Benchmarking Electro-Energetic Performance of Industrial Systems by using Novel Concept of Benchmarking Energy Factor (BEF)

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Abstract: The electro-energetic efficiencies of Industrial Systems and Processes (IS&P) are currently monitored by using different types of Energy Performance Indicators (EnPI). The EnPI represents a ratio between energy spent [kWh] per unit of product, area, volume, or other quantity directly related to production. The EnPI values are supposed to be collected in a centralized data system enabling benchmarking activity at national level. One of the major barriers for this process is related to the ethical and legal issues impeding disclosure of proprietary information. On the other hand, the tedious normalization process due mainly to volatile and un-reliable reference value is another major barrier for benchmarking process. As a result the accuracy of benchmarking IS&P represents always a challenge for governments and for corporations implementing ISO 50001.

The use of unitless indicator *i.e*. Benchmark Energy Factor (BEF) overcomes the current barriers.

The paper proposes a new concept of using Mathematical Model Benchmarking (MMB) and Benchmarking Energy Factor (BEF). The concept enables a new approach towards energy efficiency in industrial and commercial sector and help level the playing field for energy management. The use of Basics of engineering and the laws of physics indicate that only wasted energy, namely Energy at Risk (E@R) values can be controlled. The waste energy (E@R) variation is embedded in unitless Benchmarking Energy Factor (BEF). Proposed method makes possible to determine accurately the (E@R) under variable material and environmental conditions making possible to manage the energy losses and eliminating the tedious process of normalization. The benchmark rating is then solely based on how close the true energy consumption within an industrial process gets to the ideal state. Once E@R is known, it will be logical proceeding with benchmarking plants, industrial systems and commercial buildings assessing their capability of managing Energy at Risk by focusing on in-situ testing.

The paper presents the basics of MMB and basic use of BEF applied to standards accompanied by the case studies inspired from real life (industrial refrigeration and mining industries). The MMB concept can be used by any IS&P owner enabling easy implementation of ISO 50001.

The unitless BEF indicator enables a reliable and credible rating system model describing electro-energetic efficiency of any IS&P and can be used by Utilities (for their DSM programs), Natural Resources Canada (NRCAN) or U.S. Department of Energy - Energy-Star Certification for Plants Program as an alternative to the existent benchmarking practice. Canadian Standard Association, Canadian Utilities and NRCAN is currently preparing Guideline Standards of benchmarking industrial and commercial systems and processes by using the novel BEF concept.

Keywords: Benchmarking energy factor, Conservation & energy management, Energy performance indicators, Essential energy, Industrial systems and processes, Industrial refrigeration, ISO 50001, Mathematical model benchmarking, Slurry pumps mining industry, Standardization, Waste energy.

1. INTRODUCTION

The benchmarking process helps identify opportunities for energy efficiency improvements and facilitates target setting and monitoring of progress towards achieving targets as set by specific Standards. By definition, traditional benchmarking is considered to be the practice of being humble enough to admit that someone else is better at something (sometimes defined as “best practice”).

“Benchmarking energy performance of industrial applications and systems is recognized as an efficient tool in advancing energy efficiency as part of energy management framework” - as being stated by ISO 50001. This standard is an internationally recognised framework for continuous improvement in organisational energy efficiency and conservation. It is anticipated that corporations, supply chain partnerships, utilities, and energy service companies will use ISO 50001 as a tool to improve energy performance and reduce carbon emissions in their own facilities as well as those belonging to their customers or suppliers. However, the standard does not prescribe specific performance criteria or results with respect to energy [1].

Further on, ISO 50006 provides organizations with practical guidance on how to meet the requirements of ISO 50001 related to the establishment, use and

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maintenance of energy performance indicators (EnPIs) and energy baselines (EnBs) in measuring energy performance and energy performance changes.

As stated by ISO 50006: “EnPI is a value or measure that quantifies results related to energy efficiency, use and consumption in facilities, systems, processes and equipment while the EnB is a reference that characterizes and quantifies an organization’s energy performance during a specified time period”. The organization needs to consider the specific energy performance targets while identifying and designing EnPIs and EnBs (as shown in Figure **1**) with further possibilities of developing a reliable benchmarking system [2]. This type of benchmarking presented by ISO 50006 can be defined as **Internal Benchmarking**

Utilities, governmental and international organizations still estimate energy savings applied to the entire **energy consumption (E_{Used})** of industrial system or process as a whole by using the “best practice” as targets. Energy efficiency benchmarking (EEB) of industrial systems, processes, products and industry sectors is traditionally based on Best Practice Technologies (BPT) by using various energy indicators. For industrial firms, benchmarking helps identify opportunities for energy efficiency improvements and facilitates target setting and monitoring of progress towards achieving targets. As a first step of the benchmarking process at the plant-level, a sector comparator benchmark is typically identified or calculated. That will enable a comparison with best available practices and technologies, highest performing facilities or the minimum essential energy required to produce a given output [3].

Benchmarking indicators or Energy performance Indicators (EnPI) are typically expressed as electric energy intensities in order to normalize for throughput differences between facilities. Comparator benchmarks are in some cases also adjusted for material and environmental conditions at each facility to allow for an equitable comparison of different facilities within each sector.

Operational Benchmarking is the process of continuously measuring and comparing one’s business processes against comparable processes in leading organizations to obtain information that will help the organization identify and implement improvements [4]. A prominent industrial benchmark rating systems is developed by the U.S. DoE’s Energy Star Certification for Plants Program [5]. Established by the US Department of Energy (DoE) and the US Environmental Protection Agency (EPA) in 1992, the Energy Star® Certification Program is a joint voluntary program with a goal to help consumers, businesses and industry save money and protect the environment through the adoption of energy efficient products and by implementing what is considered to be defined as “Best Practice”.

Based on traditional methodology assessing system efficiencies, the Energy Star Program developed Energy Performance Indicators (EnPI) or benchmark ratings for different industrial facility types, by using a laborious and tedious methodology that is repeated every time when the REFERENCE is changed. EnPI’s are developed by using the total annual plant energy and production data. The EnPI’s are compared against other similar plants, in a specific industry, and an energy performance score is generated (also known as EPA’s 1-100 Energy Star score). An Energy Star® certificate is awarded as recognition for top performing plants for their superior energy performance.

