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An Extended Model to Analyze Energy Saving: Parameters and Composition

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Abstract- Many energy saving concepts are deployed to achieve the environmental and economic targets. But for many years, terminology and definition of energy saving concepts was a source of confusion and debate. In this paper, we analyze some representative literature examples about these concepts and their meanings. Then we develop a methodology to classify energy saving concepts in a new way with clear borders that can help energy analysts to detect all energy saving measures without interference between concepts. We first link each concept with physical parameters such as energy and output losses. These parameters are extracted from an extended energy flow model. Each parameter is related to output variation (i.e. output increased, decreased, or fixed). After that, each concept is matched with its corresponding parameter. Combining the 2 ways, the classification of energy saving concepts is finally done in relation with output variation. According to our logic, four energy use concepts are defined to compose energy saving: "Energy Recovery", "Energy Sufficiency", "Energy Efficiency", and "Useful output reduction".

Keywords Energy Saving; Energy Efficiency; Energy Sufficiency; Energy Conservation.

1. Introduction

Authors Energy Saving and renewable energy are the pillars of energy sustainability which is also a pillar of sustainable development. Many energy use concepts are deployed to achieve the environmental and economic targets such as Energy Conservation and Energy Efficiency. But for many years, terminology and definition of energy saving concepts was a source of confusion and debate. "These terms have no standardized meanings at the present time." [1]

This confusion is present in the scientific literature in many articles, theses, technical guides and reports from scholars, engineers and technicians. Most of the time, the ambiguity and confusion concerns two terms: Energy conservation and Energy Efficiency.

1.1 Justification / Significance / Need of the Study.

We think this work can be a step toward more standardization of these concepts. We do not judge the ideas presented here after but we rather aim to help figure out some of the ambiguities accumulated over decades about the issue. This analysis allow us to detect all energy saving parameters from an energy flow tracking.

The methodology developed in this study leads us to classify energy saving concepts in a new way with clear borders. The outcome model can help energy analysts to detect all energy saving measures without interference between concepts.

1.2 Confusion about Energy Conservation

In general, we distinguish four cases in the literature as shown in following citations:

1st Case: Energy conservation covers meanings about energy management in general including energy saving, renewable energy use, etc.

In Next statement, the author represents the elements composing energy conservation concept: "Energy conservation" can mean a variety of things, and this discussion covers all of them. The most common meanings are:

- using less energy in a particular application
- finding ways to purchase particular forms of energy at lower cost. […]
- shifting to different energy sources of lower price
- using "free" or "renewable" energy sources (Paradoxically, this is often expensive.)
- shifting to energy sources that are considered to be more desirable, or less undesirable, with regard to non-efficiency concerns such as availability and pollution. Such shifts typically involve serious compromises.
- conserving water and materials, as well as energy sources.

Information about energy conservation is not usually grouped in ways that distinguish between these meanings." [1]

2nd case: Energy conservation used interchangeably with energy savings; and refers to all concepts that reduce energy consumption such as energy efficiency:

"By identifying the energy consuming components of a building or plant and documenting the existing conditions, conservation opportunities can be identified and prioritized." [2]

"These energy conservation measures are general and also niche specific. Owners or managers of industrial parks and factories are not always aware of the possibilities for energy efficiency improvements. Energy audit is the first step in order to discover the possibilities of energy savings." [3]

"Some analysts, chiefly outside the United States, embrace energy conservation as an umbrella term for energy efficiency plus changes in personal habits plus changes in system design (such as spatial planning or design for product longevity and materials recovery/reuse)." [4]

"Energy Conservation includes two broad meanings that are fundamentally different. One is improving the "efficiency" of equipment or processes. The other is avoiding useless expenditure of energy." [5]

3rd case: Energy saving includes energy conservation and energy efficiency. In this case, energy conservation is often a behavioural change and energy efficiency is a technological change:

"By identifying and implementing the means to achieve energy efficiency and conservation, not only can energy savings be achieved, but also equipment/system services life can be extended. All these mean savings in money." [6]

"At the most basic level, energy conservation means using less energy and is usually a behavioural change, like turning your lights off or setting your thermostat lower. Energy efficiency, however, means using energy more effectively, and is often a technological change." [7]

"Energy conservation refers to limiting or reducing energy consumption through change in lifestyle or behaviour (e.g. turning off light in unoccupied rooms), while energy efficiency refers to limiting or reducing energy consumption through the adoption of more efficient devices (e.g. use of compact fluorescent light bulbs instead of incandescent light bulbs). [8]

"Turning off a light is energy conservation. Replacing an incandescent lamp with a compact fluorescent lamp is energy efficiency." [9]

"Energy conservative behavior of occupants, motivating and educating people for the use of renewable energy sources and use of energy efficient appliances are found to be the most efficient steps to reduce overall energy consumption by residential building sector." [10]

4th case: energy saving, energy conservation and energy efficiency considered as synonymous:

"Energy conservation: An ambiguous term best avoided; considered by some as synonymous with increased energy efficiency." [4]

"Energy conservation" and "energy efficiency" are often used interchangeably." [7]

"Energy saving or energy conservation through the change of human behavior only, without any capital cost can be a great option to meet demand instead of increasing generation. However, because of unpredictable nature of human behavior change long term individuals and organizational involvement is essential for energy efficiency achievement."[11]

1.3 Confusion about Energy Efficiency

2 notable cases are to be discussed:

1st case: Energy efficiency is included as the major component of energy saving

For instance, the US department of energy stated: "The main outcome of an energy audit is a list of recommended energy efficiency measures (EEMs), their associated energy savings potential, and an assessment of whether EEM installation costs are a good financial investment." [12]

But according to Zehner Ozzie: "When individual or organizational energy consumers institute energy efficiency measures, such as using more efficient light bulbs or machinery, they also save money on energy. However, consumers may choose to spend these savings on other products or endeavors that still lead to energy consumption. In this case, money-saving energy efficiency measures can unintentionally stimulate other forms of consumption, leaving overall energy footprints unchanged." [13]

Face up to this fact, many experts discussed other alternatives or complements to energy efficiency such as energy sufficiency: "In the last four decades, energy efficiency increased significantly in OECD countries. However, only during the most recent years, total energy consumption started to decrease a little, and much more slowly than energy efficiency potentials would suggest. Energy sufficiency has therefore gained new attention as a way to limit and reduce total energy consumption of a household or a country overall." [14]

2nd case: the definition of energy efficiency as a ratio between energy consumption and output:

Let examine these 2 examples of statements:

"It is generally thought that an increase in energy efficiency is when either energy inputs are reduced for a given level of service, or there are increased or enhanced services for a given amount of energy inputs." [15]

"Improving energy efficiency does not necessarily mean using less energy. Energy efficiency creates a range of direct benefits, or impacts, which range from less energy use to deliver the same service (energy savings), through to the same energy use to deliver more output (energy productivity)." [16]

Increasing the output without energy reduction; will not achieve the sustainability goals. At the actual rate of economic development, if the consumption remains at the same level, energy resources will not suffice for next generations. For that reason, energy productivity improvement must be followed by the reduction of output demand to ensure energy saving.

The ratio is good as an energy efficiency measure, but not quite as a definition. Therefore the issue must be examined.

In summary, there is not a clear energy saving framework that encloses all contributing concepts limiting the confusion in their interpretation. In next sections, we propose our point of view about these concepts and their meanings. At the end we present a classification model of energy saving concepts according to their relation with output variation and physical parameters.

2. Methodology of Classification of Energy Saving Concepts

Usually, energy saving concepts are defined according to their action on both energy consumption and output variation. But to enlighten fuzzy sides of the issue, we suggest to link first each concept with physical parameters.

