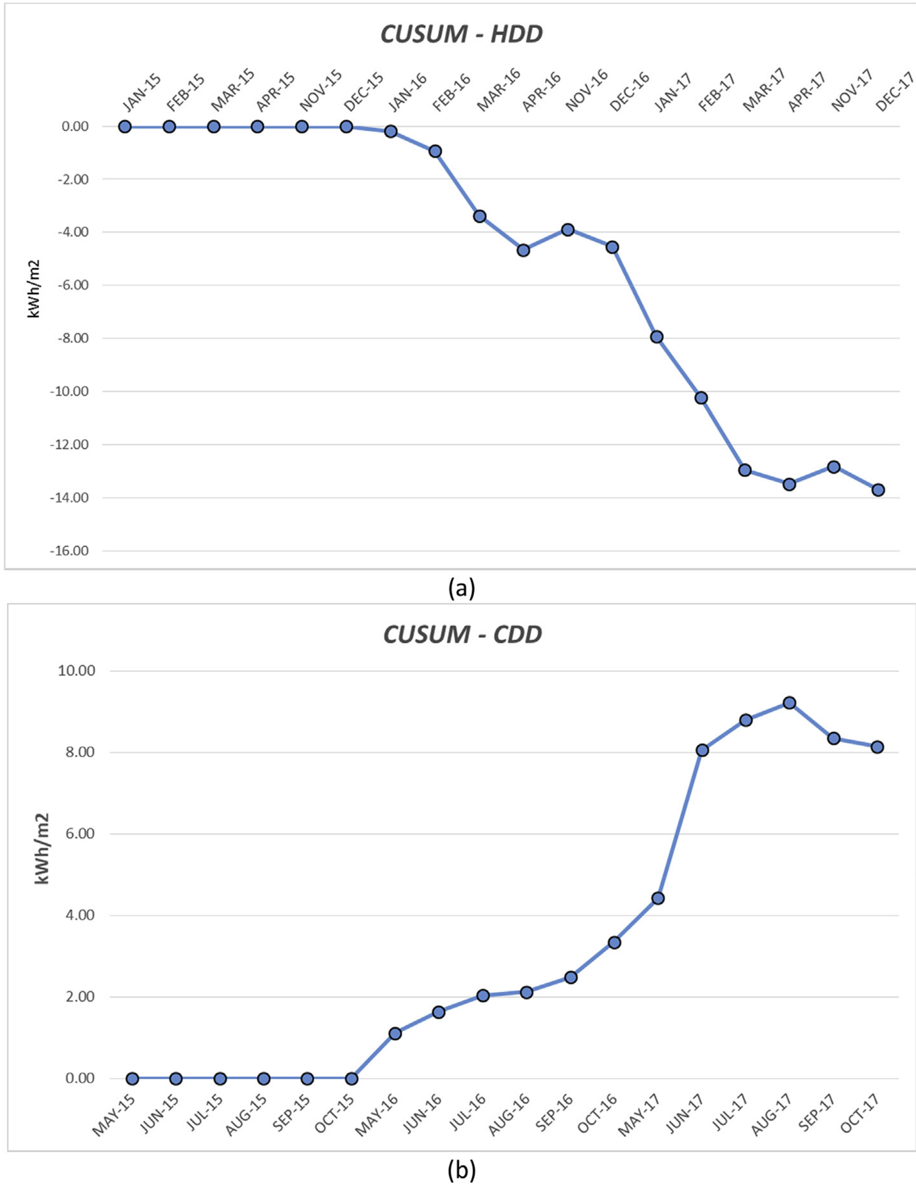


Fig. 10. CUSUM charts for the energy performances of *Building A* with reference to the (a) heating and (b) cooling period.

Being m the slope of the straight line and c the intercept for nil energy consumption. If significance is confirmed, the variable is relevant and can be used within the EMS. In this study, Heating Degree Days (HDD) and Cooling Degree Days (CDD) have been chosen as relevant variables. A Degree Day (DD) is calculated by comparing the outdoor temperature with a standard value associated to a specific location: the higher the DD, the colder (or warmer) the outdoor environment (ISPRA, 2017). More specifically, DDs are used as reference measure to establish how cold (HDD) or how warm (CDD) was the outdoor during a given period (ISPRA, 2017). Consequently, this variation is usually correlated to the energy consumption of buildings both in winter and summer seasons (Moazami et al., 2019; Moreci et al., 2016; De Rosa et al., 2014). In order to deal with reliable data on the energy consumption, the load has to be disaggregated in terms of heating and cooling loads (weather-dependent and, therefore, correlated to DD) and lighting (non-weather-dependent, i.e. not correlated to DDs), as recommended by Makhmalbaf et al. (2013). To ensure effectiveness of HDD and CDD as energy drivers for the energy consumption in buildings, the same weather climatic dataset is considered, as recommended by D'Amico et al. (D'Amico et al., 2019). Finally, with respect to the electricity consumption due to lightning, the number of hours of darkness h_d, i.e. the number of hours in which electrical appliances are turned on, is chosen as energy driver. The number of hours of darkness is calculated considering when the sun reaches the zenith distance of 96° and service lights in buildings of civilian use are turned on. The number of hours of darkness are calculated assuming that electrical appliances are turned on until 7 p.m.; after this time, motion sensors guarantee illuminance.