The Superior Energy Performance (SEP) certification requires the facility to me*et a*ll

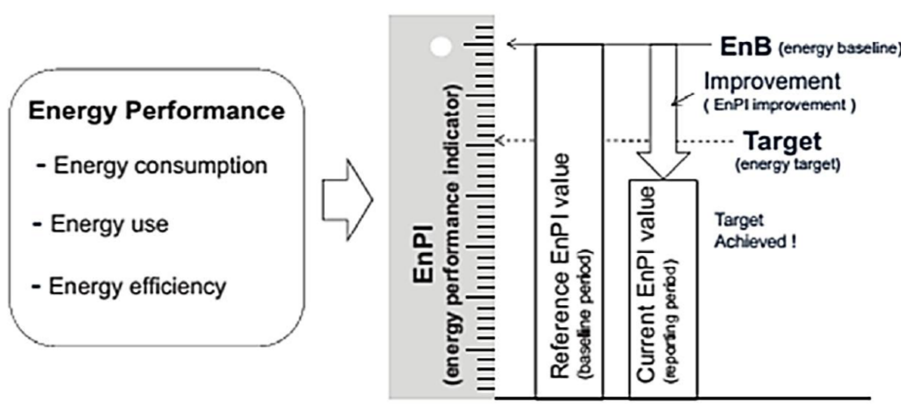


Figure1: Relationship between energy performance, EnPIs, EnBs and energy targets.

requirements of the ISO 50001. Its central element is the implementation of a global energy management system. It is considered that implementing a global energy management system will enable facilities to realize greater persistence in energy savings and higher returns on energy efficiency investments [6].

The core of the current (traditional) interpretation of Benchmarking Energy Efficiency for industrial systems and processes (as graphically shown in Figure **2**, where "N" stands for Normalization) requires the following works:

- ❖ Finding Benchmarking Partners,
- ❖ Analyze & Compare,
- ❖ Setting Key Performance Indicators,
- ❖ Do conventional Benchmarking,
- ❖ Perform Implementation,
- ❖ Perform M&V using IPMVP methods, and NORMALIZATION
- ❖ Certification
- ❖ Repeat the process when REFERENCE is CHANGING

Since 2010, overall efficiencies of industrial systems and processes (IS&P) are assessed by using Energy Usage Index (EUI) and/or Superior Energy Performance [cm] (SEP) – in a certification program that provides industrial facilities with a transparent, globally accepted system for verifying energy performance improvements and management practices. Central element of SEP is implementation of the global energy management standard ISO 50001. Energy efficiency certification is obtained by verifying energy performance through measurement and verification (M&V) at the main meter (sometime not being able assessing directly (E_{used}). Then EnPI or EUI are estimated against variable references *i.e.* "best practice" or BPT.

On the other hand, government and utilities developed energy efficiency programs that are targeting specific end-uses (compressed air, fans, blowers, pumps) or specific applications (refrigeration, drying kilns) as individual facility/equipment/process, as per ISO 50006 – Table **1** (line # 1 or # 2)

Energy studies are developed within Government or Utility's programs. An energy study will investigate the end-uses or application, defining the baseline (the EnB) and setting an energy performance indicator (EnPI). Further on the energy study proposes one or more suitable energy conservation measures (ECMs) within defined system boundary and estimates the new energy consumption (the new $EnPI_{new}$) by using specific mathematical models, direct tests and measurements, using various estimators and predictors that can be verified by a 3-rd party during Measurement & Verification process and normalization process.

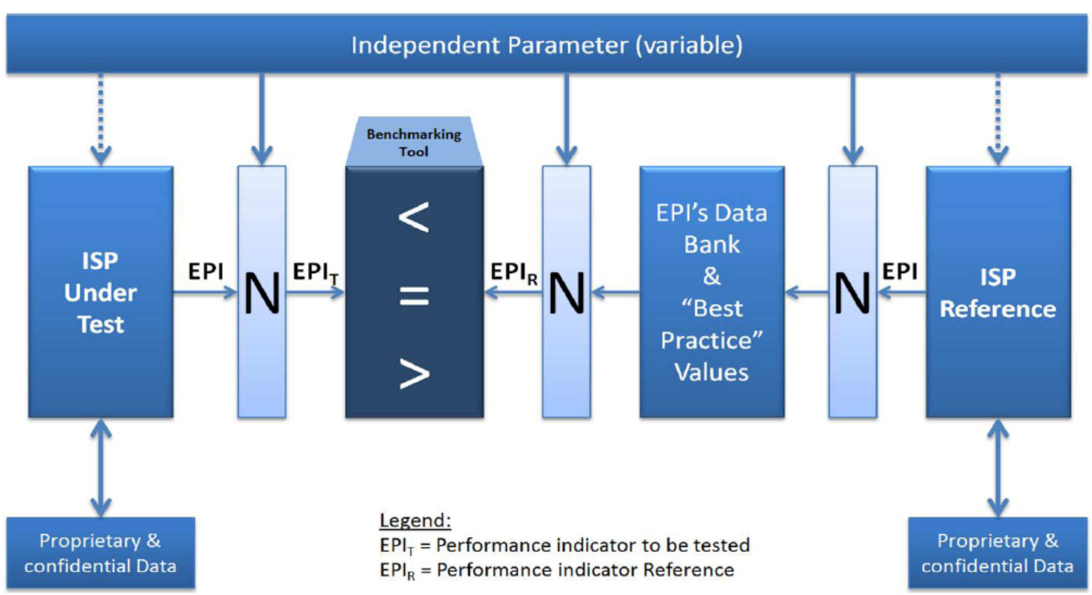


Figure2: Schematic Process of Conventional Benchmarking.

Table 1: The Three EnPI Boundary Levels

#	EnPI Boundary Levels	Description and examples
1	**Individual facility/equipment/process**	The EnPI boundary can be defined around the physical perimeter of one facility/equipment/process the organization wants to control and improve Example: The steam production equipment
2	**System**	The EnPI boundary can be defined around the physical perimeter of a group of facilities/processes/equipment interacting with each other that the organization wants to control and improve Example: The steam production and the steam use equipment, such as a dryer
3	**Organizational**	The EnPI boundary can be defined around the physical perimeter of facilities/processes/equipment also taking into account the responsibility in energy management of individuals, teams, groups or business units designated by the organization Example: Steam purchased for a factory/factories, or department of the organization

The energy savings are obtained as a difference between old and new EnPI as energetic quantities. In case of Energy Usage Index EUI the energy savings are estimated by multiplying the annual (or monthly) values of quantities being posted at the EUI's denominator. Incentives are awarded based on the calculated or measured energy savings resulting from implementation of specific energy conservation measures (ECMs) to the above end-uses or applications.

A specific number of years are considered for ECM persistence [7]. However, there is no continuous M&V activity performed during the time interval proposed as persistence for specific ECMs.

