

# ACEE PUBLICATION

**IEC Advisory Committee on energy efficiency (ACEE)**

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**Introduction to ACEE work**





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## INTRODUCTION TO ACEE WORK

Many energy efficient technologies and solutions are readily available and cost-effective; nevertheless, a variety of barriers inhibit the deployment of these technologies and impede harvesting their energy efficiency potential.

Standardization, together with testing and certification, can play an important role to help overcome these barriers and to disseminate and promote energy efficient technologies, solutions and services.

### 1 What is energy efficiency?

The IEC defines energy efficiency as the ratio or other quantitative relationship between an output of performance, service goods or energy, and an input of energy.

Energy efficiency can be achieved in several ways:

- 1) Use less energy to achieve the same outcome, which implies a higher efficiency for that service, application or product.
- 2) Use the same amount of energy to achieve a better outcome, which implies a higher efficiency for that service, application or product.
- 3) Improve the conversion of primary energy into electricity using more efficient technologies.

### 2 Why energy efficiency is important

Energy efficiency is the biggest untapped energy source in the world.

According to the International Energy Agency (IEA), energy efficiency is the largest “fuel” before all fossil and renewable energy sources combined. In the face of rising energy demand and a need to limit greenhouse gas (GHG) emissions, energy efficiency has become a pillar of the global development goals. Recognizing the importance of energy efficiency in achieving sustainability goals reflects a paradigm shift since both the supply and the demand side are taken equally into consideration.

### 3 Benefits of energy efficiency improvements

Traditionally, energy efficiency was simply viewed as delivering energy savings in the form of reductions in energy demand.

However, energy efficiency improvements provide a much wider range of benefits, including for example a reduction in GHG emissions, increased energy security, better health and well-being through lower air pollution, positive impact on public budgets and disposable incomes and much more.

### 4 Principal barriers to energy efficiency

Despite the many identified benefits of energy efficiency, many barriers to its wide adoption remain. These include:

- lack of awareness of the savings potential;
- inadequate information about performance efficiency;

- lack of widely used metrics for performance efficiency;
- focus on the performance of individual components rather than the energy yield or consumption of complete systems;
- perceived low rate of return on investment (lack of systems approach);
- tendency to focus on lowest initial cost rather than life cycle cost;
- split incentives (user is not the payer).

Standardization can play an important role in overcoming some of these barriers. Energy efficiency aspects related to definitions, measurement of performance and assessment of energy efficiency are typical domains of standardization.

## **5 Higher efficiency through a systems integration approach**

Improving the efficiency of individual devices is just one way of improving energy outcomes. A systems integration approach to energy efficiency management can go much further. It considers the energy performance of the combined efficiency optimization of many individual components within the boundaries of an integrated system. Generally, the efficiency gains of a system are much higher than those of its individual parts.

## **6 Standardization and energy efficiency: the challenge**

Energy efficiency poses a challenge not only to policy makers but also to standardization organizations. Energy efficiency has, in fact, a transversal and interdisciplinary nature. Therefore, working in the field of EE requires a shift from “traditional standardization” – which has historically focused on products and is generally “vertically” organized – to a “systems integration approach” and “application-oriented global solutions” perspective. This is not only because of the horizontal nature of energy efficiency, but also because very often a holistic approach provides the highest energy efficiency potential.

## **7 Standardization and energy efficiency: IEC approach**

IEC has set up an Advisory Committee on Energy Efficiency (ACEE) to coordinate its activities in this domain.

ACEE has developed two Guides with the aim of defining the concept of Energy Efficiency Aspects (EEAs) to provide guidance to IEC Technical Committees (TCs) on how to approach energy efficiency standardization, promoting a systems approach and defining procedures for the preparation of such standards.

With IEC Guide 118 [1]<sup>1</sup>, ACEE has proposed a general approach to energy efficiency standardization by defining the concept of EEAs. It thus describes the ways of systems analysis.

With IEC Guide 119 [2], ACEE has defined a framework to define procedures for the preparation of energy efficiency (EE) publications and how IEC TCs should cooperate. It thus describes the application of a systems approach to products and procedures.

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<sup>1</sup> Numbers in square brackets refer to the Bibliography.