Static factors, instead, do not affect the trends of energy consumption and should be identified for two main reasons; on one side, to avoid overlapping misleading results also in relation to the choice of the relevant variables and, on the other side, to record any changes that could affect the trends of the energy consumption.

The data collection is a fundamental step for the EMS. In fact, the collected data should be accurate in the *(i)* measurement, *(ii)* frequency and *(iii)* quality. Measurements are typically obtained through sensors, which ensure repeatability and reliability, and measures should be collected with reference to the same period, i.e. daily or monthly. It is worth noting that the collection frequency can differ from the reporting frequency. Actually, collection can take place most commonly due to the need of detecting deviations, but reporting can be done with more

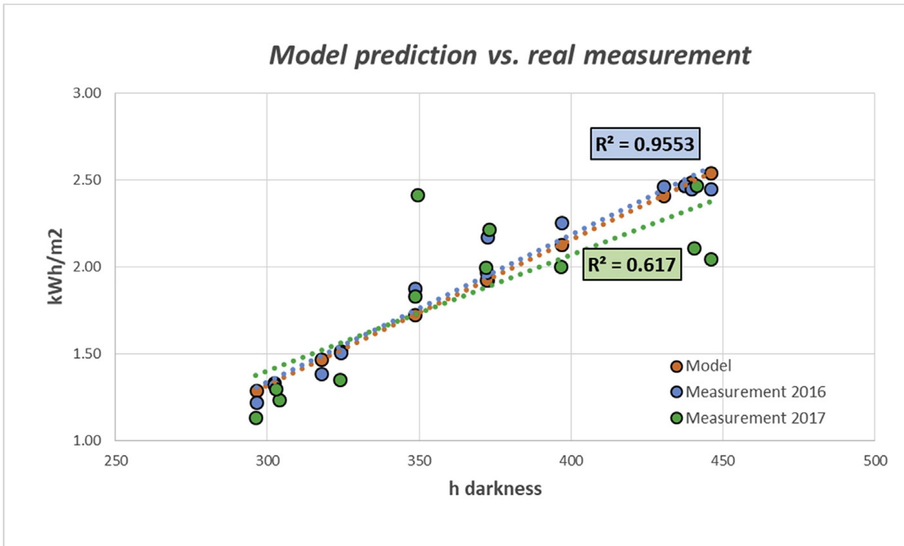


Fig. 11. Trends of the predicted and measured EnPI for the lightning load.

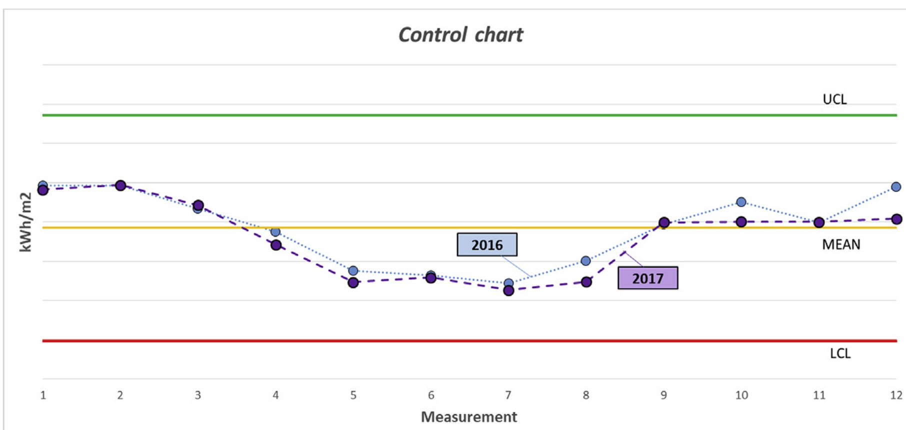


Fig. 12. Control charts for the EnPI measurements for the lightning load.

aggregated data (typically monthly) (ISO International Standard Organization, 2018). Quality should be ensured by properly checking faulty or atypical operating conditions due to the measurement devices. In this sense, the Standard suggests to maintain control of the outliers.

