

A novel systematic and comprehensive method for identification of energy-saving measures

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Abstract

Energy savings are driven by technological solutions along with behavioural changes and managerial decisions. A systematic and comprehensive method of identification of energy-saving measures can be a powerful tool for that purpose. Within this context, we propose a simplified, systematic and comprehensive method to bridge gaps of usual approaches. It was built by combining consecutively 3 developed tools: an energy-saving model, a process-oriented decomposition approach and a multi-criteria decision-making analysis of alternative energy-saving solutions. The outcome is a matrix filled with energy saving measures by corresponding sub-processes in lines to energy parameters such as energy sufficiency or output losses in columns. A central sterile service department in a university hospital in Morocco was analysed at the operating phase. Via this method, we could systematically and fluently list all viable energy-saving features. Concretely, the modernity of the installation confined the margin of manoeuvre to managerial and behavioural measures. The multi-criteria decision-making analysis process applied on steam generator of autoclaves highlighted many instructive points on induction heating development potential despite of its qualitative character.

Keywords: Energy saving, energy audit, identification, sterilization.

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1. Introduction

1.1. Energy audit role in energy-saving

Energy management intervenes on the energy supply chain from generation to end-use. It directly depends on the use of energy-efficient [1-2] and energy-generating devices. The development of alternative methods of generating electrical energy attached the interest of scientists around the world. For example, devices that convert the energy of the sun into electricity, converters of kinetic energy and other types of energy into electrical energy [3-4].

On the other side, implementing technologies was promoted widely to ensure the maximum of energy savings. But it was not sufficient, since there are complementary problem dimensions related to management and behaviour. Energy management arose as

inescapable complementary approach to improve and sustain energy savings.

In response, the International Organization for Standardization (ISO) issued a series of standards including ISO 50001, a global reference in this field. Particularly, it positions energy planning as a central feature which requires energy review, baseline and Performance Indicators [5]. The energy review as described in ISO 50001 is similar to an energy audit. The term “energy audit” is more commonly used in literature; and thus is used in next paragraphs.

The basic requirement for a working method to be called an Energy Audit is that a Core Audit exists in the procedure. The Core Audit is the heart of all possible energy audits and includes the steps of: a) evaluating the present energy consumption, b) identifying of energy saving measures and c) reporting [6].

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1.2. Identification of energy-saving measures: State of art.

Identifying is the main output of an energy audit. Distinguished identifying methods can be classified into 3 classes:

Analytical method: The process or equipment is analysed mainly by decomposition to sub-components in order to extract the elements leading to the reduction of consumption. The energy flow or energy saving (and possibly mass balance) mathematical analysis is performed to detect influencing parameters [7-10].

Empirical method: This is either an experimental or statistical analysis combined with mathematical modelling for the identification of a correlation between energy consumption and some influencing variables: relevant variables and static factors [11]. Relevant variables can be: production data, weather conditions, temperature, number of shifts, etc. [12].

Benchmarking: the process of identifying and understanding the differences in energy use practices between similar processes or organisations and collecting applicable energy saving solutions. A common feature of this approach consists of adopting a set of established measures of high energy saving level or high implementation percentage in-situ [13].

1.3. Identification methods review.

Analytical methods has the advantage to be more comprehensive as they explore all energy saving factors. Interestingly, with an adequate decomposition, they permit the use of the empirical method for some sub-components as well as measures deduced by benchmarking. Hence their great potential for achieving more completeness in the analysis. Whilst some analytical methods are more a "do-as-you-like" mere top-down breakdown; others are developed systematic approaches such as those aforementioned. Nevertheless, they present some features that partially affect - depending on each case - their ergonomics, universality, systematicity or efficiency:

- The adoption of equipment-oriented decomposition neglects the effect of processes on equipment in analysis. This point is discussed later in section 4.1.

- Only a few aspects of the energy saving concept are considered. This is partly due to the lack of a definition of the concept in relation to other common concepts such as energy efficiency. Some areas of energy savings are omitted.

- The choice of energy saving concepts is made at the beginning of the system analysis. Thus, linking system components to each energy saving concept is weak and not systematized. This reduces the completeness of the analysis.

- With the exception of Nguyen's method [16], the system components are analysed independently of each other. In case interactions are taken into account, this step of the

analysis is not systematized. This is a great loss of the method performance.

- Again, with the exception of Nguyen's method [16], the criterion of the top-down decomposition from a level to a higher one is not dealt with.

- Lack of a systematic procedure for decision-making based on well-defined criteria when there are several alternatives for an energy-saving solution.

So it seems that there is a big need to widen the range of proposed methods in literature to support professionals in identifying energy saving measures with more accuracy and simplicity. Under this goal, we develop a systematic and universal approach that can be integrated in the ISO 50001 procedure or other energy management frameworks to ensure a simplified, systematic and comprehensive energy-saving measures identification process.

