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Developing an aggregate metric to measure and benchmarking energy performance

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ABSTRACT

As key elements of energy planning, ISO 50001 recommended inter alia identifying appropriate indicators to monitor and measure energy performance. Benchmarking can be a helpful tool to establish energy efficiency or performance indicators. While we agree that is hard to get an absolutely universal indicator aggregating several physical indicators defined in differing units; it is however possible to expand the area of cases covered or improve its characteristics such as accuracy, representativeness and simplicity. In this paper, we developed an aggregated dimensionless "Indicator for Energy Benchmarking" (IEB) to enhance the range of models of indicators dedicated to the engineering field. The systems targeted are low and middle level systems of the energy indicators pyramid. We built the proposed indicator based on specific characteristics: process decomposition-oriented, increasing when energy consumption decreases, dimensionless, with limited threshold value to 1. Consequently, the indicator provides many advantages in comparison to simple metrics and complex indicators such as: direct detection of energy use failure processes, creating interdependence between benchmarked systems scores, no need for data history to start benchmarking of a multisystem. IEB can be implemented as an integral part of many energy management or energy efficiency standards, methodologies or tools such as EN 16231:2012 and ISO 50001:2018. In last section, we calculate the indicator for 2 central sterile service departments of 2 university hospitals in Morocco to show its potential and operating mode.

Keywords:

Energy performance;
Energy efficiency;
Benchmarking;
Indicator;
Central Sterile Service Department

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1. Introduction

Over the last decades, energy sustainability was on the public agenda as a main pillar of sustainable development. In response, researches has been allocated over different subjects like environment, policy, energy supply, energy use, energy security, energy transitions, etc. [1, 2, 3, 4]. In particular, energy planning and management was recognized as a central element for achieving solutions to energy sustainability by contributing to more efficient use of available energy sources, improving competitiveness and reduction of greenhouse gas emissions and other related environmental impacts [1, 5, 6].

As key elements of energy planning, ISO 50001, recommends inter alia identifying appropriate energy performance indicators to monitor and measure energy performance.[6] For that purpose, Energy efficiency benchmarking is listed as an instrument in the energy management systems standard ISO 50001. Energy efficiency benchmarking can assist the planning of energy targets and the review of energy efficiency progress. [7]

External benchmarking may be used to establish a range of energy performance indicators for an installation/facility or a specific product/service in the same field or sector. [8]

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Although many relevant indicators were developed and used in their dedicated field. We estimate that there is still a need for development of new energy performance indicators due to many restrictions found in existing metrics as detailed in discussion section. To overcome these restrictions, we suggest to construct an indicator based on following conception elements:

a) Process oriented decomposition of the system
b) Aggregation of physical indicators with different units.
c) Creation of interdependence between scores of benchmarked systems.
d) The use of a dimensionless number.
e) The higher threshold value of the indicator is limited to 1.
f) The indicator must increases when energy consumption decreases

In this study, we propose an aggregated dimensionless "Indicator for Energy Benchmarking" (IEB) to enhance the range of models of indicators dedicated to the engineering field. IEB is a process-oriented energy performance indicator to be used as a tool for assessing and benchmarking energy performance of low and middle level systems -according to energy indicators pyramid-.

Aware of existing differences and difficulty in defining some energy use related concepts such as efficiency, conservation, savings and performance. [9, 10, 11] We deal with energy performance indicators issues without discussing differences between these concepts. Fortunately but strangely enough according to IEA, there are fewer problems in defining the concept of energy efficiency indicators. [10]

2. Literature review

In this study the term "energy performance indicator" means the same as "Energy performance indicator" (EnPI) or (EPI), "Energy Efficiency Indicator (or Index)" (EEI), "Energy Use Indicator" (EUI), "Energy Intensity Index" (EII), "Measuring Energy Efficiency Performance" (MEEP) or others -used in literature as equivalent too. [12, 13, 14, 6, 10, 15, 16]

2.1. Energy performance indicators

Basically, energy performance indicators are metrics intended mainly to assess how well the energy is used to provide the output. It consists of a ratio between energy used for an output and the output itself [12]. Metrics can be indicators (figures that indicate something) or index (several indicators combined into one) [17]. However, the two terms are widely used interchangeably in literature.

Indicators can fall into four groups: Thermodynamic, Physical-thermodynamic, Economic-thermodynamic, and Economic [15, 18, 19, 20, 21]. Although economic indicators are useful at an aggregate level (i.e. the energy efficiency of the entire economy or the industrial sector as a whole), at a disaggregated level physical indicators give more insight into actual differences in energy efficiency levels. [18]

Thermodynamic indicators are more suitable to power plants and technical equipment such as rotating machines, boilers, etc. They are expressed as a ratio of 2 energy units such as kWh or joules representing the consumption versus the output as a heat content or work potential. By using conversion rates, these metrics values can be expressed in percentage as for electrical efficiency. [22, 23]. But still, Patterson mentions that consumers, of course, do not value the end use service on the basis of its heat content or work potential. Therefore, physical-thermodynamic indicators have the added advantage that they directly reflect what consumers are actually requiring in terms of an end use service [18]. In that sense, they are more useful compared to thermodynamic indicators in engineering applications in industry, tertiary and residential sectors.