These traditional methodologies are based on "mimicking the best practice" yielding large variability of benchmarking factors generated by baseline inaccuracies that requires permanent and tedious update works[1]. While the ultimate target of these initiatives is reduction of power/energy losses at the time of measurement, their magnitude (absolute value) is still unknown!

To date, studies of energetic performances of industrial systems and industries have lagged behind those used in the commercial and institutional sectors due to [8]:

- Large variability and complexity of IS&P
- Variability of material and environmental conditions,
- The absence of a large population of comparable data required for a regression-based approach that would enable the normalization of material and environmental conditions, and thus allow for a useful comparison of energy performance at the process level.
- The reluctance of industrial firms to share data on industrial processes that is often considered proprietary.
- Tedious certification process

A large variety and sizes of (IS&P) require sustainable and consistent approach. From economic standpoint, sustainability concepts favor high-efficiency systems, as any energy-efficient system translates into higher effective productivity.

2. BASICS OF BENCHMARKING ENERGY FACTOR CONCEPT

Industrial system drives (ISD) are defined as chains of power converters (PC) performing:

- Electrical Conversion (Transformers; Variable Frequency Drives, Starting devices)
- Electro-mechanical Conversion (Electric Motors)
- Mechanical Conversion (Gears, belts, couplings, ASDs)
- Process Conversion (Driven equipment Pumps, fans, air compressors, refrigeration, material handling, processes)

[1] The core of the current interpretation of Benchmarking Energy Efficiency for industrial systems and processes requires the following works: Study the System or Process, Finding Benchmarking Partners, Analyze & Compare, Normalization, Setting Key Performance Indicators, Do conventional Benchmarking, Perform normalization process, Analyze the results, Implementation, Perform M&V activities by using IPMVP methods, Awarding and Certification.

- Monitoring & Controls, Software

Power savings are currently obtained by maximizing overall efficiency given by (1) in Figure **3**

$$\eta_{ISD} = \Pi\, \eta_i \tag{1}$$

For a typical ISD the overall efficiency is η_{ISD} = 0.55 when supposing the following efficiencies of components: Transformer: η_{TRX} = 0.98, Electrical Line: η_{Line} = 0.996, Variable Frequency Drive: η_{VFD} = 0.97, Electric Motor: η_{Motor} = 0.95, The Gearbox: η_{Gear} = 0.88, Mechanical Transmission: $\eta_{Transmission}$ = 0.95, Drive End-use Equipment: η_{DEE} = 0.74

Hence, based on (1) the ideal energy required to obtain required output $\mathbf{E_{Ideal} = 0.55 \times E_{Used}}$. Waste energy or Energy at Risk (E@R) representing 45 % of the input electrical energy (or power) is wasted in Thermal Pollution [8].

source of energy/power the Benchmark Energy Factor (BEF) of the system is defined as:

$$BEF_{system} = \frac{E_{used}}{E_{ideal}}\Big|_{@\ given\ input\ parameters} \tag{2}$$

BEF splits effectively the energy consumption (**E_{Used}**) up into productive energy and non-productive energy.

The Ideal energy (power) **E_{Ideal} is productive energy** representing the theoretical energy (or power) required to accomplish the task (or manufacture the products) for what system was designed. Considered as reference, this quantity is intrinsic related to the scope of process defining energy which is technology independent, while BEF is production volume independent[3]. Ideal energy (or power if time factor is excluded) can be accurately calculated by using adequate, well known laws of physics [8, 9] chosen

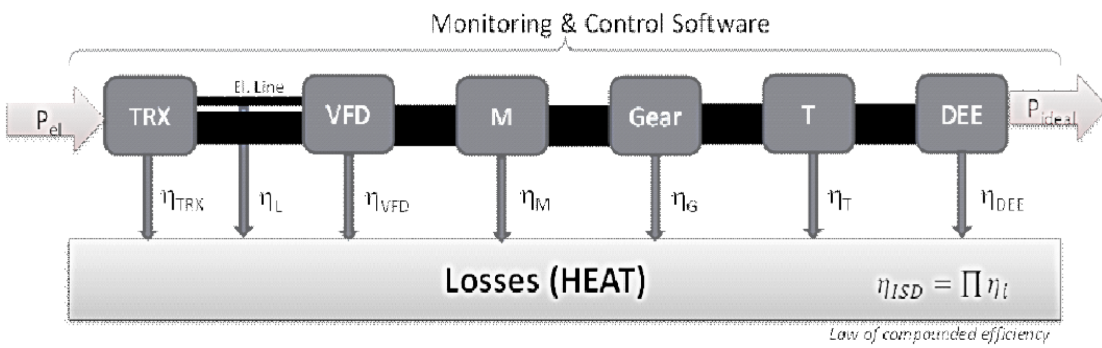


Figure 3: Schematics of power flow within an industrial system drive (ISD) depicting also the wasted energy as heat.

With reference to Figure **3**, the electric input power of ISD is considered as used power P_{used} and represents the actual electric power $P_{Electric}$ that is used by ISD to accomplish the required task P_{ideal} (that is the power provided by Drive End-use Equipment (DEE). The total Losses (heat) of a typical ISD can be expressed as:

$$\sum P_{losses} = P_{used} - P_{Ideal}$$

By definition, **BEF** represents overall invested energy **E_{Used}** that is compared to the required energy to obtain the desired output (for simplicity sake considered in this paper as **E_{Ideal}** or essential energy **$E_{Essential}$**). The value of this unitless factor depends on how "well" the overall system produces the output as well as of some boundary conditions[2]. For a single

function of the work type performed by Drive End-use Equipment (DEE).

Theoretical (idealized) system uses only the energy that is required to obtain the result, E_{Ideal}, (zero losses), while the real system uses more energy to overcome the losses embedded in the system itself. A major

[2] Although it can never be achieved, a BEF value of 1.0 indicates essential energy required for process equal to E_{Used}, would be an ideal system or no-power losses system

[3] **E_{Ideal}** energy values can be dependent of specific variables [7] like: material, environmental conditions, personnel, equipment condition, thermal insulation condition, transportation, lighting, etc. In this case **E_{Ideal}** is re-evaluated it will be increased to a new value named essential energy **$E_{Essential}$,** this value replacing ideal values of energy **E_{Ideal}** in (1) resulting in adjustment of BEF value. This adjustment enables real BEF values that will be used for M&V purposes. **E_{Ideal}** adjustment to **$E_{Essential}$** is done by using 5 (five) Essentials of Application Engineering (5 EAE) methodology [8, 9].

assumption inspired by reality is made by the authors: ***"when an industrial system is functioning, the user takes always the risk of spending extra energy in losses".*** Therefore proposed method defines these energy losses as Energy at Risk (E@R):

E@R = (Electric Input Energy, $\mathbf{E_{Used}}$) – (Ideal Energy, $\mathbf{E_{Ideal}}$) (3)

Energy @ Risk **(E@R)** of an industrial system or process is defined as "non-productive energy". It represents the waste energy spent by any ISD (heat) to accomplish the task for what system was designed. As a conjugate of ideal energy, E_{Ideal}, the Energy at Risk (E@R) variation is embedded in BEF.