2. Methodology

The energy-saving analysis method developed in this paper is an analytic method developed on the basis of 3 main pillars:

- Energy saving concept or model adopted by the analyst. In this study, the 3E1U model developed by Jemmad et al. is used [14].
- The system breakdown or decomposition method. A novel process-oriented decomposition method is used.
- Multi-criteria decision-making analysis (MCDA) of alternative energy-saving solutions.

3. Energy saving concept

In the 3E1U model adopted in this study, energy saving is composed of one of the four energy use concepts: "Energy Recovery"(ER), "Energy Efficiency" (EE), "Energy Sufficiency" (ES), and "Useful output reduction" (UOR). Hence, energy saving actions or measures are classified according to these four concepts. Each concept refers to its corresponding physical energy parameters:

- Energy Recovery: Energy Recovery
- Energy Efficiency: Energy losses; conversion process; output losses.
- Energy Sufficiency: Overrating output losses.
- Useful output reduction: Optimal output.

The integration of these concepts into an energy analysis can be total or partial according to the audit scope. Many combinations are possible, but generally the analysis is centred on energy efficiency and energy recovery to meet environmental or financial targets. In which case, there are 3 scenarios to envisage:

- 1st scenario: ER-EE.
- 2nd scenario: ER-EE-ES.
- 3rd scenario: ER-EE-ES-UOR.

Analysis completeness level increases from first to third scenario. Conversely, when Useful output reduction is introduced, the user comfort or satisfaction decreases. That's stems from the curtailment practices or policies imposed by output reduction measures on user (e.g. turn off car's air conditioner in summer to reduce fuel consumption). In case of Energy Sufficiency, the effect is felt at a lesser degree because the reduction is lesser too. It is worth mentioning that this constraining feeling is deceptive in case of energy sufficiency because it does not affect user experience as it concerns only dispensable levels of output. Such waste is defined by respecting standards, state of art, engineering rules, when defining a system output level. At personal level, it means simply act by reason to express its own needs. But capricious on unaware users may not be quite satisfied.

4. System breakdown or decomposition method

4.1. Comparison of process-oriented and equipment-oriented approaches

Most of energy use methods relies on 2 decomposition approaches: bottom-up equipment-oriented or top-down process-oriented. In the first, equipment are listed along such as motors, pumps, chillers, lighting systems, etc. Process-oriented approach consists of decomposing the system by service or process under which equipment analysis is then performed. E.g. Figure 1 illustrates the energy use analysis of a smartphone by its decomposition to main processes such as 3G, CPU, Wifi, screen, etc.

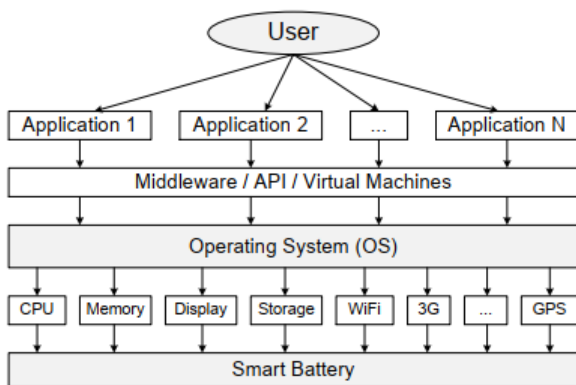


Figure 1. Example of a process-oriented breakdown of energy use in a smartphone [10].

But since energy is deployed to produce an output. The analysis of the consumption according to the processes gives more relevance on the energy use in the system. The output process is affected by equipment, human behaviour and organization of these elements. In that sense the process-oriented approach gives a holistic analysis of the

system. Compared to the classic equipment-oriented, this approach presents following advantages:

- Considers the role of human behaviour indirectly but representatively.
- Considers the effect of process management on energy saving.
- Considers differences of performance and intensity of use of an equipment in different processes of a system. In a factory for instance, industrial processes are more aggressive towards lighting systems compared to offices. Thus, energy saving measures of lighting systems will not be identical.
- Institutionalization and identification of best practices in energy saving projects of similar systems within an organization.
- Participatory approach that involves equipment users.

However, some aspects need to be added to the classical process-oriented approach to ensure accuracy and completeness of analysis.

4.2. An alternative derived decomposition method: core/ auxiliary/ interactions between processes

At the beginning, a “single-process” system can be decomposed into 2 elements:

- A core process/component producing the output.
- Auxiliary or support processes/ components supporting the core process to provide this output.

For instance; the data servers and air conditioning represent respectively the core and auxiliary processes in a data server room.

Moreover, we should mention that saving energy of a means of production is not the sum of energy savings locally collected in the different organs. Besides, some processes may have common energy input or serve in combination a common output. In such cases, we must analyse interactions between the processes enclosed within a system before dealing with processes and that for each level of decomposition. Hence a third element should be counted in process-oriented decomposition:

- Interactions between processes.