Typically, indicators can be either: output divided by energy consumption called "energy productivity" – traditionally presented as "energy efficiency" [14, 24] – or energy consumption divided by output called "energy intensity" [19, 24, 25]. The *Specific Energy Consumption (SEC)* is a basic indicator which is a common indicator of energy intensity at the process level. [26]. It is sometimes also called the Unit Energy Consumption (UEC) or Physical Energy Intensity (PEI) [13]. The specific energy consumption (SEC) is a mixed physical–thermodynamic intensity indicator. [26]

The denominator value (output) can be determined in terms of dominant parameter or unit of activity. [10] The dominant parameters can be of different types:

– Dimensional parameters (area, volume). In commercial buildings, surface (in m^2) is commonly used where energy use is primarily tied to plug loads, lighting and HVAC systems. [27]

- Not properly technical (number of personnel, clients, rooms, beds, etc.). [28]
- Properly technical: for instance, in industry the physical production corresponds to a dominant output of the branch and is usually measured in ton (e.g. crude steel, cement, clinker). [20]
- Combination of many types: The output can also be expressed by a multi-parameters function: e.g. Bakar et al. proposes a new energy index where the output is expressed as: Area (m^2) x number of occupants (person) in $kWh/m^2/$ person. [29]

Consequently, metrics that don't relate useful output to energy consumed are out of the scope. For instance, The *Power Usage Effectiveness* PUE developed by the non-profit organization of IT professionals "Green Grid" is widely used by the IT industry as an energy efficiency indicator for data centers [30, 31, 32]. Defined by PUE= Total Facility Power/IT Equipment Power, it is clear -as confirmed by its developer and other experts - that PUE is an infrastructure energy efficiency not a data center productivity metric and therefore does not provide guidance about energy use by IT equipment. [30, 31, 32]

2.2. Benchmarking Energy performance

Many definitions are available. The definition of EN 16231:2012 standard is a good one: Benchmarking is the process of collecting, analyzing and relating performance data of comparable activities with the purpose of evaluating and comparing performance between or within entities. [8]

Energy benchmarking is useful for understanding energy use patterns, identifying inefficiencies in energy use, estimating potential for energy conservation, and designing policies to improve the energy economy. [33]

Different types of benchmarking exist:

Internal: compares performance against internal baseline or benchmark.

External: compares performance against a metric "outside" of the organization identifies "Best in Class" performance.

Quantitative: data-driven; compares actual numbers.

Qualitative: based on best practices; compares actions. [34]

Energy performance benchmarking is processed at many levels of aggregation, generally known as the energy performance indicators pyramid. An example of bottom-up classification is: equipment/device, facility/ factory, sector, national economy. Energy performance indicators used for benchmarking at the down levels of the pyramid are more representative and gives more insight about energy use. However the quantity of data required at this level can be limiting. [14, 15, 19, 35]

2.3. Benchmarking Energy performance indicators - state of art:

Data analysis is a substantial step of the energy benchmarking methodology which consist of: assess current performance levels, produce tables, charts and graphs. [8] Metrics are a main tool used in practice to perform this task. Approaches distinguished can be classified into 2 categories:

1st category: Comparison of actual Specific energy consumption SECact with a reference Specific energy consumption SEC_{ref}. These energy intensity/SEC-based models are often used due to their simplicity and acceptable accuracy. [36] Many types can be used to determine a reference Specific energy consumption SECref depending on the aim of analysis:

- Average. [13, 37]
- Best plant based on an extensive survey of literature and exchange of information within the network during those years. Especially countries that are generally considered to be among the most efficient. [38]
- Best practice observed. the complete production plant with the lowest specific energy consumption that already is in full operation;
- Best practical means. the production plant with the lowest specific energy consumption that can be realized using proven technology at reasonable costs;
- Best available technology: the production plant with the lowest specific energy consumption that can be realized using proven technology [13]

2nd category: Calculate a benchmarking Energy performance indicator or Index. Generally, a dimensionless index or indicator is constructed by aggregating system decomposition based on metrics cited in 1st category. Many approaches are proposed in literature especially for industrial sector. We note following methods:

BEST: Benchmarking and Energy Savings Tool is developed by Worrell & Price and Lawrence Berkeley

National Laboratory (LBNL) based on decomposition of the entity to processes. [33, 36] The aggregated EEI "energy efficiency index" is calculated as follows:

$$EEI = 100 * \frac{\sum_{i=1}^{n} P_i \cdot EI_i}{\sum_{i=1}^{n} P_i \cdot EI_i, B} = 100 * \frac{E_{tot}}{\sum_{i=1}^{n} P_i \cdot EI_{i,} B}$$

Where:

EEI = energy efficiency index

n= number of process steps to be aggregated

EI_i= actual energy intensity (EI) of process step *i*

$EI_{i,B}$= benchmark energy intensity (EI) of process step *i*

P*i*= production quantity for process step *i*

E_{tot}= total actual energy consumption for all process steps

The Energy Efficiency Index (EEI): developed by Phylipsen et al. (2002) for the Netherlands.

$$EEI_a = 100 \frac{SEC_a}{SEC_{ref,a}} = 100 \frac{\sum_i E_i \Big/ \sum_i m_i}{\left(\sum_i m_i SEC_{ref,i}\right) \Big/ \sum_i m_i} = \frac{E_a}{\sum_i m_i SEC_{ref,i}}$$

In which EEI_a is the energy efficiency index for sector a, SEC_a the specific energy consumption for sector a, $SEC_{ref;a}$ the reference specific energy consumption for sector a,

E_i the energy consumption for product *i*;

m_i the production quantity of product *i*;

SEC_i the specific energy consumption of product *i*;

$SEC_{ref;i}$ a reference specific energy consumption of product *i*;

E_a the energy consumption in sector a, and *i* the products 1–*n* made in sector a. [38]

The Energy efficiency indicator (EEI): developed by Neelis et al. (2007a)

$$EEI_{j,k} = \frac{E_{\text{actual}j,k}}{E_{\text{reference}j,k}}$$

in which *k* is the year of analysis with 0 denoting the base year 1995, *j* the type of energy demand (electricity, fuels/ heat, non-energy use), $EEI_{j,k}$ the energy efficiency indicator for type of energy demand *j* in year *k*, $E_{\text{actual,j,k}}$ the actual energy use from energy statistics for type of energy demand *j* in year *k* and $E_{\text{reference,j,k}}$ the reference energy use for type of energy demand *j* in year *k*.