The operative framework defined up to this point serves as a basis for the identification of the energy performance indicators. The EnPIs are fundamental for organizations since they allow the detection of changes in the energy performance trends. Generally, they can expressed as a pure measured value or as a ratio between output and input (i.e. in terms of efficiency). Otherwise, they can be determined through statistical models or with reference to simulations. In this study, being sensors used to measure the energy consumed by buildings, the most appropriate EnPI results in the energy consumption expressed in kWh/m^2.

The baseline period is important to determine improvements towards the achievement of the energy objective of the organization. Typically, an EnB should be chosen in order to smooth variability and take into account seasonality; therefore, a baseline period of 12 months can fit for the scope. During this timeframe, the EnPI are recorded and tested for its validity in serving as comparison period.

To assess the trend of the energy performances, the EnPI should be quantified and compared to the baseline period. This could give an order of magnitude about the trends of the organizations in targeting the specific objective set by the energy policy. There are several methods to control the performances of the organizations. In this study, control charts and the CUSUM have been recalled from statistics and built for the EMS in buildings for public organizations. Control charts have been developed by Stewhart (1929) in 1930 and thenceforth have been largely applied. The main advantage consists in their ability to detect deviations from expected values. To build such control tools, it is fundamental to identify a reference period (which in this case corresponds to the baseline period chosen for the EnB), organize measures of energy consumptions and calculate mean and variance linked to these values. A typical control chart has the form reported in Fig. 2.

There are three main straight lines, in particular, the MEAN indicate the mean value of the energy consumption values over the period whilst the UCL and the LCL are, respectively, the upper control limit and the lower control limit. They are calculated as:

$$MEAN = \overline{X} \tag{3.2}$$

$$UCL = \overline{X} + 3\sigma^{1/2} = \overline{X} + 3\sqrt{\frac{\overline{X}(1-\overline{X})}{n}} \tag{3.3}$$

$$LCL = \overline{X} - 3\sigma^{\frac{1}{2}} = \overline{X} - 3\sqrt{\frac{\overline{X}(1-\overline{X})}{n}} \tag{3.4}$$

Table 3
CUSUM calculations for the energy performances of *Building B*.

Month	Predicted kWh/m^2	Measured kWh/m^2	Difference kWh/m^2	CUSUM kWh/m^2
JAN-15	2.45	2.45	0.00	0.00
FEB-15	2.56	2.56	0.00	0.00
MAR-15	2.07	2.07	0.00	0.00
APR-15	1.87	1.87	0.00	0.00
MAY-15	1.25	1.25	0.00	0.00
JUN-15	1.33	1.33	0.00	0.00
JUL-15	1.18	1.18	0.00	0.00
AUG-15	1.48	1.48	0.00	0.00
SEP-15	1.96	1.96	0.00	0.00
OCT-15	2.21	2.21	0.00	0.00
NOV-15	2.37	2.37	0.00	0.00
DEC-15	2.38	2.38	0.00	0.00
JAN-16	2.47	2.47	0.00	0.00
FEB-16	2.41	2.46	0.05	0.05
MAR-16	1.92	2.17	0.25	0.30
APR-16	1.72	1.87	0.15	0.45
MAY-16	1.46	1.38	−0.08	0.47
JUN-16	1.33	1.32	−0.01	0.46
JUL-16	1.28	1.22	−0.07	0.49
AUG-16	1.52	1.51	−0.01	0.48
SEP-16	1.92	1.96	0.04	0.52
OCT-16	2.13	2.25	0.12	0.65
NOV-16	2.49	2.45	−0.04	0.61
DEC-16	2.54	2.45	−0.09	0.75
JAN-17	1.73	2.41	0.68	1.43
FEB-17	2.50	2.47	−0.03	1.40
MAR-17	1.93	2.22	0.29	1.69
APR-17	1.72	1.83	0.10	1.79
MAY-17	1.35	1.23	−0.11	1.68
JUN-17	1.34	1.29	−0.04	1.64
JUL-17	1.28	1.13	−0.15	1.55
AUG-17	1.51	1.35	−0.16	1.45
SEP-17	1.92	2.00	0.08	1.44
OCT-17	2.13	2.12	−0.01	1.43
NOV-17	2.49	2.11	−0.38	1.05
DEC-17	2.54	2.04	−0.50	0.55

In Eqs. (3.2), (3.3) and (3.4), the term $\overline{X}$ represents the mean of the energy consumption measurements related to the baseline period, n is the statistical population and $\sigma^{1/2}$ is the standard deviation, typically multiplied by a factor of 3. Once the structure of the control chart has been so defined, the recorded values of the energy consumption of the building are plotted within the chart to detect deviations. The process is out of control if these typical conditions occur:

- outliers, i.e. events outside the control limits;
- increasing or decreasing trends;
- majority of events located above or below the mean, even if positioned within the limits.