4.3. Decomposition criteria

Since the decomposition requires more effort and time, it is important to judge its worthiness for deep levels from an energy-saving perspective. The judgement can be qualitative according to analyst expertise or quantitative. An example of a quantitative approach is to simply set a reference saving percentage.

Let $E_i^{(k)}$ be the energy consumption of a subsystem i at level k noted $X_i^{(k)}$.

$E_i^{(k+1)}$ is the estimated energy consumption of $X_i^{(k)}$ due to energy saving measures expected from its decomposition to level $(k+1)$. Then we have $E_i^{(k+1)} \leq E_i^{(k)}$. Let's note

$$x_{ref} = \frac{E_i^{(k+1)}}{E_i^{(k)}} \quad (1)$$

x_{ref} is a reference value of x in % set at the beginning of the analysis for each level.

If $x < x_{ref}$: decomposition can be done.

If $x \geq x_{ref}$: no decomposition to be done.

For instance, we suppose that $x_{ref} = 85\%$ and $E^{(3)} = 100\text{kWh}$.

If $E^{(4)}$ is estimated to 80kWh , then $x = 80\%$. So $x < x_{ref}$, consequently, we can proceed to decomposition, otherwise we keep energy saving measures of level 3.

5. Multi-criteria decision-making analysis of alternative for energy saving measures

5.1. Multi-criteria decision-making analysis process

In some cases, many alternatives are available but only one can be used. We are then faced to a decision-making problem that should be analysed and solved based on multiple criteria. The Multi-criteria decision-making analysis (MCDA) followed in this study consists of many stages as described in Figure 2.

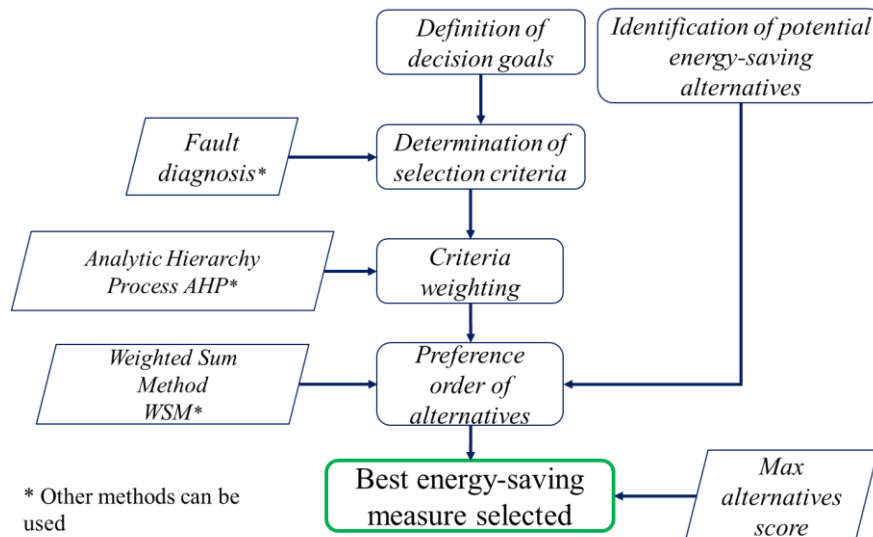


Figure 2. MCDA selection process of energy-saving measures alternatives.

These stages are described in detail one by one in next sections. At each stage, a specific method was selected according to our preferences. However other methods can be used by auditors.

The important thing is to finally determine suitable criteria, weight them and order alternatives appropriately.

5.2. Criteria selection and definition

Selection criteria are defined based on a decision goal which is: applicability and sustainability of energy saving measures. That is to say when an equipment or a system is selected to save energy; it must firstly, really achieve it and secondly, keep this performance during its lifecycle. A fault diagnosis is conducted to identify the faulty states that prevent a measure from achieving the main goal: applicability and sustainability. Consequently, a criterion emerges from each state. A multiway selection Flowchart in Figure 3 represents this process.

Accordingly, Seven (07) selection criteria are considered:

- Energy-saving performance: refers to real energy-savings that can be achieved with respect to output characteristics of existing alternatives.
- Safety: “Freedom from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment” [15].
- Operating cost: comprises all costs related to operating energy-saving equipment or system. In case that Cost-benefit analysis (CBA) and Cost-effectiveness analysis (CEA) are used for implementation, operating cost are counted too in analysis.

- Reliability/Availability: according to IEC standards: Reliability: is the ability of an item to perform as required, without failure, for a given time interval, under given conditions. Availability: is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided [16].

- Implementation cost or cost investment: comprises all costs relating to manufacturing, purchase, or installation.
- Maintainability: Wulfinghoff pointed out: “Unfortunately, there is a tendency to believe that energy conservation is exempt from maintenance. “Do it and forget it.” Nothing could be more wrong.”[17].