The reference energy use represents the amount of energy an industrial sector would have used if no improvements in energy efficiency had taken place with respect to a certain base year (in this case 1995). The reference energy use is therefore also referred to as 'frozen-efficiency' energy use. The reference energy is based on the physical production of products of an industrial sector and the specific energy consumption for these products in the base year 1995:

$$E_{\text{reference}\,j,k} = \frac{\sum_i SEC_{i,j,0}\, P_{i,k}}{\sum_i SEC_{i,j,0}\, P_{i,k}} E_{\text{actual}\,j,0}$$

in which $SEC_{i,j,0}$ is the specific energy demand for energy demand type *j* to produce product *i* in the base year (e.g. in GJ per tonne of product) and $P_{i,k}$ the physical production of product *i* in year *k*. [39]

ENERGY STAR score

The U.S. Environmental Protection Agency (EPA) supported the development of ENERGY STAR Energy Performance Indicators program (ES-EPI) for benchmarking energy performance of industrial facilities and ENERGY STAR Commercial Buildings Program for commercial buildings. Energy performance Indicators EPI score ranges from 1 to 100. According to Boyd et al.: The EPI is a statistical benchmarking tool that provides a "birds-eye" view of sector specific plant-level energy use via a functional relationship between the level of energy use and the level and type of various production activities, material input's quality, and external factors, e.g. climate and material quality. The EPI uses stochastic frontier regression to estimate the lowest observed plant energy use, given these factors. [40]

The physical production indicator: developed by Farla and Blok (2000) especially for the country-level analysis:

$$\text{Physical production indicator}_{(country)} = \sum_{i=1}^{m} \left(PPI_i \times \frac{E_{i,0}}{PPI_{i,0}} \right)$$

where $E_{i,0}$ is the energy consumption of (sub-)sector *i* and subscript 0 refers to the base-year of the analysis. PPI_i is the physical production index of sector *I* expressed by:

$$PPI_i = \sum_{x=1}^{n} \left(P_x \times w_x \right)$$

$PPI_{i,0}$ refers to the base-year of the analysis

P_x=the physical production of product x; w_x= the weight of product x in the index.

The aggregate SEC of each product (in a specific base-year) $SEC_{agg,i,0}=E_{i,0}/PPI_{i,0}$ is chosen as the weight w_x in the physical production index. Comparable results will be obtained if a best-practice SEC for a specific product would be considered as the weighting factor. Unlike the SEC of a specific product, the aggregate SEC will not have a meaning in itself, but will serve only to indicate the relative development of (physical) energy intensity in time. [26]

3. Methodology - aggregated dimensionless indicator for energy benchmarking

In this section, we will present a developed Energy performance indicator as a contribution to enhancing the range of models of indicators available especially in the engineering field.

3.1. Construction basis

The indicator proposed is intended for use especially in the engineering fields at the bottom and middle level of the energy performance indicator pyramid. That is to say, at the level of: company, factory/facility, and equipment/appliance. The systems targeted are mainly those powered by electrical energy. However it could be exploited for others energy sources.

3.2. Basic metric selection

The relation between energy and output is generally represented by 2 basic forms:

S/E "energy productivity" and E/S "specific energy consumption". And as reported by Chang and Hu 2010, each represents identical measures from different perspectives, and they are used interchangeably in traditional literature. [24]

We need to check that the increase in energy performance is equivalent to the decrease in consumption $\Delta E<0$.

1st *case:* $\frac{E}{S}$ $\quad E_2 < E_1 \Rightarrow \frac{E_2}{S_1} < \frac{E_2}{S_1}$; indicator decreases

2nd *case:* $\frac{S}{E}$ $\quad E_2 < E_1 \Rightarrow \frac{S_1}{E_2} < \frac{S_1}{E_2}$; indicator increases

So, we choose to use S/E ''energy productivity'' as the basic form to construct the indicator.

Pérez-Lombard et al. (2012) consider that initial value judgments for the definition and qualification of service output become essential as a first step in the energy efficiency Indicators construction process. [11] However, definition of process/output intrinsic characteristics is out of the scope of this study. While some metrics are well known some are hidden/complex. In this study, we are not concerned by the determination of a specific metric for each process. Our work consists of how to use metrics to build an aggregated dimensionless indicator for benchmarking and assessment of energy use/performance. It is supposed in next sections that the output/process values to be used in equations are already clearly defined within the professional community related to systems in study.

3.3. Process indicator

In the methodologies based on energy intensity -applicable to energy productivity too-, determining the benchmarks consists primarily of establishing the benchmark intensities for each of the sub-processes. [28]

Then, as recommended by ISO 50001, indicators should be compared to a reference. [6] So we divide $\frac{S}{E}$ by a reference $\left(\frac{S}{E}\right)_{ref}$, which by the way ensure a dimensionless value.