Although the validity of control charts in detecting outliers, they are not able to establish whether there is improvement or worsening of the energy performances of buildings over time. In addition to this, eventual shifts are not correlated to previous observations. To overcome these limitations, it is convenient to use CUSUM charts alongside control charts. The term CUSUM is an acronym, which stands for "cumulative sum of differences". This definition is helpful to explain the main purpose of this statistical tool, i.e. the analysis of eventual discrepancies existing between expected values (deriving from the EnB) and actual values of the EnPI and recorded over time. Thus, this feature makes the CUSUM charts more responsive even in detecting small deviations, being they constructed cumulating past observations. The CUSUM reports the trend of the cumulative sums calculated as:

$$s_j = s_i + e_{meas} - e_{mod}, \quad i < j \tag{3.5}$$

The terms s_j and s_i represent the cumulative deviations calculated at each step, and e_{meas} and e_{mod} the measured EnPI and the EnPI calculated through the model, respectively. The CUSUM evidences whether there are improvement of the energy performances of the building over time or not. In particular, moving from the baseline, each point of the CUSUM is calculated as the difference between the predicted measure and the real measurement of the EnPI. The value of each difference can be randomly positive or negative; however, above all, by cumulating these differences it is possible to interpret any changes in the slope of the CUSUM as an improvement (decreasing trend) or a worsening (increasing trend) of the energy performances of the building.

4. The case study

The methodology introduced in the previous Section has been applied to the University of Catania, in Italy. The University has 75 buildings with different destinations and uses, such as classrooms, offices, libraries, computer rooms or archives. To assess energy performances as well as to evaluate any improvements, the key steps of the methodology, graphically summarized in Fig. 1, have to be followed.

As a first and crucial step, it is fundamental to identify the boundaries of the EnPI. As widely discussed, buildings have been identified as the most appropriate choice for those organizations offering immaterial services, as indeed the University of Catania. Among the different buildings, the proposed EMS scheme has been validated with respect to two different buildings. The first building, called *Building A*, has different rooms used as offices, reading rooms, help desk rooms and classrooms with a net area of 1595.23 m^2 on a single floor. The plant and an image of the building are reported in Fig. 3. The second building, called *Building B* has a net area of 886.57 m^2 distributed in two floors and is reported in Fig. 4.

With respect to the energy flows definition, the energy performance assessment process for *Building A* takes into account the heating and cooling loads whilst for *Building B* the lightning consumption are examined. It is worth noting that the sole source of energy for both buildings is electricity. The trend of the monthly energy consumptions of *Building A* for the period 2015–2017 is illustrated in Fig. 5. The graph reports heating and cooling loads as well as lightning (as a reminder, in order to pursuit a well-structured energy performance assessment process, loads have been made available in a disaggregated form).

For *Building B*, the trends of the electricity consumption for the period 2015–2017 are shown in Fig. 6. As can be seen, the lightning consumptions are more significant from October to March and decreases during the spring and summer months because of the latitude and longitude of the city of Catania.

Having identified boundaries and energy flows, the subsequent step consists in the identification and quantification of relevant variable. As motivated in the previous Section, the relevant variables chosen in this study are HDD and CDD when heating and cooling loads are taken into account (being these loads strictly weather-dependent) and the hours of darkness in the case of lightning (being it weather-independent). For the quantification of HDD and CDD, the Italian Decree n. 412/1993 serves as reference (D.P.R, 1993). According to this regulation, Catania belongs to the climatic zone B and space heating in this zone is allowed during 8 h per day from 1 December to 31 March. The hours of darkness instead are calculated considering the hours in which the sun reaches the zenith distance of 96° during each day of the specific year under analysis.

Data collection and measurement campaign refer to the period 2015–2017. During these three years, measurements occurred monthly for each building owned by the University. As what the identification of EnPIs concerns, it has already been discussed how kWh/m^2 and hours of darkness h_d can be selected respectively for heating and cooling energy and for lightning performance evaluation.

To this point, following the steps of the EMS proposed in Fig. 1, the identification of a proper EnB should be pursued. Energy baseline determination is fundamental for two main reasons: *(i)* to effectively