- Usability: according to ISO 9241-11 usability is: “extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” [18].

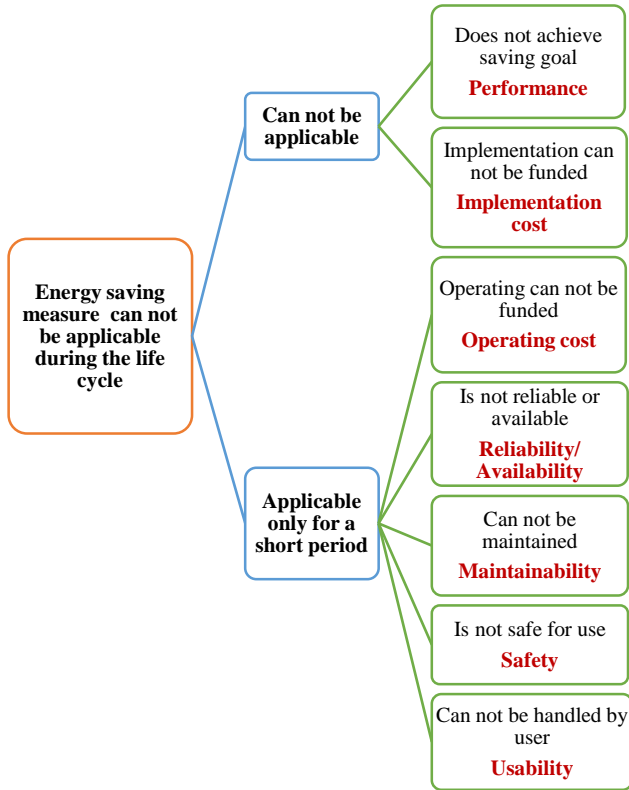


Figure 3. Energy-saving measures selection criteria by fault diagnosis method

Table 1. Pair-wise comparison matrix of criteria for energy-saving measures selection

Criteria	Energy-saving Performance	Safety	Implementation cost	Operating cost	Maintainability	Reliability/ Availability	Usability
Energy-saving Performance	1	2	3	3	3	4	4
Safety	1/2	1	2	2	2	3	3
Implementation cost	1/3	1/2	1	1	1	2	2
Operating cost	1/3	1/2	1	1	1	2	2
Maintainability	1/3	1/2	1	1	1	2	2
Reliability/ Availability	1/4	1/3	1/2	1/2	1/2	1	1
Usability	1/4	1/3	1/2	1/2	1/2	1	1
Weight	0.322	0.204	0.115	0.115	0.115	0.064	0.064

5.3. Criteria weighting

Criteria weights influence directly the decision-making results of energy projects’ alternatives. Equal criteria weights are still the most popular in weighting methods [19]. However, the criteria selected in this study have not the same impact on energy-saving measures selection. Therefore another consistent method is necessary. In the rank-order weighting methods, Analytic Hierarchy Process (AHP) method is more and more prevalent because of its understandability in theory and the simplicity in application [19]. Following analysis is referred to Saaty’s description of AHP method [20]. Table 1 presents the suggested matrix of pairwise comparisons between considered criteria. Worked out, the suggested weight of each criterion is presented therein.

5.4. Energy-saving alternatives selection method

The MCDA problem of this paper involves m alternatives evaluated on 7 proposed criteria. However, some may be interested with other criteria set. Hence in this section, we will discuss the selection for n criteria. After weighting criteria, energy saving measures alternatives are evaluated. In that field, Weighted Sum Method (WSM) is the most commonly used approach in sustainable energy systems [19]. The score of an alternative is calculated as:

$$S_i = \sum_{j=1}^n w_j x_{ij} \quad \text{where } i=1,2, \dots,m. \quad (2)$$

x_{ij} is the performance of j -th criteria of i -th alternative. Any alternative that have a criteria with zero performance is rejected; therefore $x_{ij} \neq 0$. w_j is the weight of criteria j .

For each criteria, corresponding performance of all alternatives x_{ij} must be rated on the same scale (e.g. from 1 to 5 or 1 to 10). For instance, we can assign 5 for a very high energy-saving performance and 1 for a very low one. And 5 for a very easy maintainability level and 1 for a very hard level and so forth. Finally, the alternative that obtained the highest score is the best one. Table 2 represents the criteria performance matrix and the best alternative selection process.

Table 2. Criteria performance matrix and best alternative selection process for an energy-saving measure.