So we get process indicator (PI) in the form:

$$PI = \frac{\frac{S}{E}}{\left(\frac{S}{E}\right)_{ref}} \quad (1)$$

Until then, the use of $\left(\frac{S}{E}\right)_{ref}$ as a reference ratio is the common method as detailed in section 3. Now, we suggest another procedure:

Decompose $\left(\frac{S}{E}\right)_{ref}$ into 2 reference values S_{ref} and E_{ref}. That is to say

$$\left(\frac{S}{E}\right)_{ref} = \frac{S_{ref}}{E_{ref}} \quad (2)$$

It follows $PI = \frac{\frac{S}{E}}{\frac{S_{ref}}{E_{ref}}}$ (3); or in another way $PI = \frac{S}{S_{ref}} \times \frac{E_{ref}}{E}$ (4)

Let consider a set of m comparable systems; each system composed of n processs of different or identical units as presented in Table 1. The process j belonging to system i is represented by the pair (S_{ij}, E_{ij}).

Let $E_{min,j}$ be the minimum value of the energy consumptions of all processes j in the set.

$$E_{min,j} = \min \ \{E_{1j}, E_{2j}, ..., E_{nj}\} = \min_i E_{ij} \quad (5)$$

Table 1: Example of decomposition of *m* systems to n processes of different units per system

	Process 1	…	Process *j*	…	Process *n*
	(kg, kWh)		(m3, kWh)		(nbr of pieces, kWh)
System 1	(S_{11}, E_{11})	…	(S_{1j}, E_{1j})	…	(S_{1n}, E_{1n})
□	⋮	⋮	⋮	⋮	⋮
System *i*	(S_{i1}, E_{i1})	…	(S_{ij}, E_{ij})	…	(S_{in}, E_{in})
□	⋮	⋮	⋮	⋮	⋮
System *m*	(S_{m1}, E_{m1})	…	(S_{mj}, E_{mj})	…	(S_{mn}, E_{mn})

We note $E_{min,j,0}$ the first recorded value of $E_{min,j}$.

And $S_{max,j}$ is the maximum value of the outputs of all processes j in the set.

$$S_{max,j}=\max\{S_{1j}, S_{2j}, \ldots, S_{nj}\} = \max_i S_{ij} \quad (6)$$

$$\text{Then, we set} \begin{cases} E_{ref,j} = \alpha E_{min,j,0} \\ S_{ref,j} = S_{max,j} \end{cases} (7); \text{ where } 0 < \alpha \le 1$$

α is defined according to the analyst estimation in order to keep $E_{ref,j}$ invariant for many years of benchmarking. E.g. if $E_{min,j}$ can fulfill this condition, then α=1 and $E_{ref,j}= E_{min,j,0}$.

From (4) and (7), we define the j process indicator of a system i $(PI)_{ij}$ as:

$$(PI)_{ij} = \frac{S_{ij}}{S_{ref}} \times \frac{E_{ref}}{E_{ij}} = \frac{S_{ij}}{S_{max,j}} \times \frac{\alpha E_{min,j,0}}{E_{ij}} \quad (8)$$

By definition, $(PI)_{ij}$ is dimensionless.

We have $\forall i, j \;\; S_{ij} \le S_{max,j}$ and $\alpha E_{min,j} \le E_{min,j} \le E_{ij}$,

$$\text{then} \begin{cases} \dfrac{\alpha E_{min,j,0}}{E_{ij}} \le 1 \\ \dfrac{S_{ij}}{S_{max,j}} \le 1 \end{cases} \quad (9)$$

From (8) and (9); we $(PI)_{ij} \le 1$ deduce that (10)

When using $\left(\frac{S}{E}\right)_{ref} = \frac{S_{max,j}}{\alpha E_{min,j,0}}$, each time numerator or denominator changes, all the systems will have their scores changing. Which keep the users in a continued quest of energy performance improvement.

The ratio $\frac{S_{max,j}}{\alpha E_{min,j,0}}$ is different from other references examples such as $\left(\frac{S}{E}\right)_{max}$ as it presents additional advantages:

- It raises the bar higher: i.e. it is hard -however not impossible- to get $\left(\frac{S}{E}\right)_{ref} = \frac{S_{max,j}}{\alpha E_{min,j,0}}$.
- Creates interdependence between systems scores. If one system make a positif step in one of the two drivers (E, S), the score of the others will get lowered if they don't follow. This characteristic can help induce diligence and assiduity even among the best of class.

3.4. Aggregating processes indicators

One of the major problems in creating indicators is the aggregation of different output units. S_{ij} can be mass, volume, bulk, km, etc. The construction of a dimensionless process indicator in section 3.3 simplifies now the aggregation.

The proposed aggregation of processes indicators to system-level indicator is a weighted arithmetic mean WAM. Since energy saving is the ultimate goal behind the use of energy performance indicators; the weight chosen is energy consumption. In other words, the indicator must expose the effect of big energy consumers performance on the system energy saving. The aggregated *dimensionless indicator for energy benchmarking* (IEB) of a system i is represented by Eq. (11):

$$(IEB)_i = \frac{\sum_{j=1}^{n} E_{ij} \times (PI)_{ij}}{\sum_{j=1}^{n} E_{ij}} = \frac{\sum_{j=1}^{n} E_{ij} \times \frac{S_{ij}}{S_{max,j}} \times \frac{\alpha E_{min,j,0}}{E_{ij}}}{\sum_{j=1}^{n} E_{ij}} \quad (11)$$

Eq. (11) can be simplified to $(IEB)_i = \frac{\sum_{j=1}^{n} \alpha E_{min,j,0} \times \frac{S_{ij}}{S_{max,j}}}{\sum_{j=1}^{n} E_{ij}}$ 12; however it is more insightful and instructive to calculate process indicatorsn $(PI)_{ij}$

first. This step can help direct effort towards energy performance failure zones in the system. Figure 1 summarizes the key steps followed in this paper to develop the IEB indicator.