These parameters are extracted from an extended energy flow model (the model is general but it is more adapted with industrial and services sector). Within this phase, each parameter is related to its corresponding output variation.

On the other side, each concept is matched with its corresponding parameter.

Combining the 2 ways, the classification of energy saving concept is done in relation with output variation of a system. "Figure 1" summarizes the methodology followed in this paper to determine and define all energy saving concepts.

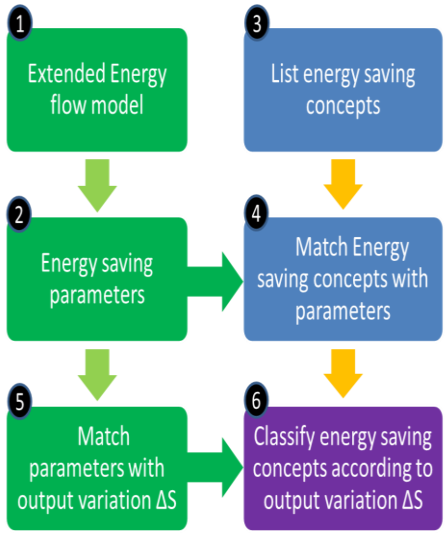

Fig. 1. Methodology used to determine and define all energy saving concepts..

3. Extended Energy Flow Model

Energy saving includes all actions that reduce energy consumption regardless of output variation. Let Su be the useful output (service or product) and E_i the corresponding energy consumption.

To detect all energy saving opportunities in a system or equipment, we track down all energy and output routing through usual energy flow model (Fig. 2).

Overrating output demand increases energy consumption level. As the usual energy flow model doesn't include this aspect, we rebuild it in the opposite direction.

To make an enough complete energy analysis, we start from output by defining optimal output as a target instead of useful output. Then we consider alongside the energy-output flow, all possible and distinct losses and conversion processes.

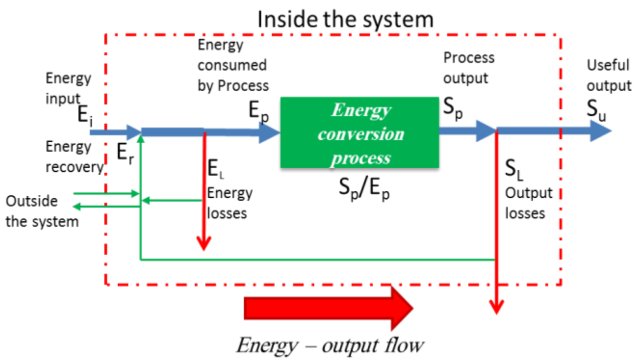

Fig. 2. Classic energy-output flow

In this expanded model, we add two elements:

- S_{op} representing the optimal output because the useful output Su is not optimized.
- S_{ov} representing losses between optimal and useful output due to overrating output.

The outcome is an extended energy-output rating model (Fig.3). These elements are discussed with more detail in section 3.

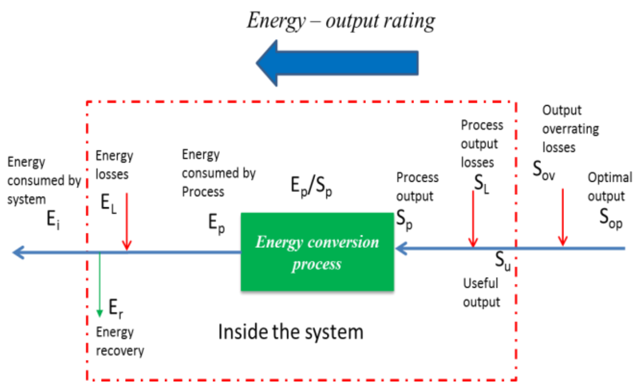

Fig. 3. Energy-output rating model.