## 8 IEC Guide 118

IEC Guide 118 proposes a general approach to energy efficiency standardization by defining the concept of Energy Efficiency Aspects (EEAs) as all those elements/services that a standard can provide to support a generic “energy efficiency improvement” process.

A generic “energy efficiency improvement” process can be imagined to comprise four simple steps: the definition of the context (system boundaries, energy efficiency indicator, etc.), the measurement, the assessment, and eventually the improvement of the performance. These steps, plus one (all enabling factors), represent areas in which a standard can provide a tool that might support this “energy efficiency improvement” process.

Five categories of EEA that should be considered when developing a standard have been proposed:

- energy efficiency definition;
- energy efficiency measurement;
- energy efficiency assessment;
- energy efficiency improvement;
- energy efficiency enabling.

In other words, these categories are the “dimensions” of energy efficiency that should be ultimately addressed by standards writers when developing a standard on energy efficiency. Examples of energy efficiency aspect categories and energy efficiency aspects are presented in Table 1.

These “dimensions” of energy efficiency should ensure the development of a rational and effective standardization process in the energy efficiency domain as they provide a systematic approach to identify the relevant scope for standardization and might serve as a taxonomy to map existing standards to identify standardization gaps and areas where standards can support regulation and to streamline the activity of IEC TCs.

## 9 IEC Guide 119

Coordination between IEC TCs is also necessary to achieve a coherent approach to energy efficiency standardization. For this reason, IEC Guide 119 proposes a structured approach to promote a systems approach when carrying out standardization activity in this field and to ensure the consistency of standards relating to EEAs common to a number of IEC TCs by avoiding duplication of work and contradictory requirements.

IEC Guide 119 defines procedures for the preparation of energy efficiency (EE) publications and provides a framework on how IEC TCs should cooperate. In particular, IEC Guide 119 defines the following EE publications:

- basic energy efficiency publication: a publication covering EEAs, applicable to products within the scope of two or more IEC TCs;
- group energy efficiency publication: a publication covering EEAs, applicable to a specific boundary including products within the scope of two or more IEC TCs.

**Table 1 – Energy efficiency aspect categories and examples**

Energy efficiency aspect category	Energy efficiency aspect
Define energy efficiency	Define terminology
	Define system boundaries (including the scope for energy efficiency)
	Define EE KPIs (energy efficiency key performance indicators)
	Define energy baseline
	Define driving parameters (adjustment factors, static factors)
	Define reference applications
	Define reference load profiles
	Define reference control strategies
Measure energy efficiency	Define test methods
	Define measurement methods
	Define measurement plans
	Define calculation methods
	Define classes
Assess energy efficiency	Energy audits
	Benchmarking methods
	Energy efficiency investment evaluation
Improve energy efficiency	Energy management system
	Design criteria guidelines
	Application guidelines
	Best practices
	Losses reduction
	(Standby losses)
Enable energy efficiency	Interoperability
	Communication
	Standardized data format
	Qualification of energy efficiency services
	Measurement infrastructure

## Annex A

### Application of principal physical background and KPIs

#### A.1 Common basic physical rules of thermodynamics

The basic laws for describing the quality of energy use are the first and second laws of thermodynamics.

The first law stands for the conservation of energy and the second for the limitations of the conversion of energy in any process. They provide the physical framework for KPI definitions.

Annex A explains the importance of these considerations for practical use starting from a simple example but leading to an overview of the major examples of current technologies. A helpful tool is the use of reference processes. There are several textbooks available worldwide that allow a detailed study of this item if needed. The purpose of Annex A is its application to energy efficiency.