In next sections, both formulas will be used.

3.5. Verification of: $(IEB)_i \leq 1$

According to (10),

$$(PI)_{ij} \leq 1, \text{ so } E_{ij} \times (PI)_{ij} \leq E_{ij}. \text{Then } \sum_{j=1}^{n} E_{ij} \times (PI)_{ij} \leq \sum_{j=1}^{n} E_{ij}$$

Thus $\frac{\sum_{j=1}^{n} E_{ij} (PI)_{ij}}{\sum_{j=1}^{n} E_{ij}} \leq 1$ which means $(PI)_{ij} \leq 1$.

3.6. Verification of monotonicity: indicator increases when consumption decreases

If we note $E_i = \sum_{j=1}^{n} E_{ij}$ (13) we can write

$$(IEB)_i = \frac{1}{E_i} \sum_{j=1}^{n} \alpha E_{min,j,0} \times \frac{S_{ij}}{S_{max,j}} \quad (14)$$

We assume that when a system energy consumption decreases $dE_i \leq 0$; the process output is either fixed or increased $dS_{ij} \geq 0$.

α, $E_{min,j,0}$ are fixed by definition. E_i is decreasing, so $\frac{1}{E_i}$ is increasing.

S_{ij} is increasing. If $S_{ij} < S_{max,j}$ then $S_{max,j}$ is fixed. And according to E_i, $(IEB)_i$ is increasing.

If $S_{ij} \geq S_{max,j}$, then by definition $S_{ij} = S_{max,j}$ which means $\frac{S_{ij}}{S_{max,j}} = 1$. Consequently $(IEB)_i$ is increasing.

In sum, within the context of energy efficiency $\begin{cases} dE_i \leq 0 \\ dS_{ij} \geq 0 \end{cases}; (IEB)_i$; is increasing while the energy consumption E_i is reduced and the output is fixed or increased.

3.7. Exceptional cases:

Output reduction $dS_{ij} < 0$

Practically, there is no need for benchmarking when the energy saving is due to output reduction. This kind of actions can go so far as to eliminate the output and the comparison loses its significance. However, it is worth to mention that small variations of output that do not affect energy consumption $\frac{dE_{ij}}{dS_{ij}} = 0$; can be supported as

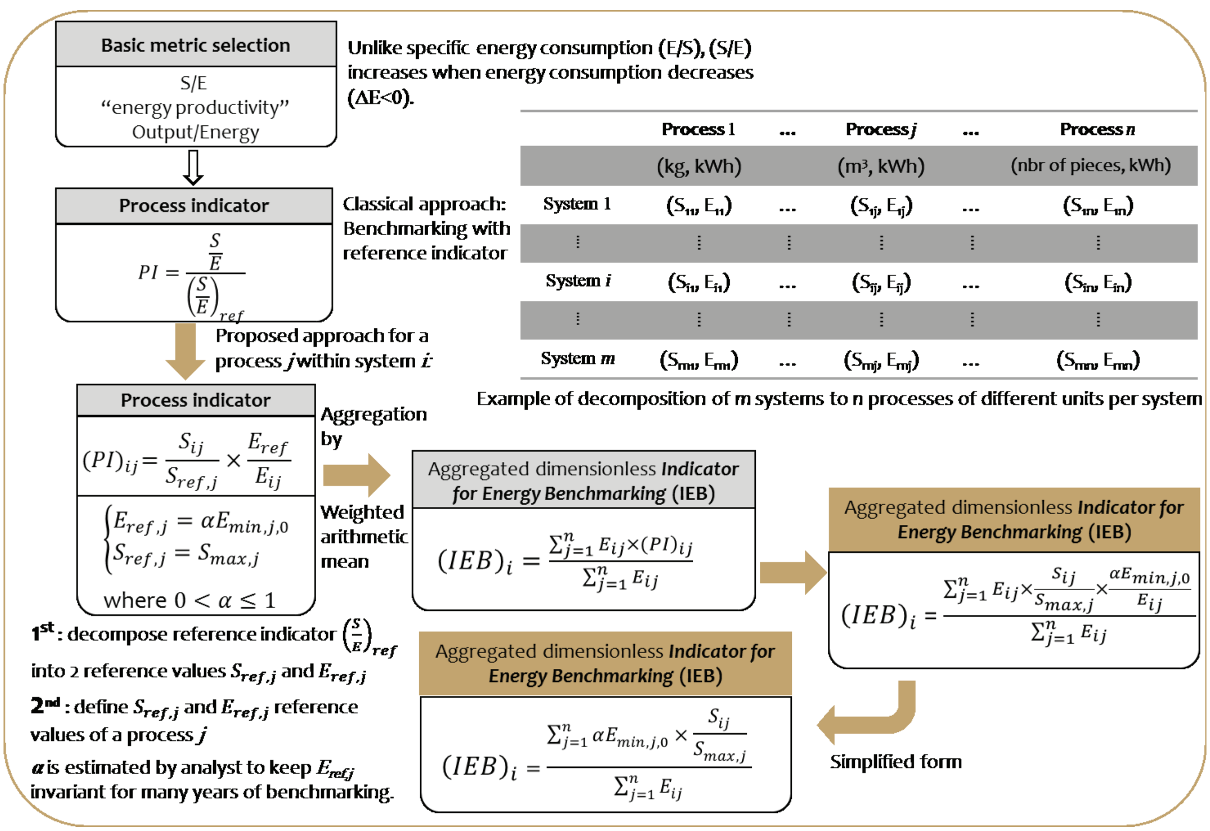

Figure 1: Flowchart of key steps followed to develop the IEB indicator

they do not perturb the indicator. Particularly in this case, the indicator will be decreased according to monotonicity analysis as performed in section 3.6. This result is perfectly in concordance with our logic: reducing output with no benefit to energy consumption is a worthless action that need to be penalized by indicator score reduction.