It follows that $E_i + E_r = E_L + E_p$ (1)

And $S_p = S_L + S_{ov} + S_{op}$ (2)

As $E_p = (E_p/S_p)^* S_p$ (3)

So $E_i = E_L + (E_p/S_p)(S_L + S_{ov} + S_{op}) - E_r$ (4)

By analyzing "equation (4)", we determine all parameters to reduce energy consumption E_i throughout 3 phases of the energy output flow:

1. Upstream conversion process :
   - a- E_r energy recovery
   - b- E_L reduce energy losses
2. During conversion process: $\frac{E_p}{S_p}$ improve the energy conversion process by reducing the ratio value.
3. Downstream conversion process : when $E \propto S_u$,
   - a- S_L, S_{ov} reduce output losses
   - b- S_{op} reduces optimal output level

4. Energy Saving Parameters

4.1. Energy Recovery

E_r represents the part of energy recovered from energy input losses and process output losses inside or outside the system. By this way, a part of initial energy supply can be ensured by the recovery system and then the energy consumption from the source is reduced. The inherent energy consumption of the system doesn't change by energy recovery, it only reduces the proportion of main energy sources in powering the system. So E_r ensure $\Delta E<0$.

4.2. Reduce Energy Losses

E_L: Energy input losses. In electrical production, we can cite low electrical power quality due to harmonic distortion, iron or core losses and copper losses in induction motor, heat dissipating in ballast of fluorescent lamp. In electrical generation, "loss of the amount of sunlight falling on a photovoltaic panel surface because of dust shading" [17] is an example of losses. Low fuel quality due to presence of water and dirt in power generators is another common one.

This measure can be performed while the output is kept the same, hence it can be classified into the category $\Delta S_u=0$ & $\Delta E<0$.

4.3. Improve the Energy Conversion Process $(E \propto S_u)$

$\frac{E_p}{S_p}$ concerns changes inside process (a part from input losses). If we reduce E_p and fix S_p Then $\Delta S_u=0$ & $\Delta E<0$. If we Increase S_p and fix E_p, it means the energy productivity of the system is improved. Then we reduce S_p level to the initial value to get $\Delta S_u=0$ and consequently $\Delta E<0$.

If the energy productivity is more improved, we can reduce S_p to a higher level than initial value, to get finally $\Delta S_u>0$ & $\Delta E<0$.

"Figure 4" explains graphically this issue. We start from a couple (S_1, E_1) and make changes on energy productivity and output demand to check the result.

f represents the relation between energy consumption and output while g represents the new relation after improving energy productivity of the system. We suppose in the following that $i<j \Rightarrow \begin{cases} S_i < S_j \\ E_j < E_i \end{cases}; i,j \in \mathbb{Z}$

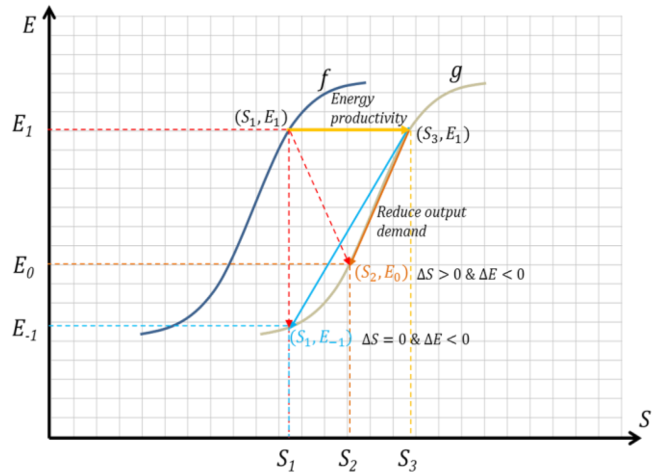

Fig. 4. Action on energy consumption by energy productivity improvement combined with output level reduction

In summary, changing or optimizing the conversion process ensure both $\Delta S_u>0$ & $\Delta E<0$ and $\Delta S_u=0$ & $\Delta E<0$.