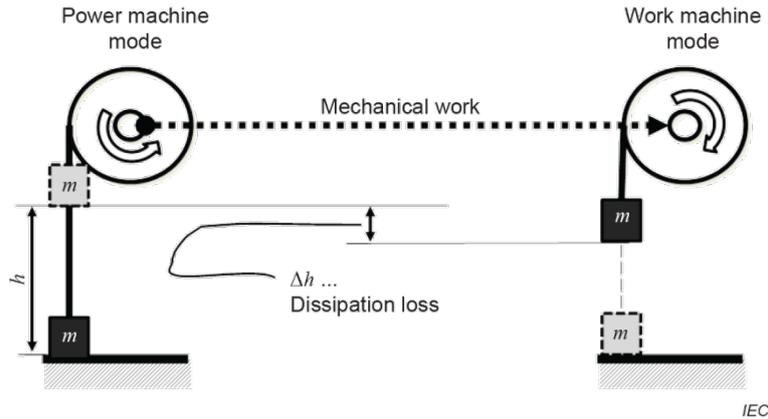
#### A.2 Mechanical system and system integration example

The operation of mechanical systems like a cable winch can be easily understood by everyone and this helps us to understand the main principles we need for our thermodynamic considerations.

Figure A.1 shows two cable winches connected by a shaft as an example of an integrated mechanical system consisting of two connected subsystems: two equal cable winches. Instead of the shaft, we could also use an electric generator on the left side connected with an electric motor on the right side for demonstrating a mechatronic system. This equipment could be used, for example, to do some production steps of parts at height  $h$  while the rest of the production chain is operating at ground level.

At the beginning of our observations, the left cable winch is wound up with a mass  $m$  as a load at a height  $h$  above ground and the right cable winch has its load with the same mass  $m$  on the ground.

When the left cable winch is unwound the mass  $m$  is on the ground. Considering now the right cable winch, we see that the load  $m$  reached only a height  $h - \Delta h$  above ground. Obviously, the difference  $\Delta h$  is caused by dissipation. Thus, we need to supply extra work,  $W_{\text{add}} = m \cdot g \cdot \Delta h$ , to the integrated system to bring the load of the right-side cable winch to the height  $h$  above ground and overcome these losses.



**Figure A.1 – Cable winch as example of a mechanical system and its possible system integration**

Considering now the energy balances and the detailed processes behind the observed entire process of the integrated system, we can easily understand the following basic principles.

- The left cable winch operated as a power machine because it converted the original thermodynamic potential  $E_{pot1} = m \cdot g \cdot h$  of the mass  $m$  to the electric work  $W_{gen1}$  of the generator transferred by the connecting cable and arriving as the electric work  $W_{mot}$  of the electric motor of the right cable winch.
- This yields  $W_{mot2} < W_{gen1} < E_{pot1}$  because of the ohmic losses of the cable and the friction in the left cable winch.
- Finally, we identify that  $W_{mot2} > m \cdot g \cdot (h - \Delta h)$  whereas  $E_{pot2} = m \cdot g \cdot (h - \Delta h)$  stands for the final thermodynamic potential of the entire integrated system of the two cable winches.
- The entire losses of the integrated system are equal to the needed additional work  $W_{add}$  as already mentioned above.

This simple calculation is possible because we have the thermodynamic potential  $E_{pot1}$  at the beginning of the process and  $E_{pot2}$  at the end of the process, and the difference is  $W_{add}$ . We would have got the same result if we could have calculated the whole process chain: left cable winch – generator – connecting cable – motor – right cable winch.

We could also have solved the problem to lift the mass  $m$  to height  $h$  and to lower the mass  $m$  again to ground level by two non-connected cable winches, the left one equipped with a brake only and the right one with a motor. In this case, we would need the electric work  $W_{mot2} > m \cdot g \cdot h$  to operate the right cable winch and obviously  $W_{mot2} > W_{add}$ . The entire potential  $E_{pot1} = m \cdot g \cdot h$  would be dissipated as heat. This very simple example shows clearly the importance of system integration to recover available thermodynamic potentials. A possible KPI of this integrated system IS could be the ratio of  $E_{pot2}$  to  $E_{pot1}$  as:

$$KPI_{IS} = \frac{m \cdot g \cdot (h - \Delta h)}{m \cdot g \cdot h}.$$

A second possible KPI could be a comparison between the two options as  $KPI_{opt}$  to quantify the benefit of system integration:

$$KPI_{opt} = \frac{W_{add}}{W_{mot2}}.$$

However, we considered here the mechanical system, but we did not discuss in detail the significance of the operation mode of the cable winch and the thermodynamic consequences of dissipation and how far a further recovery of dissipative losses might be possible.