Salient benefits of proposed method are:

- ❖ Ability to estimate E@R under variable material and environmental conditions
- ❖ Benchmarking and compare similar processes over their operating profile
- ❖ Ability to manage the E@R by setting SMART targets
- ❖ Ability to calculate the Avoided E@R (energy savings) consistently, repeatable & accurately with dynamic reference (baseline) adjustments
- ❖ Measure continuous improvement results with improved ability to model and compare current state (baseline) and future state (target).

3. THE USE OF BENCHMARKING ENERGY FACTOR CONCEPT IN REFRIGERATION INDUSTRIES

Canadian Utilities undertook the initiative of applying the new concept of Benchmarking Energy Factor – BEF, to different end-uses. One of the first standard being released is CSA C500-2018: "Monitoring and energy performance measurement of industrial refrigeration systems (IRS) using benchmark energy factor (BEF) concepts" [10]

As a preamble to CSA C500-2018 standard, a mathematical energy benchmark model (and software) for refrigeration facilities was developed. The software was used to evaluate the essential (ideal) energy that represents the minimum energy required by a facility (or end-uses) to perform required task in conditions of their non-controllable operational parameters and utilization of refrigeration system equipment. The refrigeration equipment was considered working at the peak efficiency of what is currently commercially available.

The essential energy tool serves to compare a facility's potential, most efficient operation according to several controllable variables. The energy benchmarking tool will develop the essential energy for refrigeration load requirement for a facility based on variables entered by the user. The total facility refrigeration load will be comprised of the following sources [11]:

- ❖ Envelope Load: Created by heat transfer across the external surfaces of the space (walls, ceiling and floor)
- ❖ Lighting Load: Created by lighting fixtures within a space
- ❖ Product Load: Load from a product entering a space at a higher temperature than the temperature of the space
- ❖ Motor Load: Created by evaporator fan motors within space

The following loads will not be included as sources of the total facility refrigeration load:

- ❖ Infiltration Load: Created by openings, leaks, or air changes in a space (The opening of an exterior door or window is an example of infiltration.). The load from infiltration only accounts for just over 0.7% of the total load; therefore, the load from infiltration is neglected
- ❖ Human Activity Load: Load created by people working within a space. Human activity is difficult to quantify in terms of additional load. A facility with an efficient operation will limit employees' presence within a zone as much as possible and ensure that all employees working within a zone wear heavy clothes. Since measures can be taken to significantly reduce the load due to human activity, it's considered negligible.
- ❖ Freezer Floor Ground Freeze Protection Load: Load created by underfloor heating for frost protection. Floor heating varies between refrigeration facilities. Floor heating consumes a relatively low amount of energy, and would contribute a similar amount of load as a floor without heating in contact with the ground, which is accounted for in the envelope load.

- Material Handling Load: Load created from product handling equipment (*e.g.*, forklifts, pallet jacks, conveyors, etc.) within a space

However, the following data will be automatically available by selection: meteorological data (related to geographic location) envelope load parameters, product load entering product category, rate of product loading, incoming product temperature, product storage temperature), lighting load, fan motor load.

The user will enter their facility's monthly utility data for a given year, and this data will be plotted against the monthly essential energy use.

An example of a specific Industrial Refrigeration System consumption, Energy at Risk and Essential energy is shown in Figure **4** [11].

In Figure **4** the table indicates essential energy obtained by analysing compressor, condenser, evaporator and lighting set ups in the most efficient manner according to details of each suction system - that will give the total essential energy use published in blue field.

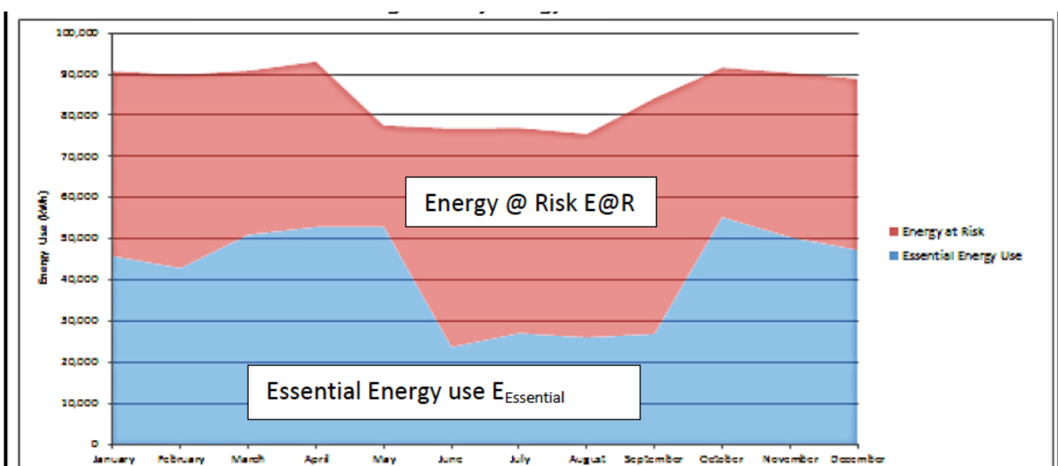
The red field represents the Energy @ Risk (E@R) that is actually the REAL Conservation Potential for this specific Industrial Refrigeration System.

The last column on the table shows monthly BEF values; these values can be compared against a benchmarking "witness" table giving indications of possible conservation measures that can be taken to reduce E@R values.

Based on previous studies performed on sample population of 10 (ten) different IRS it was found that achievable conservation potential for IRS represents about 25 - 30 % of Energy at Risk (E@R) [9]. Further on E@R reduction could be tested prior Energy Conservation Savings (ECM) implementation by using available dedicated software. It is estimated that energy saving potential of 480 GWh…580 GWh/y is obtainable on IRS (retrofits and new designs) by introducing this new standard in Canada.