Criteria performance matrix $(x_{ij})_{ij}$					Alternative score (WSM) $S_i = \sum_{j=1}^n w_j x_{ij}$	Best alternative $\max S_i$ $1 \leq i \leq m$
Alternatives	Criteria					
	C ₁	C ₂	...	C ₇		
	Weights					
	w_1	w_2	...	w_7		
A ₁	x_{11}	x_{12}	...	x_{17}	S ₁	
A ₂	x_{21}	x_{22}	...	x_{27}	S ₂	
⋮	⋮	⋮	⋮	⋮	⋮	
A _m	x_{m1}	x_{m2}	...	x_{m7}	S _m	

microorganisms”. According to WHO: “The fundamental role of the sterilization service is to receive, clean, decontaminate, package, sterilize and distribute medical devices.” [21]. When these activities are centralized in one service, it is called central sterilization service department (CSSD). The system studied is the CSSD serving Mohammed VI University Hospital (UH) of Oujda city in Morocco. It has a bed capacity of about 673 beds. All site data presented in this study were collected through a site survey and by interviewing staff department in the CSSD. Figure 5 illustrates the architecture of the studied CSSD. Three (03) zones are defined: dirty area, clean area, and sterile area. It includes a technical zone.

6. Method workflow summary

A system is decomposed to sub-systems in columns. Each sub-system is analysed through 3 elements: Core processes; auxiliary processes; interactions between processes. Upon a quantitative or qualitative judgement, the same decomposition will be executed further in a new column for core or auxiliary processes and so on until the final level. The final column will be then split to rows composed of one of the 3 elements and then constituting the matrix rows. On the other hand, from audit scope, the energy scenario is set and then energy parameters are put as matrix columns. The matrix is now build.

Pursuant to the cycle-life phases in study: Design, installation, operating, and maintenance; the analyst or auditor can fill the cells with energy saving measures. For each phase, only certain energy parameters are involved except for design where all of them are applicable.

In case that many alternatives are available for a measure but only one can be applied; the MCDA process is executed separately. The final decision is put in the corresponding cell. Finally, we get a decomposition matrix filled with energy saving measures. This approach is described in Figure 4.

7. Case study: central sterilization service department CSSD

7.1. Site introduction.

In simple terms, World Health Organization (WHO) states: “sterilization is the elimination of all disease-producing

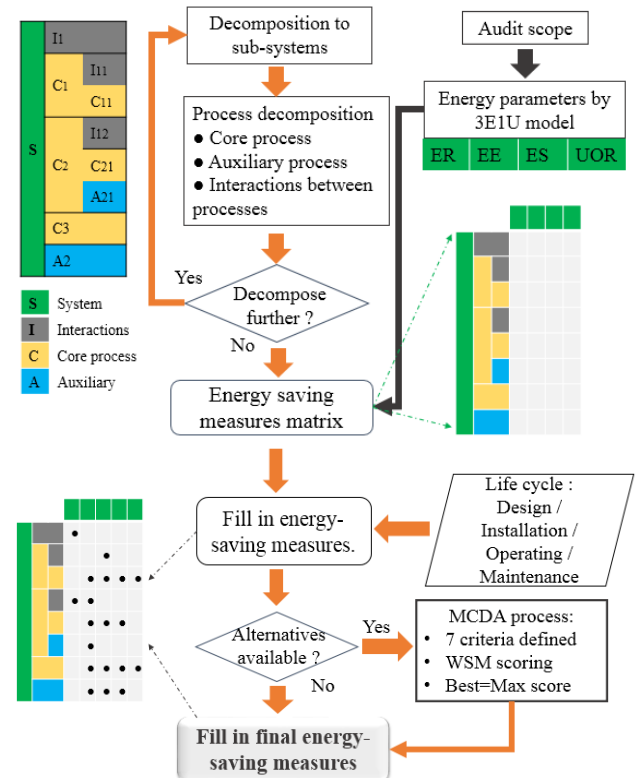


Figure 4. Energy-saving analysis method

Figure 5 shows also the flow of medical instruments to be sterilized across the 3 areas.

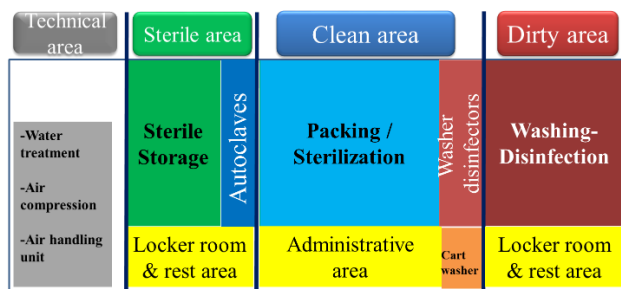


Figure 5. CSSD-UH of Oujda city: architecture and functional processes inside.

7.2. Identification of energy saving measures

Equipment and installation used in the CSSD are presented in Figure 6 and Figure 7. All surgery materials are brought to CSSD to be cleaned and put in washer-disinfectors machines.

Then after being packed, they are put in autoclaves. At the end, they are placed in sterile storage area. All the machines are installed as to ensure separation wall between areas.