### A.3 Principal machine definitions and reversibility of processes

The main interest of thermodynamic considerations of power conversion in the past has been focused on power generation and not so much on the investigation of work machines and their thermodynamic role. They were just seen as widespread energy consumers and a relatively small cost factor in most cases. Only big consumers, such as in the chemical industry, were the objects of system integration and energy recovery. The definition of work machines in the literature mainly focused on their production target and not on their thermodynamic meaning; however, the latter is important for any recovery measure. According to their thermodynamic role, we can precisely define the type of machines used in any system.

A **work machine** is a machine or an assembly of machines which generates from supplied real work a thermodynamic potential. The thermodynamic value of the potential is defined by its reversible work, as is well known.

A **power machine** is a machine or an assembly of machines which generates from a provided thermodynamic potential real work. Again, the thermodynamic value of the potential is defined by its reversible work, as is well known.

A **regenerative machine** is a machine or an assembly of machines which operates in one working cycle or operation mode as working machine and in another working cycle or operation mode as power machine. The supplied work to this machine can never be less than its generated work under the same conditions.

A **reversible machine** or a reversible assembly of machines is a regenerative machine or a regenerative assembly of machines where its supplied and its generated work are identical under the same conditions.

Work and power machines are operating reversibly if the thermodynamic potential and its associated work are identical.

Following these definitions, we see that the assembly of machines as shown in Figure A.1 is a regenerative machine. We could also design only one cable winch with the same thermodynamic properties of a regenerative machine if we used a motor/generator as a drive and a grid connection or an electric storage. The characteristic property of a regenerative machine is the feasibility to recover the thermodynamic potential generated in work machine mode in a following or parallel power machine mode.

We are now easily able to define KPIs generally for work and power machines by describing with  $W_{\text{real}}$  the real supplied or generated work and with  $W_{\text{rev}} = E_{\text{pot}}$  the generated or supplied thermodynamic potential that is equal to the reversible work.

The thermodynamic task of any work machine is to produce a thermodynamic potential by using real work. Beside the example of a cable winch representing mechanical systems, heat pumps are examples of thermal work machines and electrolyzers are examples of (electro)chemical work machines. Mechanical, thermal, and chemical systems will be explained in detail in A.5. The  $\text{KPI}_{\text{WM}}$  thus generally relates the gained thermodynamic potential to the supplied (electric) work  $W_{\text{real}}$ .  $\text{KPI}_{\text{WM}}$  is identical to the definition of the exergetic efficiency  $\zeta_{\text{WM}}$  in textbooks of thermodynamics:

$$\text{KPI}_{\text{WM}} = \frac{W_{\text{rev}}}{W_{\text{real}}} = \frac{E_{\text{pot}}}{W_{\text{real}}} = \zeta_{\text{WM}}.$$

The thermodynamic task of any power machine is to produce real work by using a thermodynamic potential. Beside the example of a cable winch representing mechanical systems, heat engines (diesel engines, gas turbines, etc.) are examples of thermal power machines and fuel cells are examples of (electro)chemical power machines. Mechanical,

thermal, and chemical systems will be explained in detail in A.5. The  $KPI_{PM}$  thus generally relates the gained (electric) work  $W_{real}$  to the supplied thermodynamic potential.  $KPI_{PM}$  is identical with the definition of the exergetic efficiency  $\zeta_{PM}$  in textbooks of thermodynamics:

$$KPI_{PM} = \frac{W_{real}}{W_{rev}} = \frac{W_{real}}{E_{pot}} = \zeta_{PM}.$$

Following the definition of the reversible processes, we can write for reversible machines:

$$KPI_{PM,rev} = KPI_{WM,rev} = \zeta_{PM,rev} = \zeta_{WM,rev} = 1.$$

Although reversible machines and processes cannot be found in nature, they are important because they represent the limiting process of any real process of similar type. They are thus useful for general considerations. Reversible process structures can be easily transferred to real structures by using the exergetic efficiencies (KPIs) as defined above.