In case of considerable output variation $\frac{dE_{ij}}{dS_{ij}} < 0$; two situations can be distinguished:

First: for a given process k if the corresponding energy consumption is negligible $E_{ik} \ll \min_{j\neq k} E_{ij}$

Faced with this situation, the indicator of the system i concerned can be calculated without counting this process:

$$(IEB)_i = \frac{1}{E_i}\sum_{\substack{j=1\\ j\neq k}}^{n} \alpha E_{min,j,0} \times \frac{S_{ij}}{S_{max,j}} \tag{15}$$

Second: if the E_{ik} is non-negligible, the indicator should be frozen to last score before the output reduction. To allow its reintegration in the multisystem, the process new output level must be within the actual range of output of benchmarked processes: $S_{ik} \geq S_{min,j}$ (16).

Another criterion of reintegration may be discussed: the process new output level is back to last value before output reduction. This criterion is not considered because there may be some considerable variations in output values of the multisystems. This can be due to drop in customer demand, technological development, health and environmental obligations, etc. That is why, it is more relevant to use compare frozen process to multisystem actual output levels.

Inequality of number of processes between systems:
The process-oriented decomposition can involve some differences between benchmarked systems in the number of processes used to produce the output.

If a process k is not existing in a system i, and the corresponding energy consumption is negligible $E_{ik} \ll \min_{j\neq k} E_{ij}$; the $(IEB)_i$ will be computed without counting this process. Eq. (15) will be used then for this system only. Conversely, if a process k is existing only in a system m, and the corresponding energy consumption is negligible $E_{mk} \ll \min_{j\neq k} E_{mj}$; the $(IEB)_m$ will be computed using Eq. (11) or Eq. (12).

3.8. Selection process of indicators according to output variation

The indicator selection process after output variation is described in Figure 2.

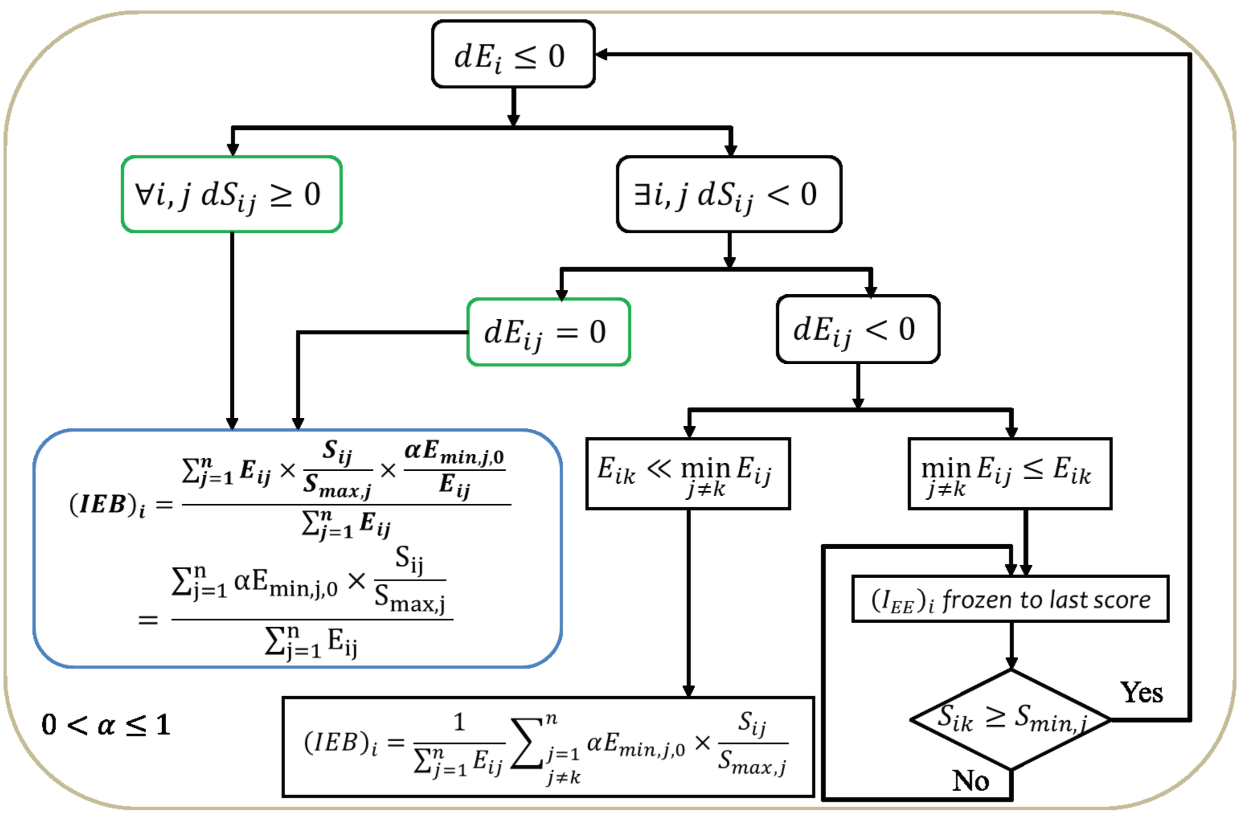

Figure 2: Flow chart of the aggregated dimensionless Indicator for Energy Benchmarking selection after output variation