4.4. Process Output Losses $(E \propto S_u)$

S_L: Process output losses reduction is separated from conversion process (e.g. windage and friction in induction motor, illuminating undesired area, and production losses in manufacturing). Basically, this measure leads to useful output increasing $\Delta S_u>0$ & $\Delta E=0$. Followed by a reduction of output demand, it saves energy since energy consumption and output are correlated. So this case can ensure both $\Delta S_u>0$ & $\Delta E<0$ and $\Delta S_u=0$ & $\Delta E<0$.

4.5. Optimal Output Level $(E \propto S_u)$

S_{ov}: Overrating losses.

Each user expects from an energy system or equipment to provide a service or produce a good under specified requirements such as quality, quantity, and time of processing…etc. But these specifications can be overestimated, like using a powerful laptop for secretarial work. This can be caused by:

- Exaggerating needs and requirements in matter of technical utility and comfort.
- Activating unnecessary technical features that consume energy.
- Not respecting the state of art by neglecting or omitting standards, engineering rules, and other field related scientific documents or experience feedback.

Reducing overrating losses means $\Delta S_u<0$ & $S_u \geq S_{op}$ which ensure energy saving when the output is related to energy consumption.

S_{op}: Optimal output level under which the requirements are partially or totally abandoned. Reducing output under this level save energy too under the category: $\Delta S_u<0$ & $S_u<S_{op}$

5. Energy Saving Parameters in Relation with Energy Saving Concepts

A is an action or measure that transforms an initial situation (S_i, E_i) to a final one (S_f, E_f). We denote $\Delta S_u=S_f - S_i$ and $\Delta E=E_f - E_i$, then the set of Energy saving measures or actions noted (ES) is defined by:

$$(ES) = \{A/ \Delta E <0\} \quad (4)$$

5.1. E_r: Recover Energy from Internal or External Wastes

Energy recovery provides an additional amount of energy E_r that can be reduced from energy source. So energy is saved. This action does not have any effect on useful output variation.

5.2. $\frac{E_p}{S_p}$, E_L, S_L : respectively Conversion Process, Energy Losses, Process Output Losses

These parameters reduce energy consumption while maintaining the same output level or increasing it.

The corresponding concept is unanimously recognized as energy efficiency; as explained in next statements:

"In general, energy efficiency refers to using less energy to produce the same amount of services or useful output." [18]

"[…] Efficiency, on the other hand, maintains the same level of output but uses less energy to achieve it." [7] "Energy efficiency reduces energy input while keeping the utility/services from energy constant. " [19]

"Energy efficiency means doing more (and often better) with less". [4]

5.3. S_{ov}:

Reducing overrating losses S_{ov} means useful output is reduced but only until optimal level. Let's examine these 2 following statements:

"With energy sufficiency, energy consumption is reduced while the utility/technical service changes in quantity or quality." [14]. But this changes don't affect the usefulness of the service. Another definition of energy sufficiency is: "Identifying 'optimal' energy service levels." [19]

Considering these statements, we can say that energy sufficiency aims to reduce the output -and then energy consumption- to the minimum uncompromising level so that user's interests are preserved. So reducing S_{ov} corresponds to energy sufficiency.

Sometimes, defining optimal level is subjective and is then hard to fix especially in cases such as residential buildings. However, we believe that even in those cases, by informing and sensitizing users, the gap between optimal output and output demand can be reduced.

5.4. S_{op}:

Reducing optimal output level, reduces certainly energy consumption but sacrifices some or all service features such as comfort, processing time, quality etc.

From all used concepts, energy conservation -in one of its meanings, as we present in introduction- is the only concept that matches with this parameter as we can see in following statement:

"Conservation certainly reduces energy use, but it's not always the best solution because it may impact comfort or safety as well." [7]

Energy conservation has been used for a long time by some experts as synonymous for all energy saving concepts and sometimes including "renewable" energy sources.