4. THE USE OF BENCHMARKING ENERGY FACTOR CONCEPT IN MINING INDUSTRIES

Benchmarking energy usage in mining operations, where energy costs are high and represent a significant



System Parameters	Average Total Load (TR)	Compressor Essential Energy Use (kWh)	Condenser Essential Energy Use (kWh)	Evaporator Essential Energy Use (kWh)	Lighting Essential Energy Use (kWh)	Total Essential Energy Use (kWh)	Actual Facility Energy (kWh)	Energy at Risk (kWh)	Benchmark Energy Factor
January	0	25,454	3,389	7,950	9,002	45,796	90,773	44,976	1.98
February	0	24,155	3,177	7,431	8,131	42,894	89,917	47,022	2.10
March	0	29,249	3,819	8,918	9,002	50,989	90,901	39,912	1.78
April	0	31,034	3,955	9,183	8,712	52,884	93,113	40,229	1.76
May	0	32,223	3,613	8,115	9,002	52,953	77,593	24,640	1.47
June	0	15,484	1,655	3,665	2,904	23,708	76,843	53,135	3.24
July	0	18,199	1,844	4,015	3,001	27,059	76,998	49,939	2.85
August	0	17,328	1,787	3,913	3,001	26,029	75,535	49,506	2.90
September	0	17,815	1,918	4,258	2,904	26,895	84,230	57,335	3.13
October	0	32,766	4,077	9,410	9,002	55,254	91,654	36,400	1.66
November	0	29,172	3,757	8,745	8,712	50,387	90,394	40,007	1.79
December	0	26,587	3,509	8,215	9,002	47,313	88,945	41,633	1.88
TOTAL		299,466	36,500	83,818	82,377	502,160	1,026,896	524,736	2.04

Figure 4: Graphical representation of an IRS' current energy consumption, Energy at Risk (E@R) – red field and Essential energy (blue field).

portion of overall operating expenses, is challenging due to uniqueness of each mining operation. Slurry pumps count for an average of 10% – 15% of total installed power and 8% – 12% of the total energy consumption of a mineral mine (Pitis, 2008). The slurry centrifugal pumps feeding cyclones systems (as shown in Figure **5**) are critical equipments handling aggressive fluids, featuring highly wear and corrosion of the wetted components [12].

The slurry pump system influences the efficiency of the cyclone and ultimately the efficiency of the entire processing system by:

- ❖ Achieving required fluid power to the cyclone feed
- ❖ Performance persistence of the cyclone (due to persistence of slurry pump performances)
- ❖ Consistent quality of the separation process
- ❖ Less residence time in the grinding mill
- ❖ Lower milling energy per ton of the material
- ❖ Increased competitiveness and sustainability

Canadian Standard Association – CSA, Canadian Utilities and NRCAN undertook initiative of setting the new concept of benchmarking slurry pump systems, as a Customer Orientated Standard (CSA – C 502). The proposed standard will cover in-situ energy consumption measurements in relation to the slurry pump system performances and system efficiency (sump - pump - cyclone and motor) and fits within the Benchmark Energy Factor (BEF) strategy endorsed by Canadian Utilities and NRCAN.

The mathematical model is designed to replicate a generic cyclone feed pump system, one with a typical basic layout as depicted in figure **6**, from which the Essential (Ideal) energy (that is technologically independent) can be determined. The Excel based

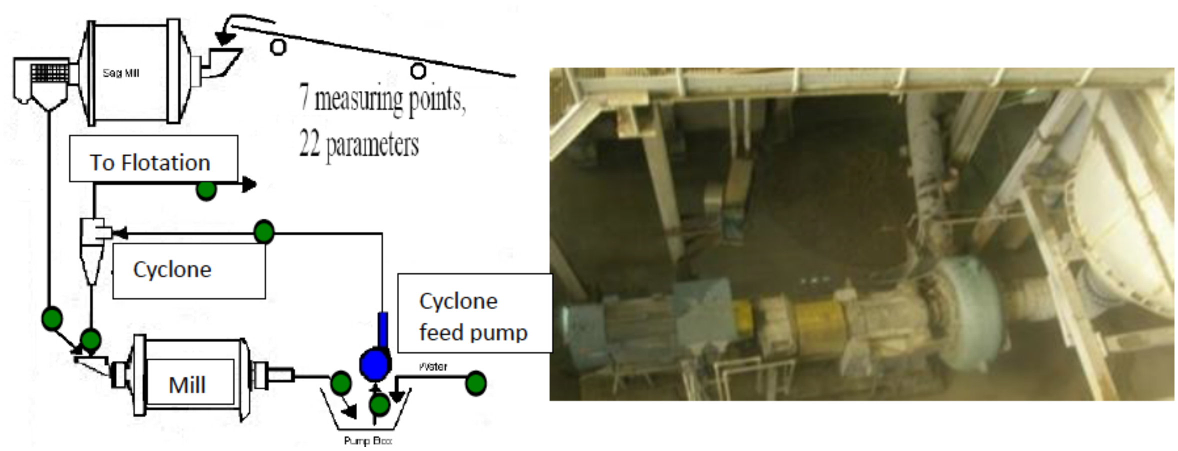


Figure 5: Slurry pump system and schematics of a slurry pump cyclone feed circuit.

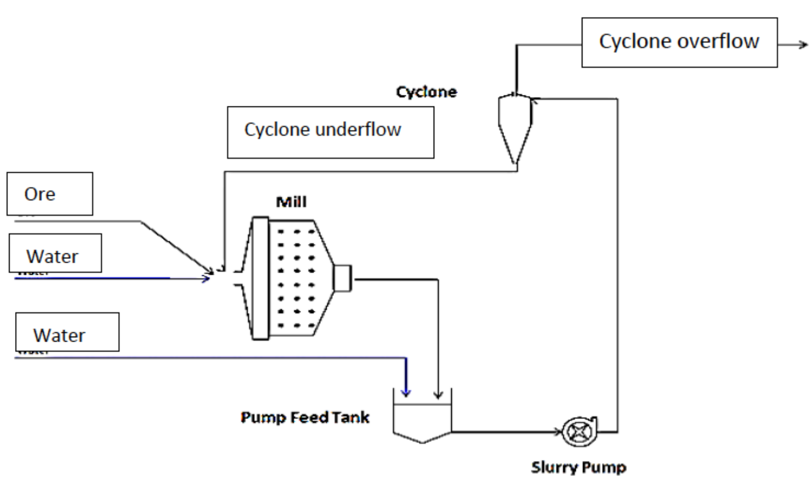


Figure 6: Schematic diagram of the studied slurry pump system.

model will be used to calculate the theoretical and practical energy consumption of individual systems, setting the benchmark for the system. The Energy Benchmark Model is aiming to: a) Include input parameters for all significant components that have influence on energy consumption, including factors that cannot be changed, or are extremely difficult to control, b) Be universal for ideal conditions (excluding the impacts of actual abrasion, erosion and corrosion, etc.) c) Be technology independent (excluding pump type, materials and efficiency).