Decomposition level was estimated qualitatively to 3rd level based on experience. Hence, there is no need for quantitative judgment in our case. Indeed, at the 3rd level, the processes are represented by end-use equipment where all measures can be discussed. Above that level, we have to inspect big consuming equipment such as autoclaves from inside.

Unfortunately, this can only be done at maintenance phase which is out of the scope of this paper to avoid burdening its contents.

Moreover, because of the modernity of the installation; it is not currently expected to find out relevant maintenance related measures.

Another point is that, given the economic feasibility, it is not viable to replace big equipment with others more energy efficient. Some of them are already energy efficient such as steam autoclaves for which the manufacturer claims an energy saving of 40%. By experiencing this tool in this case study; we get an abroad view on the system. According to our scope and preferences, we could list all viable energy saving features at operating phase within the CSSD as presented figure 8 and figure 9.

8. MCDA case study: Electric heating steam generator

8.1. Introduction

The steam generator (SG) can be either integrated in the autoclave or external. In the latter, the most of saving potential is available. Power rating of resistive heating elements counts for 75 to 95% of autoclave power rating depending on its capacity. For external steam generators,

induction heating (IH) steam generator can be proposed for comparison to ohmic heating (resistance heating) elements. Because the external SG is encouraged to be installed near to sterilizers; the gas/fuel boilers are excluded from comparison.

An average 500L autoclave with integral SG requiring 25kg/h steam flow rate, would have about 45kW power rated. Some established IH-SG propose a 26kVA water-cooled SG with up to 60kg/h. One will need a 60kVA power rated ohmic external SG to deliver a steam flow rate around.

8.1. Energy-saving comparison of ohmic and induction heating steam generators.

Energy-saving Performance: Induction heating well designed apparatus is largely more energy saving. With less power and fast heating, the total energy consumption can be reduced by at least 40% in sterilization [38].

Safety: In general, both are safe electrically and thermally [24]. In normal conditions, a few concerns were evoked about electromagnetic fields exposure by operating personnel, though without full investigation [25]. But still, considering that sterilization personnel does not approach often external SG and relying on metallic shielding of the SG; we can consider in the meantime that it cannot pose any hazard.

Implementation cost: This is the major inconvenient of IH technology compared to indirect ohmic heating [24]. The cost become higher with water cooling system or high output frequency inverters [25].

Operating cost: Limescale deposits on water resistance heaters will lead to increased running costs, as the heater will now require more to heat the water. Considering energy price, the IH with lower consumption entails less costs. In case of water cooling, SG water can be used firstly in inductor coil and then injected after being pre-heated in the reservoir which help reducing energy demand. Otherwise both systems does not consume other resources.

Maintainability: The complexity of IH machine due to power inverter and water cooling system reduces its maintainability. The indirect ohmic heating needs generally the replacement of the heating elements which are available and easy to install.

Reliability/Availability: IH are generally reputed highly reliable. Water resistance heaters are facing major problems: despite the use of treated water, limescale deposits occurs and cause cracks and fracture of tubes which will causes in turn electrical leakage and consequently power shut off [26].

A comparison between the 2 technologies would be then justified. A qualitative comparison is presented in Table 3.

Operating				Energy recovery	Energy input losses	Conversion process	Output losses	Output oversizing losses	Optimal output	
	1 st level	2 nd level	3 rd level							
CSSD	Interactions 1 (Washing/disinfection, Packing / Sterilization, sterile storage and technical zone)					Optimizing sterilization logistics (a)	Improve quality of task execution by the personnel			
	Washing/ disinfection ©	Interactions 2.1		solar energy for locker room & items manual washing		Optimizing work planning				
		Washing ©	Interactions 3.1							
			Ultrasonic washing machine ©				energy efficient equipment			
			Pump for drain pan @						Manual drain	
			Dosing pump @						Manual dosing	
		Disinfection ©	Interactions 3.2				reduce the number of washers working simultaneously by optimizing work planning			
			Washer-disinfector (x3) ©		use solar thermal energy (washer needs water & air above 93°C)			turn off or standby mode when not used		
			Cart washer ©							
		Storage @	Lighting ©				LED		resize to 100 lux (b)	

CSSD	Washing/ disinfection ©	Traceability by IT system @	PC ©				turn off or standby mode when not used			
			Printer @							
		Locker room / rest area @	Lighting ©			LED	Occupancy control	resize to 100 lux (b)		
			TV ©				turn off when not used			
			A/C ©				turn off when not used			
		Electric wall hatch 1 @								
		Area process lighting @						resize to 300 lux (b)		
© core process, @ auxiliary process (a) E.g. work published by Van de Klundert, Muls and Schadd [22]. (b) EN 12464-1:2011										

Figure 8. Matrix of proposed energy-saving measures- washing disinfection zone- CSSD- University hospital.