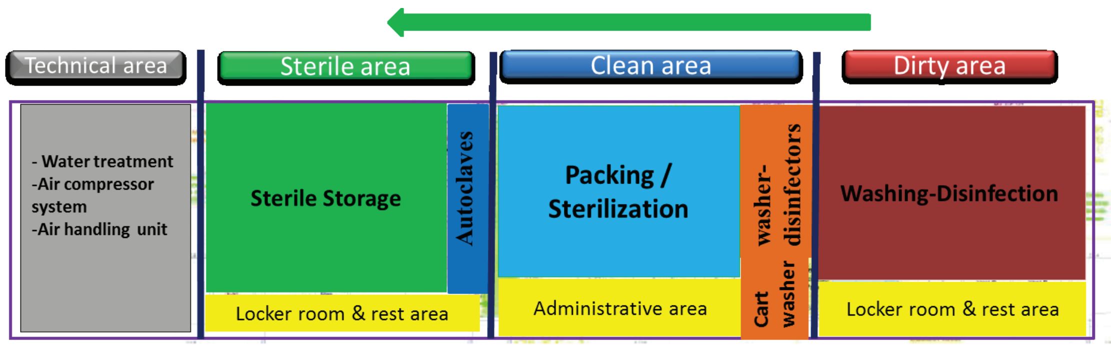

Figure 3: Flow of medical instruments inside a CSSD

Figure 4: Main Equipment in a CSSD

Figure 5: Typical technical installations in a CSSD

4. Case study: benchmarking 2 central sterile service departments

In this section, we apply the proposed indicator on 2 central sterile service departments CSSD of 2 university hospitals in Morocco to show its potential and operating mode.

The two CSSDs benchmarked serve respectively "Arrazi hospital" (586 beds) - university hospital of Marrakech city and Mohammed VI university hospital (673 beds) of Oujda city; both in Morocco.

4.1. System presentation

"The fundamental role of the sterile supply department SSD is to receive, clean, decontaminate, package, sterilize and distribute medical devices." [41]

"When these activities are centralized in one service within the hospital, it is called central sterilization service department or central sterile supply department (CSSD). "When the surgery is finished, all materials will be brought to the contaminated storage of the operating theatre, from where they are taken to the goods receipt of the CSSD. There they are dismounted, disinfected, perhaps precleaned, and subsequently put into the washing machines. After washing, the materials are regrouped to form nets. The nets are put into the autoclaves where the sterilization takes place." [42] Figure 3 represents the architecture of a typical CSSD including technical area. The figure shows the flow of medical instruments to be sterilized. An example of typical equipment and installation used in the CSSD are presented in Figure 4 and Figure 5.

4.2. IEB calculation

Each CSSD is decomposed to four main processes: a- Washing-disinfection, b- Packing/Sterilization, c- Sterile storage, d- Technical process. Table 2 details main equipment used in each process to provide sterile medical instruments. The IEB is computed on a 24-hour basis. Table 3 presents results of indicators calculation by equation 11 based on collected data from survey on site.

4.3. Case study discussion

First, we outline that we are more interested in showing the operatory mode of the indicator than benchmarking the two presented systems.

Table 2: Main equipment used by processes in CSSD

Process	Washing-disinfection	Packing/ Sterilization	Sterile storage	Technical process
Main equipment	Washer-disinfector, PC, lighting, Ultrasonic washing machine, Cart washer*	Steam autoclave, sealing machine, PC , lighting	Lighting, PC*	Water softening Reverse osmosis Air-Compressor Air handling unit Lighting
Output unit	Washer-disinfector Cart **	Autoclave cart	Volume of storage racks	Autoclave cart***

*Only in Oujda-city university hospital

**The Washer-disinfector cart is different in size from autoclave cart.

***The technical process provides different outputs (water, air, etc.) and therefore its related metric will be more complex than other processes. To ease the analysis, we prefer to use the number of sterilized carts as the final useful output; since these equipment serve mainly sterilization and disinfection processes.

Table 3. Indicators calculation for CSSDs benchmarking - Marrakech and Oujda university hospitals

	Washing-disinfection		**Packing/Sterilization**		**Sterile storage**		**Technical service**	
	S (cart)	E (kWh)	S (cart)	E (kWh)	m^3	E (kWh)	S (Cart)	E (kWh)
Marrakech	3	156.02	9	283.96	4.2	74.52	9	128.40
Oujda	6	159.64	6	245.12	4.73	33.7	6	267.17
$S_{max,j}$, $E_{min,j,0}$ (α=1)	6	156.02	9	245.12	4.73	33.70	9	128.40
	$S_{ij}/S_{max,j}$							
Marrakech	0.50		1.00		0.89		1.00	
Oujda	1.00		0.67		1.00		0.67	
	$\alpha E_{min,j,0} \times S_{ij}/S_{max,j}$							
Marrakech	78.01		245.12		29.92		128.40	
Oujda	156.02		163.41		33.70		85.60	
	$(PI)_{ij} = (\alpha E_{min,j,0} / E_{ij}) x (S_{ij}/S_{max,j})$							
Marrakech	0.50		0.86		0.40		1.00	
Oujda	0.98		0.67		1.00		0.32	
	$\Sigma(\alpha E_{min,j,0} / E_{ij}) x (S_{ij}/S_{max,j})$							
Marrakech	481.45							
Oujda	438.73							
	$E_i = \Sigma E_{ij}$							
Marrakech	642.90							
Oujda	705.63							
Indicators	**$(IEB)_i$**		Specific energy consumption E_i(kWh)/S(beds)		Energy productivity S(beds) /E_i(kWh)			
Marrakech	0.75		1.10		0.91			
Oujda	0.62		1.05		0.95			

In a summary manner, the IEB inform us that Marrakech CSSD is clearly better than Oujda's CSSD. Moreover, the process indicators $(PI)_{ij}$ shows that Marrakech CSSD energy performance needs to be improved in washing-disinfection and sterile storage.