According to the software, the creation of the mathematical model of (technologically independent) Essential (Ideal) energy and subsequently of the Benchmark energy factor (BEF) are based on (three) 3 major categories of input parameters required to be completed for each slurry pump system.

A. Process (controllable by pump system operator)

- ❖ Concentration of solids in slurry (% by volume/weight)
- ❖ Pump sump slurry level (head)
- ❖ Pump speed
- ❖ Actual energy used by the Pump
- ❖ Cyclone inlet pressure – relative (biased)

B. Process (uncontrollable by pump system operator)

- ❖ Mass flow rate of solids
- ❖ Specific gravity of solids - constant
- ❖ Average particle size/diameter
- ❖ Particle size distribution
- ❖ Minimum cyclone inlet pressure

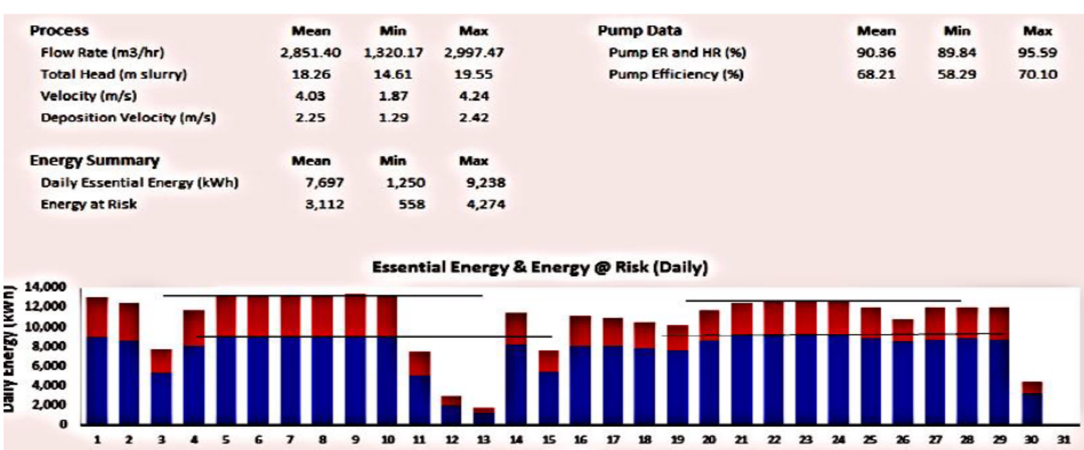
C. Design & Environment (uncontrollable by pump system operator)

- ❖ System Layout (*e.g*. sump, pump and cyclone Datum levels0
- ❖ Pump impeller diameter
- ❖ Pipe size (velocity > limiting settling velocity)
- ❖ Equivalent pipeline friction head factor (that is predicted by the model)
- ❖ Slurry Pump HR - Head Ratio (that is predicted by the model)
- ❖ Slurry Pump ER - Efficiency Ratio (that is predicted by the model)

Screenshot of Output Data: Model & Results and Summary Report are shown in Figure **7**

As shown in Figure **7**, the software estimates daily average values of essential energy, energy at risk and Benchmark Energy Factor. For this particular case, the flow rate and BEF trends are shown graphically in Figure **8** (the graphs are based on output data provided in Excel-data not included).

It is believed that any changes in BEF values can be related to the flow rate fluctuation, the pump efficiency changes (due to impeller wear or change-over) and/or both. Figure **8** confirms that the BEF increases or decreases with the flow rate increasing or decreasing. Since day 12, a significant drop in BEF is



Process	Mean	Min	Max
Flow Rate (m3/hr)	2,851.40	1,320.17	2,997.47
Total Head (m slurry)	18.26	14.61	19.55
Velocity (m/s)	4.03	1.87	4.24
Deposition Velocity (m/s)	2.25	1.29	2.42

Pump Data	Mean	Min	Max
Pump ER and HR (%)	90.36	89.84	95.59
Pump Efficiency (%)	68.21	58.29	70.10

Energy Summary	Mean	Min	Max
Daily Essential Energy (kWh)	7,697	1,250	9,238
Energy at Risk	3,112	558	4,274

Figure 7: Screenshot of report depicting Essential energy (blue) and E@R (red).

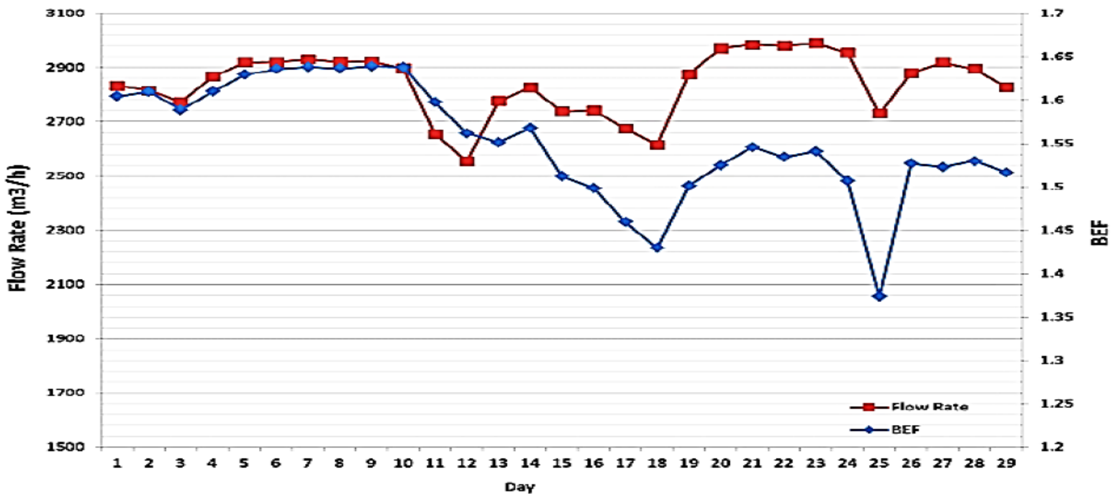


Figure 8: Flow rates and Benchmark Energy Factor (BEF) trends.

recorded that imply the system operated more efficiently in comparison to the previous period (*i.e*. days 1…11). This might be because of a new impeller replaced the worn one: the operational recorded data shows that, there was a shut down for a period of 8 hours. The miner have changed the impeller and/or might have done some new settings to the system (*i.e*. cyclone replacement or cyclone feed pressure adjustment)