Operating				Energy recovery	Energy input losses	Conversion process	Output losses	Output oversizing losses	Optimal output
	1 st level	2 nd level	3 rd level						
Packing / Sterilization ©	Interactions 2.2					Optimizing work planning (a)			
	Inspection & packing ©	Interactions 3.3							
		Inspection lamp ©					turn off when not used		
		Sealing machine ©				energy efficient equipment	turn off when not used		
		Traceability IT system @				energy efficient equipment			

CSSD	Sterilization ©	Interactions 3.4			reduce the number of autoclaves working simultaneously by optimizing work planning					
					Compare alternative : External Steam generator SG by induction heating (c)					
		Autoclave steam (x3) ©	Heat recovery from steam exhaust by plate heat exchanger				turn off or standby mode when not used			
		Autoclave (H ₂ O ₂ -plasma) ©					turn off or standby mode when not used			
		Administration @	office lighting @			LED	occupancy control	resize to 500 lux (b)		
			office IT systems ©			energy efficient equipment	turn off when not used			
		Area process lighting @				LED	apply zoning & use dimmers in inspection zone	resize to 300 lux (b)		
		Sterile storage ©	Area process lighting ©				LED	occupancy control	resize to 100 lux (b)	
			Locker room / rest area @	Lighting ©			LED	occupancy control	resize to 100 lux (b)	
				TV ©			energy efficient equipment	turn off when not used		
A/C ©					energy efficient equipment	turn off when not used	adapt power to real need			
CSSD										

CSSD	Technical support @	Water treatment ©	Water softening ©	No energy saving potential			
			Reverse osmosis ©	No energy saving potential			
		Air Compression ©	Air Compressor ©	No energy saving potential			
			Air treatment ©	Air handling unit ©	No energy saving potential		
	Lighting technical area @				LED	occupancy control	resize to 200 lux (b)
(c) Developed in section 8							

Figure 9. Matrix of proposed energy-saving measures - packing sterilization, sterile storage and technical support zones - CSSD- University hospital.



Figure 6. Equipment and installation in disinfection and sterilization zones in CSSD-UH of Oujda city.

Table 3. Energy-saving comparison of ohmic and induction heating for steam generator in sterilization

Criterion	Weight	Score (scale 1 to 5)	
		Ohmic heating	Induction heating
Energy-saving Performance	0,322	2	4
safety	0,204	5	4
Implementation cost	0,115	5	2
Operating cost	0,115	2	3
Maintainability	0,115	4	2
Reliability/ Availability	0,064	3	4
Usability	0,064	5	5
Final score (WSM)		3.44	3.48



Figure 7. Equipment and installation in technical zone in CSSD-UH of Oujda city.

The example presented above is based on a qualitative assessment. This preliminary result indicates that external IH-SG are equivalent to standard resistance. However more effort need to be undertaken to develop external IH-SG especially in the implementation cost part. By doing so, IH-SG can be then introduced in the future at a large scale as a real alternative for ohmic heating SGs. But still, it can be applied in some actual cases. The outcome of this brief comparison cannot be considered as universal: the results may vary in other cases depending mainly on the exact energy-saving performance of each equipment as well as its implementation cost. Hitherto, ohmic heating SG is still the unique technology used and no substantial development is practicable yet.

Conclusions

Concretely, the modernity of the installation confined the margin of manoeuvre to managerial and behavioural measures. Despite of its qualitative character, the developed MCDA highlighted the potential of induction heating -based external steam generators as a real alternative for actual ohmic heating model. In sum, the method developed and presented in this paper is an attempt to provide auditors with a powerful tool for identification of energy-saving measures during an energy audit. The method sets itself apart by systematic and comprehensive approach which help attain the maximum of opportunities. The usefulness of the method is enhanced by a comparison method of multiple energy-saving alternatives based on relevant weighted criteria to make good decision motivated by an ultimate goal: applicability and sustainability of energy-saving solutions. It can be integrated as a part of an energy management system or energy audit. By experiencing this tool in several fields in the future, we can gather various practical feedback. All consolidated energy-saving practices can be then standardised within similar professional entities. This will promote substantially the method's efficiency and practicality.