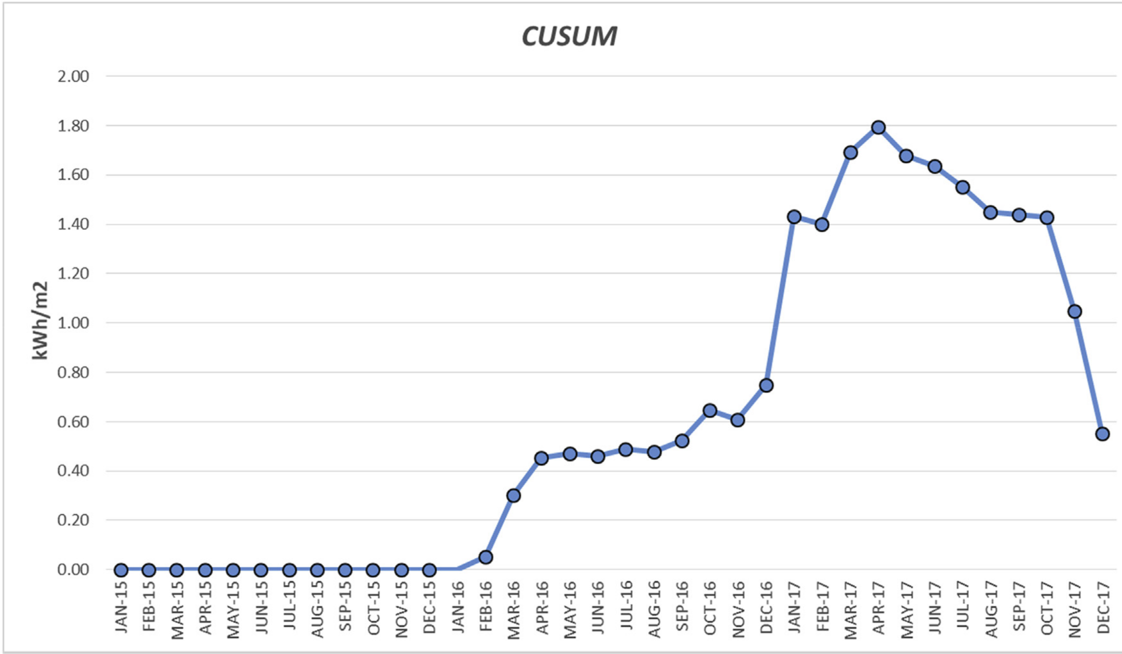


Fig. 13. CUSUM charts for the energy performances of *Building B*.

determine to what extent the chosen relevant variables fit to describing variations in the EnPI trends and *(ii)* to constitute a dataset to which future EnPI measurements should be compared. To target these issues, a regression analysis is pursued to correlate HDD and CDD to the energy consumptions due to heating and cooling of *Building A* having chosen the year 2015 as baseline period. The results are plotted in Fig. 7, distinguishing between HDD and CDD.

A general measure expressing how well the data fit the regression line is the coefficient of determination R^2. This coefficient is expressed as a percentage from 0% to 100%; generally, the higher R^2 the better the model fits the data. The ISO 50006 recommends values of R^2 higher than 0.75 in order to effectively confirm the significance of the relationship between the chosen relevant variables and the EnPI (Li et al., 2017). As emerge from the regression analysis of Fig. 7(a and b) and, in both cases the coefficients of determination is largely above this threshold value, being they $R^2 = 0.905$ for HDD and $R^2 = 0.9481$ for CDD. Therefore, the corresponding functional relationships between the EnPI and both the HDD and the CDD can be derived as:

$$y = 0.0367x + 7.9572, \quad \text{for } x = HDD \tag{4.1}$$

$$y = 0.0433x + 9.2092, \quad \text{for } x = CDD \tag{4.2}$$

Thus, Eqs. (4.1) and (4.2) represent the prediction model for the energy performance assessment process. The same procedure is then carried on for the EnB determination in the case of *Building B*, as reported in Fig. 7(c). In this case, the regression analysis reveals that the relevant variable h_d significantly explains the variations in the trends of the EnPI, with $R^2 = 0.9603$. The associated model equation is:

$$y = 0.0084x - 1.2051, \quad \text{for } x = h_d \tag{4.3}$$

From the analysis of Fig. 7, it is quite noticeable how an increase of HDDs or CDDs yields a correspondent increase of the energy