5. DEVELOPMENT OF BENCHMARKING ENERGY FACTOR STANDARDS

The concepts of Mathematical Model Benchmarking (MMB) by using Benchmark Energy Factor (BEF) as reliable energy efficiency indicator is intended to be introduced in various new Canadian standards, offering specific guidance to those involved in benchmarking activities and implementation of ISO 50001 and ISO 50006 standards. Under auspices of Canadian Standard Association – CSA, Canadian Utilities and NRCAN undertook initiative of setting the new concept of benchmarking various industrial and commercial systems, as Customer Orientated Standards, or Customer Centric Standards

The concepts of Energy at Risk (E@R) and Benchmark Energy Factor (BEF) as reliable energy efficiency indicators were proposed to be introduced in various new standards being intended to offer specific guidance to various segments involved in conservation activities:

- ❖ Customers and consultants approaching retrofit or new plant design of industrial systems
- ❖ Utilities setting priorities inside specific program, claimed savings and their costs, consultant fees, level of incentives
- ❖ Government policies

The following standards are finalized or developing:

- ❖ CSA C500-2018: “Monitoring and energy performance measurement of industrial refrigeration systems (IRS) using benchmark energy factor (BEF) concepts” [10]
- ❖ CSA C502: Monitoring and energy performance measurement of Slurry pumps in mining industry using benchmark energy factor (BEF) concepts
- ❖ CSA C504: Monitoring and energy performance measurement of pump systems in mining using benchmark energy factor (BEF) concepts
- ❖ CSA C510: Monitoring and energy performance measurement of Data Centers using benchmark energy factor (BEF) concepts
- ❖ CSA C802.6: Guide for energy estimation of dry-type distribution transformer configuration in commercial buildings

The concept addresses the issues related to currently used methodologies (as presented in chapter 2) setting a reliable Reference for benchmarking purposes that can be used within ISO 50001, ISO 50006 and SEP™. The standards will enable establishing a BEF range of values that will enable:

1. Setting predetermined targets for industrial systems that can be used for assessing new designs

2. Direct-on-line monitoring performance of industrial systems and processes that will drive continuous improvements by setting achievable targets of BEF values

3. Further diagnostics for existent systems that might trigger operational decisions

4. Estimates of conservation potential that might trigger Energy Conservations Measures sponsored by utility or government DSM programs

An example of such type of BEF scale applied to slurry pumps in mining industry is shown in Figure **9**.

In the case of CSA C500-2018 for Industrial refrigeration systems, the exercise of obtaining the BEF Range was performed for over 25 industrial refrigeration systems (IRS). The outcome of this activity was a range of BEF (average annual) values assigned to every facility of the same category. It was found that these values belong to an interval varying between 3.5 and 6.4 (annual average values) as shown in Figure **10**. The attached comments for each of the BEF values provide justification for obtaining such different BEF values. The maximum value on the BEF scale (*i.e.* BEF_{Max} = 6.40) was found for a new plant design where the customer decided NOT to implement the appropriate Energy Conservation Measures (ECM). As a result, this value can be considered as a reliable

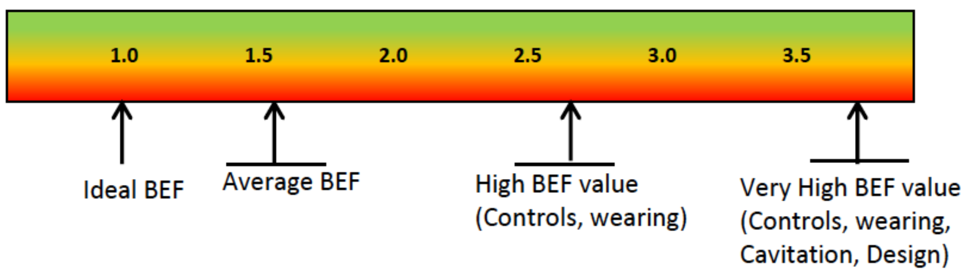


Figure 9: Proposed scale of Unitless BEF values for CSA C 502.

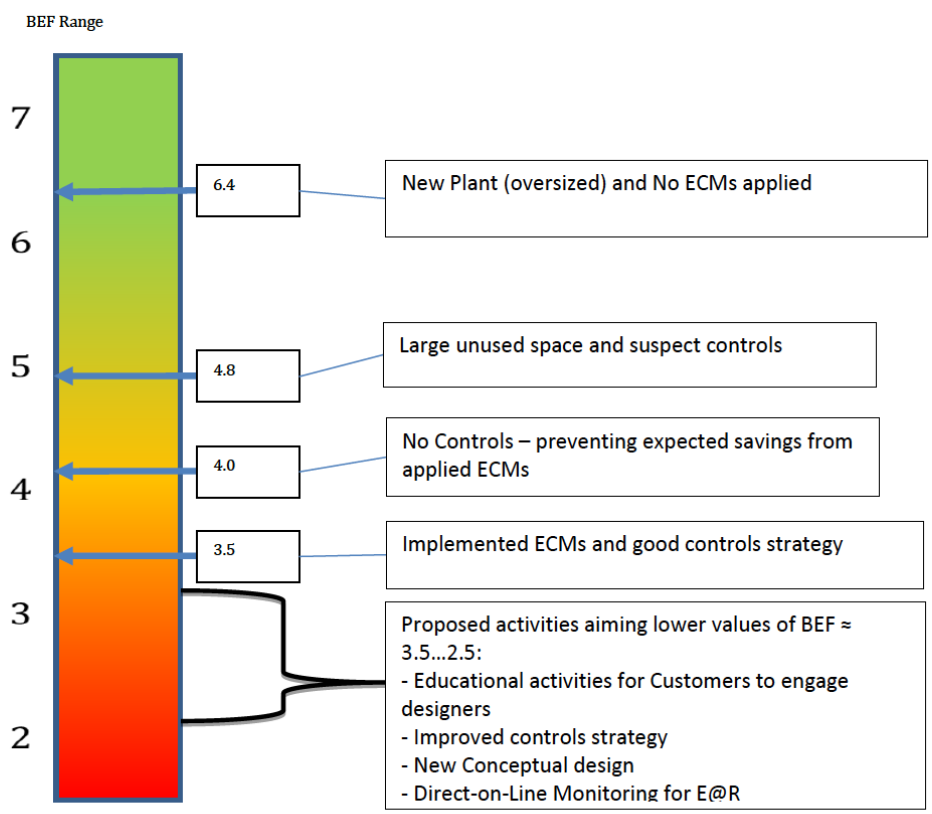


Figure 10: BEF range for Industrial refrigeration systems (CSA C 500 – 2018).

indicator of a simulated Baseline, (*i.e.* "do nothing") for future new plant design projects.