In Comparison, classic indicators "Specific energy consumption" and "Energy productivity" show a little difference –in favour to Oujda city however-. Which means that the two CSSDs have practically the same energy performance. Furthermore, they don't help to detect directly the failing processes.

5. Discussion

The IEB is intended for energy performance benchmarking of systems with different outputs or single output. Performance of a single system over time can also be compared by considering each year as single system. The IEB indicator is limited to low and middle level systems - according to energy indicators pyramid – and dedicated primarily to engineering applications in industry and service sectors. The IEB has the advantage to be implementable as an integral part of many energy management or energy efficiency standards, methodologies or tools such as EN 16231:2012, ISO 50001:2018, UNIDO energy policy tool [37], Minnesota Technical Assistance Program (MnTAP) [43], Benchmarking and Energy Management Schemes in SMEs (BESS) [44], Energy Efficiency Benchmarking Methodology (E^2BM) [45].

On the other hand, aggregation of economic indicators at the economy level of energy pyramid is out of the scope of this study. Besides, the IEB does not state the units of output to be used in metrics. Rather than that, it represents a method of using standard metrics for benchmarking. Each energy manager or analyst can use the suitable ones for his application.

As a process-oriented indicator, the calculation of IEB by system decomposition does not seem appropriate for residential sector. Decomposing households to processes, i.e. pieces, implies that the output of each piece need to be defined separately which is a daunting task. This stems from the facts that: firstly, the outputs in residential sector are very subjective. Secondly, the households do not have necessarily the same architecture and composition of pieces inside to be compared in a relevant manner. The use of standard basic metrics is preferable in this case.

It is important to mention too, that similarly to comparable indicators, IEB indicator is a technical performance indicator. As such, they analyze the output production way and how energy has been used to produce this output regardless of energy type-related characteristics. In other words, they do not consider environmental impact, availability, or cost of energy used. Nevertheless, they can be integrated in a global energy sustainability indicator.

Regarding existing models, experience shows that none of existing energy performance indicators could be claimed to be the best in all situations. [15] The indicator proposed in this study aims to enhance the range of models of indicators dedicated to the engineering field as described in section 2. We can distinguish some relevant issues about these indicators classified into 2 categories:

1st category: basic metrics:

– Some of the dominant parameters do not correspond well with production energy use: e.g. in hospitals, according to IEA [10], the unit of activity is bed capacity or number of occupied beds, however not all the patients stay in bed.
– Multi-output systems cannot be represented by basic form.
– No insight about energy use differences between processes inside the system.

Compared to this category of metrics, the construction of IEB upon its basic characteristics provides many advantages:

– Benchmarking systems with different outputs.
– Compensates the lack of representativeness of some units of activity used as the denominator in energy/output ratios (e.g. bed for hospitals or room for hotels).
– Identifies processes which are contributing the most in reducing and increasing energy consumption.
– Allows prioritization and targeting of energy saving actions.
– Creates competition between users within a system.

2nd category: complex metrics:

Generally, as Ang emphasizes, each group of indicators tends to serve a certain purpose and the appropriate indicator to use depends on the objective. The models described in literature review present many strengths, of which we mention the aggregation of physical indicators defined in differing units which is a difficult task as evaluated by LBNL [46]. They also provide the same previous 4 advantages as IEB compared to basic metrics; albeit with some notable restrictions:

- Some indicators return unlimited scores like 120% which are less practical for interpretation than values limited to 1 or 100%.
- Independence of systems scores in BEST tool: the score variation of an entity does not change the score of others. As a result, entities with acceptable score may not step up their effort to follow up.
- The ENERGY STAR EPI model is a closed system.
- The *physical production indicator* method has several challenges related to data requirement. [46]
- Identically, *EEI* models needs data history for many years to determine *reference SEC*
- Some indicators are less representative as they decrease when the energy consumption decreases and/or output increases. This is the opposite of the common and spontaneous interpretation, which consider that energy performance or efficiency is enhanced when energy consumption is reduced or output is increased.

In comparison, the aggregated dimensionless *Indicator for Energy Benchmarking* (IEB) was developed with the aim to overcome most of these restrictions. That is to say: The indicator value must be a dimensionless number limited to 1; increases when energy consumption decreases. Besides, the way of construction of reference values E_{ref} and S_{ref} leads to creating interdependence between scores of benchmarked systems. I.e. when the score of system rises, the others scores are reduced. Consequently, this characteristic can induce benchmarked entities to strive to catch up the gap.

6. Conclusion

While we agree that is hard to get an absolutely universal indicator aggregating several physical indicators defined in differing units; it is however possible to expand the area of cases covered by it or improve its characteristics such as accuracy, representativeness and simplicity. By limiting the threshold value to 1, the presented form of the IEB seems to be more understandable even for non-experts decision makers. Unlike many models, we give a special attention in the construction of the indicator to monotonicity. We demonstrate that when the energy consumption decreases and/or output increases; the indicator increases in concordance with our spontaneous- yet logical- interpretation of energy performance or efficiency variation. Besides, the indicator variation of a system induces the variation of the others which is in favour of competitiveness. In sum, the IEB seems to be a serious contribution to the range of available benchmarking indicators, but of course it needs to be tested in different case studies to discover its real potential.

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