In that sense, they avoid to narrow its meaning and give it a negative label which is reducing energy to the detriment of service level: "Energy conservation: […] to many others connoting the opposite: privation, curtailment, and discomfort, i.e., getting fewer or lower quality energy services." [4]

For that reason, we decide to avoid using it as suggested by A.B. Lovins:"Energy conservation: an ambiguous term best avoided". [4]

At least, it can be named literally: useful output reduction.

Practically, this action is limited to the case of personal commitment to environmental cause, or under politic decision motivated by energy crisis or financial austerity.

6. Energy Classification of Energy Saving Concepts Upon Output Variation

The set of Energy efficiency measures or actions noted (EE) is defined by:

$$(EE) = \{A/\ \Delta S \geq 0\ \&\ \Delta E < 0\} \quad (5)$$

- If $S_{op} \leq S_u < S_i$, the action is Energy Sufficiency.

$$(ESU) = \{A/\ \Delta E < 0\ \&\ S_{op} \leq S_u < S_i\} \quad (6)$$

- If $S_u < S_{op}$, it is useful output reduction

$$(UOR) = \{A/\ \Delta E < 0\ \&\ S_u < S_{op}\} \quad (7)$$

According to the energy-output rating model; we match each energy saving parameters with corresponding concepts based on output variation ΔS as shown in “Table 1.” All parameters are combined in “Eq. (4)”.

$$E_i = E_L + (E_p/S_p)(S_L + S_{ov} + S_{op}) - E_r \quad (4)$$

During time of service, E_L can be decomposed to n parts E_{Li} where $1 \leq i \leq n$, that stays an amount T_{Li} of time with a P_{Li} power level. So:

$$E_L = \sum E_{Li} = \sum P_{Li} * T_{Li} \quad (8)$$

“Table 1.” presents the classification of energy saving concepts in relation to the variation of output. For practical implementation of these concepts during an energy analysis; each concept is presented by its corresponding physical parameters extracted from energy flow model. The classification is aimed to cover all phases of life-cycle of an equipment, or an energy system from design and conception to operation and maintenance.

7. Application Examples

The classification methodology we present in this paper can be used as a tool to extract all possible energy saving measures in a structural way.

In cases where time and financial resources are limited; it helps also improving the flexibility of energy auditors’ solutions in the way that they can implement multiple combinations of energy concepts.

Two examples of application are presented below in tables. “Table 2.” Concerns lighting while “Table 3.” is about a production line of recyclable products including machines, personnel and auxiliary equipment such as HVAC, lighting, etc.

Table 1. Classification of energy saving concepts upon output variation

<table>
<tr><th rowspan="3">ΔE<0</th><th colspan="5">ΔE<0</th></tr>
<tr><th colspan="2">ΔS_u<0</th><th colspan="2" rowspan="2">ΔS_u=0</th><th rowspan="2">ΔS_u>0 $(E \propto S_u)$</th></tr>
<tr><th>$S_u < S_{op}$</th><th>$S_u \geq S_{op}$</th></tr>
<tr><td rowspan="3">E_r
Increase the amount of energy recovered</td><td rowspan="3">S_{op}
Reduce output level.</td><td rowspan="3">S_{ov}
Reduce overrating losses</td><td colspan="3">Reducing the ratio value $\frac{E_p}{S_p}$</td></tr>
<tr><td colspan="2">E_L
reduce energy losses</td><td rowspan="2">S_L
Reduce output losses then reduce output level</td></tr>
<tr><td>P_{Li}
Power losses</td><td>T_{Li}
Time use losses</td></tr>
<tr><td>Energy Recovery</td><td>Useful Output Reduction</td><td>Energy Sufficiency</td><td colspan="3">Energy Efficiency</td></tr>
</table>

Table 2. Example of classification of energy saving opportunities in lighting using the proposed model