The lower value on the scale – the "Reference" was found for IRS where various ECMs have been implemented using a good control strategy (BEF_{Min} = 3.50). This value can be considered as a target for any energy efficiency improvement. These values are basic tools in estimating energy savings (and conservation potential) for any IRS (retrofit or new). In the case of considering the essential energy $E_{Essential}$ to be constant in pre and post situations, the Conservation Potential (CP) can be estimated as follows:

$$CP = [BEF_{Max} – BEF_{Min\ (Reference)}] \times E_{Essential}$$

For specific IRS having essential energy $E_{Essential}$ = 4 GWh/y and BEF = 3.8 the Conservation Potential (CP) is therefore: CP = [3.8 – 3.5] x 4 = 1.2 GWh/y

6. COMMENTS, CONCLUSIONS AND RECOMMENDATIONS

Key Performance Indicators (KPI) and/or Energy use intensities (EUI) are traditionally used as energy performance indicators EnPI in international energy management standards (ISO 50001 and ISO 50006).

The most prominent EnPIs - the Energy Use Intensity (EUI) is commonly measured in [kWh/t], [kWh/ft^3], or [MMBtu/year/unit of product] and can be determined for any primary energy source. The EnPI or EUI values can be obtained by any of the followings methods: direct estimation of the ratio, regression methodology, direct test and measurements and/or by using other estimators and predictors that can be verified by a third party during M&V processes.

The purpose of energy use intensities (EUI) and benchmark energy factor (BEF) is different and they complement each other.

EUI answers the question about how much energy is used for production of industrial system or process at a specific measurement point. The EUI has a weakness as comparator as it is strongly dependent on operating conditions.

The unitless BEF answers the question how energy efficient is an industrial system or process in the very same point. BEF uses a technological independent reference – Essential Energy. That means BEF can be compared with values obtained for any other conditions and shows the potential for optimization and the quality of EUI.

While Demand Side Management (DSM) industry programs consider the total Energy Consumption (E_{Used}) of an IS&P as a whole, the proposed concept splits this energy in 2 (two) specific components: Ideal Energy (E_{Ideal}) and Energy-at-Risk (E@R) or wasted energy [11]. By considering these two components of energy, the Benchmark Energy Factor (BEF) can be defined. The Figure **11** represents schematically the total energy flow in a IS&P and the split between the Ideal Energy and the Energy-at-Risk (or wasted energy).

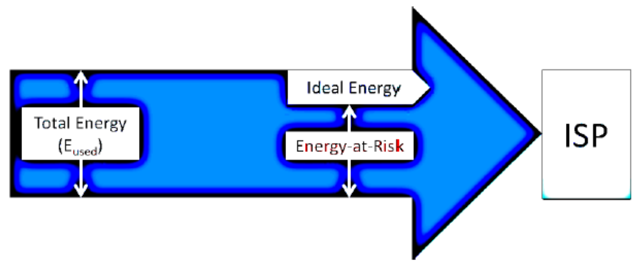


Figure 11: Energy flow and split for an IS&P.

By definition, Benchmark Energy Factor (BEF) represents the overall invested energy E_{Used} compared to the minimum energy required to obtain the desired output (for simplicity considered in this paper as essential energy $E_{Essential}$ or ideal energy E_{Ideal}). Although it can never be achieved, a BEF value of 1.0 indicates that E_{Used} is equal to the minimum energy required E_{Ideal}.

$$BEF_{system} = \frac{E_{used}}{E_{ideal}} \Big|_{@\ given\ input\ parameters}$$

Therefore BEF rating is solely based on how close the true energy consumption within an industrial process is to the Ideal Energy. The Ideal Energy can be calculated very accurately by using well known laws of physics chosen as a function of the work type performed by the end-use equipment.

A mathematical model incorporating all the independent parameters and automatically normalize for any variability is used to determine the Ideal Energy, eliminating the tedious normalization process. This methodology produces a solid (not empirical) Reference for Benchmarking an IS&P, which eliminates the variability related to independent parameters and normalization process. With a theoretical Benchmark (Reference) in place, the ethical and legal issues involved with traditional benchmarking can be avoided. Confidential and proprietary information related to the IS&P is not required to be shared externally. As a result, this UNITLESS indicator will ensure better accuracy of the benchmarking process.

This new concept will also reduce the time and labour associated with the benchmarking process. M&V activities can be replaced by a continuous monitoring process that can be easy adjusted at any time to account for changes in independent parameters.

BEF answers the question how energy efficient the industrial system or process is in the same point. BEF uses a technological independent reference – Essential Energy. That means, the unitless BEF can be compared with values for other conditions and shows the potential for optimization and the quality of EUI.

The concepts of Mathematical Model Benchmarking by using Benchmark Energy Factor (BEF) as reliable energy efficiency indicator is intended to be introduced in various new Canadian standards, offering specific guidance to those involved in benchmarking activities and implementation of ISO 50001 and ISO 50006 standards. Salient benefits of new concept are:

- ❖ Proposed method uses well-known physical laws of science and physics to determine theoretical minimum required *i.e*. Essential (or Ideal) energy, $E_{Essential}$. The methodology can be expanded defining essential energy, $E_{Essential}$ that is technology independent but depending on material, environment conditions with allowance for lighting, personnel, transportation and equipment condition. That means the $E_{Essential}$ concept is technologically independent

- ❖ Unitless BEF is useful metric for assessing energy performance without the need for extensive site-specific measurements, normalization and complex process of modeling the actual energy baseline.

- ❖ Unitless BEF eliminates the ethical and legal issues impeding disclosure of proprietary information.

- ❖ Benchmarking and compare similar processes over their entire operating profile, eliminating “mimicking” practice

- ❖ Ability to estimate and manage the waste energy (E@R) by setting SMART targets

- ❖ Ability to estimate potential energy savings consistently, repeatable and accurately in dynamic conditions providing automatically reference (baseline) adjustments (no tedious process of normalization)

- ❖ Measure continuous improvement results with improved ability to model and compare current state (baseline) and future state (the target); BEF performance can be permanently direct-on-line monitored by end-user.

This concept has been already proven successful in industrial fields. Canadian Standards Association (CSA), Canadian Utilities and NRCAN are working on a series of new standards addressing the guidelines for benchmarking the energy performance of industrial. These standard will provide a unified and consistent methodology for performing measurement activities with the ability to measure and verify the system energy performance in the field through the Benchmark Energy Factor (BEF) approach. Practical examples based on the new concept with comments and recommendations are presented.

In this paper, this new concept is applied to electrical energy only; however, it can also be used for benchmarking any other energy sources (gas, oil).

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