References

- [1] Gnatov A, Argun S (2015) New Method of Car Body Panel External Straightening: Tools of Method. *International Journal of Vehicular Technology* 2015:1–7. <https://doi.org/10.1155/2015/192958>
- [2] Singh J, Juneja S, Ghosal A, Ghosal A (2019) Energy Harvesting: Role of Plasmonic Nanocomposites for Energy Efficient Devices. *Integrating Green Chemistry and Sustainable Engineering* p.81–112.
- [3] Patjins A, Arhun S, Hnatov A, Dziubenko O, Ponikarovska S (2018) Determination of the Best Load Parameters for Productive Operation of PV Panels of Series FS-100M and FS-110P for Sustainable Energy Efficient Road Pavement. In: 2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON 2018): Conference Proceedings. Riga, Latvia, p.1–6
- [4] Hnatov A, Arhun S, Dziubenko O, Ponikarovska S (2018) Choice of Electric Engines Connection Circuits in Electric Machine Unit of Electric Power Generation Device. *Majlesi Journal of Electrical Engineering* 12:87–95.
- [5] ISO (2018) Energy management systems - Requirements with guidance for use, ISO 50001:2018.
- [6] SAVE-Project (2000) Energy Audit Management Procedures PART I, Final Report. The Guidebook for Energy Audits, Programme Schemes and Administrative Procedures. <http://docplayer.net/18342579-The-guidebook-for-energy-audits-programme-schemes-and-administrative-procedures.html>
- [7] Park W.Y, Phadke A, Shah N, Letschert V (2013) Efficiency improvement opportunities in TVs: Implications for market transformation programs. *Energy Policy* 59:361–372. <https://doi.org/10.1016/j.enpol.2013.03.048>
- [8] Diaz-Elsayed N (2013) Development of Energy Models for Production Systems and Processes to Inform Environmentally Benign Decision-Making", Ph.D thesis, University of California, Berkeley. <https://pdfs.semanticscholar.org/a55f/0a455379cda74abc086c4d17e4d344b5f423.pdf>
- [9] Nguyen T.A.L (2016) Reconception de l'outil de production dans un contexte de minimisation de la consommation énergétique. Ph.D thesis, Université Grenoble Alpes. <https://tel.archives-ouvertes.fr/tel-01315171/document>
- [10] Palit R (2012) Modeling and Evaluating Energy Performance of Smartphones. Ph.D thesis, University of Waterloo. <http://hdl.handle.net/10012/6534>
- [11] ISO (2014) Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance, ISO 50006:2014.
- [12] Carrillo C, Díaz-Dorado E, Cidrás J, Silva-Ucha M (2013) A methodology for energy analysis of escalators, *Energy and Buildings* 61:21–30.
- [13] Saidur R, Rahim N.A, Hasanuzzaman M (2010) A review on compressed-air energy use and energy savings. *Renewable and Sustainable Energy Reviews* 14:1135–1153. <https://doi.org/10.1016/j.rser.2009.11.013>
- [14] Jemmad K, Hmidat A, Saad A (2018) An Extended Model to Analyze Energy Saving: Parameters and Composition. *International Journal of Renewable Energy Research* 8(1): 495–503.
- [15] US department of defense (2012) System safety, standard practice, MIL-STD-882E.
- [16] IEC (2014) Dependability management –Part 1: Guidance for management and application, IEC 60300-1:2014.
- [17] Wulfinghoff D. R (2004) The Four Steps of Effective Energy Management. <http://energybooks.com/wp-content/uploads/2015/06/FOUR-STEPS-of-Energy-Management-for-EIP-Website-071025.pdf>
- [18] ISO (2018) Ergonomics of human-system interaction-Part 11: Usability: Definitions and concepts, ISO 9241-11: 2018.
- [19] Wang J-J, Jing Y-Y, Zhang C-F, Zhao J-H (2009) Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews* 13(9): 2263–2278.
- [20] Saaty T.L (2013) Analytic Hierarchy Process, *Encyclopedia of Operations Research and Management Science*, 3rd ed. Springer: In: Gass S.I, Fu M.C, editors p. 52–64.
- [21] WHO (2016) Decontamination and Reprocessing of Medical Devices for Health-care Facilities.
- [22] Van de Klundert J, Muls P, Schadd M (2008) Optimizing sterilization logistics in hospitals. *Health Care Management Science* 11(1):23–33. <https://doi.org/10.1007/s10729-007-9037-4>
- [23] Kameda T, Ohkuma K, Sano N, Batbayar N, Terashima Y, Terada K (2014) orthodontics waves. Development of a compact induction-heated autoclave with a dramatically shortened sterilization cycle in orthodontic clinics *73(2):55–60*. <https://doi.org/10.1109/TIE.2013.2281162>
- [24] Sadhu P.K, Pal N, Bandyopadhyay A, Sinha D (2010) Review of Induction Cooking - a Health Hazards Free Tool to Improve Energy Efficiency as compared to Microwave Oven. The 2nd International Conference on Computer and Automation Engineering (ICCAE) Singapore p.650–654.
- [25] Frogner K, Andersson M, Cedell T, Siesing L, Jeppsson P, Ståhl J-E (2011) Industrial heating using energy efficient induction technology. Proceedings of the 44th CIRP International Conference on Manufacturing Systems.
- [26] Ersoy N, Wang L, Shatil G (2002) A case study of the failure of an electric heater by thermal fatigue. Conference: Fatigue 2002 – Proceedings of the 8th International Fatigue.