ΔE<0	**ΔE<0**			
	ΔS_u<0		**ΔS_u=0**	**ΔS_u>0**
	$S_u < S_{op}$	$S_u \geq S_{op}$		
Energy recovery For instance : Power supply from Waste heat recovery system.	- Turn off light *even if used or needed* - Use lamp *under rated or needed* illuminance.	- Optimize lighting parameters required - especially illuminance- according to standards (e.g: - European Standard EN 12464. - IES lighting Handbook	*Energy losses* (power & time): - Turn off or reduce light when not necessary: • Manually ✓ Enhanced by optimized wiring design (e.g. avoid 1 switch for a group of dispersed lamps) • By lighting control & management ✓ occupancy/movement control ✓ daylight sensors ✓ programmable clocks/timers ✓ dimmers - Use high efficiency ballast - improve power supply quality (e.g. lower THD) - reduce wiring losses	*Output losses* - High performance reflectors - Optimizing directions and positions of lamps and luminaires - Light reflective paint - Cleaning lamps and luminaires
			Conversion process: - Daylight harvesting - LED, - Fluorescent lamp, - High intensity discharge (HID) for exterior lighting	
Energy Recovery	**Useful Output Reduction**	**Energy Sufficiency**	**Energy Efficiency**	

Table 3. Example of classification of energy saving opportunities in a production line of recyclable products {Machines +personnel + auxiliary equipment (lighting, HVAC ...etc.} using the proposed model

<table>
<tr><th rowspan="3">$\Delta E<0$</th><th colspan="4">$\Delta E<0$</th></tr>
<tr><th colspan="2">$\Delta S_u<0$</th><th rowspan="2">$\Delta S_u=0$</th><th rowspan="2">$\Delta S_u>0$</th></tr>
<tr><th>$S_u < S_{op}$</th><th>$S_u \geq S_{op}$</th></tr>
<tr><td rowspan="2">Energy recovery
For instance :
- Waste heat recovery system.
- Machines: Kinetic energy recovery system (KERS)</td><td rowspan="2">- Reduce production amount under rated level
- Turn off or reduce environment equipment usage: lighting, HVAC, etc.
even if used or needed</td><td rowspan="2">- Optimize production requirements in terms of :
Quantity, quality, processing time, etc.
- Optimize auxiliary equipment’s specifications according to new production targets.</td><td>*Conversion process*:
- Optimize the production process for less energy consumption
- use energy efficient machines
- use energy efficient components or algorithms for exisiting machines.</td><td>1- Improve energy productivity
- apply methods such as :Total Productive Maintenance
- optimize the production process
- motivate and train the personnel
- reduce machine failures.
2- Then reduce quantity to produce</td></tr>
<tr><td>*Energy losses*:
Reduce energy losses of auxiliary equipments: lighting, HVAC…etc by applying energy efficiency measures.</td><td>*Process output losses*:
Reduce quantity of non-compliant products :
- Apply quality Improvement methods such as:
Lean manufacturing, six sigma, Total quality management,…etc
- training personnel</td></tr>
<tr><td>**Energy Recovery**</td><td>**Useful Output Reduction**</td><td>**Energy Sufficiency**</td><td colspan="2">**Energy Efficiency**</td></tr>
</table>

8. Conclusion

According to our logic, any energy saving action or measure belongs to one of the four energy use concepts: “Energy Recovery”, “Energy Sufficiency”, “Energy Efficiency”, and “Useful output reduction”. Energy conservation is too ambiguous that we prefer to avoid. Each concept was defined based on output variation and implemented through physical parameters extracted from an extended energy output flow model. These concepts must be implemented in synergy rather than being put in competition. The model proposed can be integrated in energy management program as a useful tool to collect the maximum of energy saving opportunities of an energy system or equipment. It can be implemented during the design and conception phase as well as during operation & maintenance.

This study is a platform on which we can build an energy saving audit model. This platform can be enriched by methods of implementation of energy saving measures in the field over a life-cycle of an energy system.

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