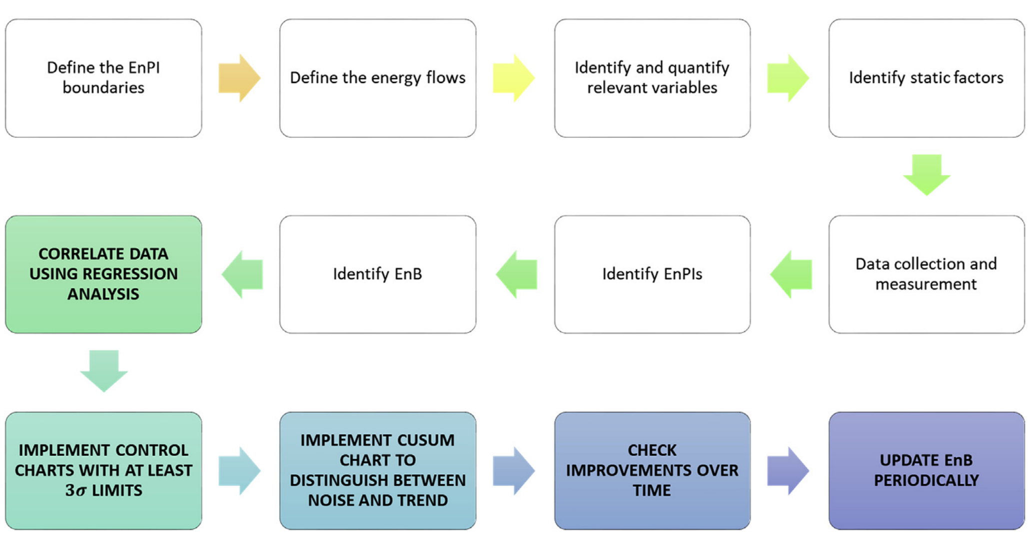


Fig. 14. The EMS tailored to public organizations implementing control practises.

consumption of the building. However, the physical meaning of the derived correlations, especially from the building analysis perspective, deserves some discussion. As can be noticed, in fact, the mathematical correlations of Fig. 7(a and b) are nearly comparable, showing similar values of both the slope *m* and the intercept *c*. In particular, the slope measures the incremental increase nof the eergy consumption per m^2 at increasing the relevant variable, whilst the intercept indicates the base load. From an operation and management viewpoint, the similarity can be explained by the fact that the energy source for heating and cooling is the same, i.e. electricity. Analogous considerations apply to the correlation developed in Fig. 7(c) between the electricity consumption per m^2 and the hours of darkness. In this sense, any operation and management action needs to focus towards a decrease the slope of the correlation lines in Fig. 7, in order to obtain a decrease the energy consumption against the increase of the correspondent relevant variables.

5. Results and discussion

5.1. Control management of Building A

The control management step consists in the real-time monitoring of the energy performances of each building. Firstly, *Building A* and the two different examined loads, i.e. heating and cooling, are discussed. The trends of the energy performances related to the heating and cooling periods are reported in Fig. 8(a) and Fig. 8(b), respectively. The graphs plot the EnPI at varying the relevant variables HDD and CDD; the three regression lines refer to the model prediction and to the real data measurements for 2016 and 2017.

Starting from the discussion of the results attained for the EnPI during the heating period in Fig. 8(a), there is a moderately good agreement between the predicted and the measured values; in particular, the coefficient of correlation for the measured data is $R^2 = 0.6975$ for 2016 (note that it is $R^2 = 1$ for the model) and $R^2 = 0.7395$ for 2017. It has to be pointed out, however, that the maximum delta between predicted and measured values of the dataset is around the 19%. A further information that can be drawn from these trends is related to the energy efficiency. As known, the regression line has the typical structure of $y = mx + c$, where x correspond to the relevant variable (HDD, CDD or h_d) and y to the EnPI, m is the slope of the regression line and c a constant. From the mathematical definition, the slope corresponds to the variation of the output (the EnPI) at varying the input (the relevant variable), as expressed in Eq. (5.1):

$$m = \frac{dy}{dx} \tag{5.1}$$

Thus, changes in the slope of the regression line can be useful to evaluate any improvements or worsening in the energy efficiency. Particularly, an increase of the slope indicates a worsening of the performances and, vice versa, the decrease is representative of any improvements. Therefore, the decrease in the slope of the regression line for actual measures indicates an overall improvement of the energy performances. This is useful also to explain the moderately changes in the predictability of the model. Similar comments arise for the trends of the EnPI during the cooling periods in 2016 and 2017. Therefore, as a general consideration, the coefficients of determination R^2 show a good significance of the model in fitting the measured data, being they very close or above the target value of 0.75. In particular, for the cooling periods, the performances exhibit $R^2 = 0.9559$ in 2016 and $R^2 = 0.7805$ in 2017, and slopes of the regression lines are less evident.

The information gained up to this point can help the energy manager to get a general impression about the energy performances of the building under control. However, at this stage, the manager is not aware if any of the measured value of the EnPI is in line with the configured EnB. Gaining this understanding is, however, crucial to detect deviations from the expected values and, therefore, to establish in-time correction actions. To this scope, control charts are developed and used. As explained in Section 3, a control chart is structured by defining upper and lower control limits (UCL and LCL) and a mean line (MEAN), calculated with reference to the chosen baseline. Three main occurrences determine that the process is out of control, i.e. the presence of outliers (measures positioned outside the limits), increasing or decreasing trends and incidence of the majority of measures above or below the mean (although inside the CLs). Under these premises and as can be observed from Fig. 9, the process is completely in control, for both heating and cooling periods and both 2016 and 2017. It has to be pointed out that the similarity in the trends of 2016 and 2017 in both charts refers to the fact that measurements have been collected during the same period for both examined years. Therefore, for a fixed measurement corresponds a similar placement of the related observation within the control chart.

Finally, the CUSUM chart has been built in order to evaluate the energy performances with respect to both heating and cooling periods in 2016 and 2017. As previously highlighted, the CUSUM is able to detect small deviations from the expected values and to distinguish from “noise”, i.e. errors and residuals deriving from an unexplained variability within the dataset of energy consumption measure. Moreover, the CUSUM permit to draw conclusions about the improvement or not of the energy performances within the considered period. To construct the chart, the calculations of Table 1 and Table 2 are reported below for the control of the energy performances of *Building A* during the heating and cooling periods, respectively. The first column of both Tables reports the period to which energy consumptions refer and the second column the chosen relevant variables (HDD or CDD). The third and the fourth columns contain the predicted and measured values of the energy consumption. As a remark, predicted and measured values are identical in 2015, having this year been chosen as baseline within the EMS. The difference between measured and predicted values is reported in the penultimate column. Finally, in the last columns the CUSUM calculated as in Eq. (3.5) is reported and the graphical outputs are illustrated in Fig. 10 for heating and cooling periods, respectively.

As can be seen from the CUSUM reported in Fig. 10(a), there is a significant decrease in the slope of the curve, corresponding to an improvement of the energy performances. In particular, the first shift can be detected in February 2016 and up to April 2016. From November 2016 to April 2017 the energy performances improve again, supposedly thanks to the implementation of operational and management actions or for maintenance actions on electrical equipment or, even, for a more competitive contract conditions with the market operator. Obviously, the energy manager is aware on the adopted actions and can take note on the effective impact that any of the implemented action has on the energy performances of the building under management and control.

During the cooling periods, the energy performances significantly get worse, with an initial improvement only in August 2017. At this point, it is interesting to note how the control charts presented in Fig. 9 and the CUSUM of Fig. 10(b) presents two apparently opposite results. Precisely, if on one side, the control charts during the cooling periods in both 2016 and 2017 state that energy performances are in control with no particular anomalies to be identified, on the contrary, the CUSUM reveals a general worsening of the energy performances in the same periods. Actually, this confirm the importance of combining the information from the CUSUM charts to those deriving from the control charts. Indeed, the mere analysis of the control charts is not sufficient to draw conclusions on how the building under investigation performs. In fact, control charts and CUSUM increase the understanding of the energy manager from two different but both fundamental viewpoints: the control charts in detecting anomalies or failures and immediately identifying potential deviations, the CUSUM to assess improvements (or worsening) over time and, therefore, to distinguish between effective improvement and “noise”.

5.2. Control management of building B

The procedure for the monitoring of the energy performances of

Building B follows the same steps already discussed for *Building A* but considering the sole lightning load also in light of demonstrating the importance of identifying the correct relevant variable when aiming at measuring and monitoring different energy consumption types. As a reminder, the regression analysis conducted in Section 4 revealed that the hours of darkness h_d can be chosen as relevant variable, being they able to significantly explain the variability in the energy consumption due to lightning. Having stressed this correlation, the model prediction obtained through the functional relationship in Eq. (4.3) is compared to the trends of the energy performances for 2016 and 2017 in Fig. 11.

As can be observed, the model is able to predict the measured data related to 2016 with a high level of accuracy, being the regression line for the measured dataset almost coincident with the model prediction and displaying the measured data a coefficient of correlation equal to $R^2 = 0.9553$. In 2017, the model is still able to describe the measured data but there is a certain unexplained variability within the sample, as also demonstrated by the decrease of the value of the coefficient of correlation. Concerning the issue of the energy efficiency evaluation, no significant information can be extrapolated, being the slopes of both curves for predicted and measured data almost overlapping. The control charts reported in Fig. 12 increase the awareness with respect to the variability detected in 2017. In fact, in both cases, even if all measurements are inside the control limits, a suspected trend can be detected from measurement 9 to measurement 12. Indeed, four consecutive measurements are aligned slightly above the mean, a trend that may be representative of a process out of control. Despite owning evidences on a process out of control, the energy manager needs to gain a more detailed understanding with respect to the period in which deviations have been recorded and, generally, to what extent these shifts from the expected trend effectively impacts on the continuous improvement of the energy performances. Thus, as also above stressed, the need to integrate the analysis conducted so far with the CUSUM is all the more evident.

Table 3 reports the preliminary data and calculations necessary to build the CUSUM, then graphically reported in Fig. 13. As a brief reminder, Table 3 contains the month of measurement in the first column and the predicted and measured values of the EnPI respectively in the second and third columns. Then the difference between the measured and predicted values can be find in the fourth column, from which the CUSUM can be derived, as reported in the last two columns.

The analysis of the trend of the CUSUM for *Building B* permits to assess that performances are completely worsening with respect to the initial baseline period (2015). In fact, as can be seen, there is a constant increase of the energy consumptions due to lightning. This increase, moreover, becomes more significant from January 2017 to April 2017, where malfunctioning or dispersion can be supposed. During this period, the building consumes in an inefficient way. In the subsequent periods, the performances start to improve probably due to maintenance interventions: the first dated in March 2017 and the second (and more relevant) dated in September 2017, which confirms the implementation of correction actions, also due to the high slope of the curve.

A relevant consideration needs to be made from the examination of the CUSUM trend. In fact, a first and indicative worsening of the energy performances can be detected in February 2016, i.e. almost in correspondence to the end of the baseline period. With this premise, the causes of the shift from the expected values can be two: either a malfunctioning or an inefficacious baseline. In the first case, the energy manager should conduct an internal investigation to detect the malfunctioning, whilst in the second case he/she should proceed with an adjustment process for the EnB. Some would question if the cause of this deviation could instead be associated to an incorrect choice of the relevant variable. However, an evidence that the hours of darkness are able to explain the variability within the sample is given also for the trends of 2016, with a coefficient of correlation equal to $R^2 = 0.9553$. In addition, the decrease of the value of R^2 in 2017 is evidently due to an external cause as confirmed by the control chart in Fig. 12.

5.3. Benefits and drawbacks of the proposed methodology

As said, production volumes strictly affect the energy consumptions of any organization and relationships between input (energy) and output (product) are of extreme importance for any energy manager who aims at targeting energy performances improvements over time (ISO International Standard Organization, 2018).

This paper can be considered as innovative with respect to the current state-of-art in the field of energy management, offering a reliable methodology framed within the Standards and specifically tailored to public entities. Being the implementation of Standards in public organizations a multifaceted problem, this work aims at responding to questions such as "which output (service) should be related to the input (energy consumption) avoiding biased results?"; "how to correlate measured data for public organizations?"; "which strategies should be carried on to improve energy performances?". If on one side this could already be considered significant, the most recognizable contribution of this paper can be detected in the practical application of control practises devoted to the energy performances evaluation over time. In fact, as common in literature when dealing with public organizations, methods mainly focus on forecasting energy savings for new energy systems (Ocampo Battle et al., 2019) or on *a priori* analyses to establish the convenience of retrofitting existing buildings (Dzene et al., 2015; Dall'O' et al., 2020) or, again, on developing energy-aware indicators (Benedetti et al., 2017). In this paper, instead, tailored control and monitoring steps are implemented to offer a systemic procedure for the application of best practises devoted to the continuous improvement, thus avoiding a limited system- or facility-based perspective.

As a further consideration, an integration in the energy management system procedure presented in Fig. 1 and referring to the recommendation of the Standards (ISO International Standard Organization, 2018; ISO International Standard Organization, 2014), can be suggested. In fact, the procedure could be more easily adopted by public organization if specifying the following steps presented in Fig. 14:

Despite highly recommended, the proposed methodology can be effectively and successfully implemented within public organizations if:

- An EMS is supposed to be already in force within the organization;
- The energy manager has been formed to deal with the correct interpretation of control charts (which means owning a high confidence in the statistics principles governing these tools);
- Data are available and updated within a congruent period chosen by the manager and coherently with the utilization purpose (weekly for specific electric equipment consumption or monthly for general trends).

6. Conclusions

In this paper, a common framework has been developed for the assessment of an Energy Management System (EMS) tailored to immaterial services organizations in which buildings are identified as cost centres. The proposed EMS is grounded on the ISO 50001 principles and follows the practical guidelines of the ISO 50006. In particular, beyond the definition of a proper EnPI able to describe the energy performances of buildings, this paper contributes to the application of control charts and CUSUM charts for the detection of shifts from expected values and for the evaluation of the effective trend of the energy performances over time.

The University of Catania has been selected as a case study and, in particular, two buildings have been involved to serve as an illustrative application to demonstrate the general validity of the proposed methodology. For the first building, labelled *Building A*, consumptions due to heating and cooling needs have been considered; for the second building, named *Building B*, the sole lightning load has been studied. The application of the entire control management stages to the two buildings has revealed how the energy manager cannot plan to make decisions with the sole information gained by the comparison of the measured EnPI with a general sector-based benchmark. On the contrary, to build a suitable EMS, EnPI should be compared to proper calculated baselines that refer to the same building, thus effectively making any comparison reasonable. In addition, the monitoring and control of the performances has been proven to be a fundamental step to gain awareness on how the organization performs. In particular, control charts are more indicated to detect real-time shifts from expected values, although being not able to evaluate trends of performances over time. CUSUM, on the other hand, gives insights on the effective improvement of the performances, confirming the need to include monitoring and control in any buildings of public organizations.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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