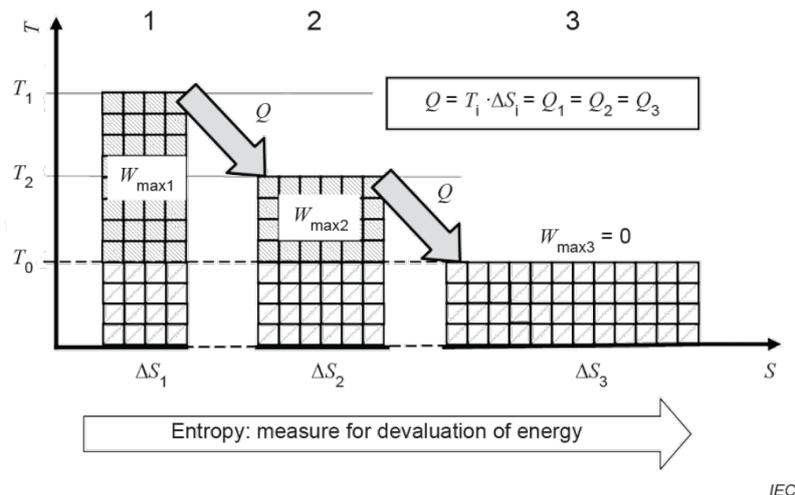
#### A.4 Thermal machines and explanation of entropy

The introduction of entropy by the formulation of the second law of thermodynamics delivered the basics to understand energy conversion processes. Although entropy has a much broader importance in physics than only explaining thermal energy conversion processes, the principal thoughts of Sadi Carnot formulated in 1824 are still the most impressive way to understand the principles.

Observations show that thermal energy is more effective the higher its temperature is. So, we can give the following geometric interpretation of thermal energy that it is represented by a two-dimensional area where its height is defined by its thermodynamic (absolute) temperature  $T$  (K) and its gauge as base length by a new variable called entropy  $S$  (J/K). The dimension J/K of  $S$  is obvious because its product with  $T$  has to deliver the dimension J for energy. We immediately recognize that the entropy increases  $\Delta S$  caused by the supply of  $Q$  is an adequate definition for the base length, as shown in Figure A.2. For a better understanding of the meaning of these definitions, we observe three system states supplied with the same heat  $Q$  (identical areas in Figure A.2) but the only difference is the temperature of any state decreasing from  $T_1$ ,  $T_2$  to  $T_0$ .

If we want to determine the amount of maximum work  $W_{max1}$  that can be generated from the supplied heat  $Q$  with the temperature  $T_1$ , we immediately see that only this amount of heat can be used for work production which has a higher temperature than the ambient temperature  $T_0$ , the minimum temperature of the released heat from the system. If we transfer the supplied heat  $Q$  to another system state 2 with the lower temperature  $T_2$ , the area  $T_2 \cdot \Delta S_2$  has to be equal to the area  $T_1 \cdot \Delta S_1$  since in an ideal heat transfer (as assumed here) no heat loss occurs. Thus, the entropy increases irreversibly from  $\Delta S_1$  to  $\Delta S_2$  and the maximal producible work decreases from  $W_{max1}$  to  $W_{max2}$ .

The maximal work described here is the reversible work of the supplied heat  $Q$  at any temperature  $T$ . If we finally transfer the heat  $Q$  to the ambient temperature  $T_0$ , no work production is possible any more. We immediately identify heat transfer as an irreversible process and the potential work  $W_{max1}$  has been completely dissipated in heat with ambient temperature  $T_0$  and the irreversible entropy with the amount  $\Delta S_3 - \Delta S_1$  has been finally produced in system 3.



**Figure A.2 – Increase of entropy  $S$  means decrease of maximal potential work  $W_{\max} = W_{\text{rev}}$**

The condition so that the maximum work  $W_{\max1}$  of the heat  $Q$  supplied at  $T_1$  can be produced is that the entropy  $\Delta S_1$  remains constant during energy conversion. This defines the reversible case, because we need the same maximum work  $W_{\max1}$  to generate the same amount of heat  $Q$  with the temperature  $T_1$  by using ambient heat characterized by the ambient temperature  $T_0$  and the entropy  $\Delta S_1$ . The process cycle following this principle is known as the Carnot cycle. The content of maximum possible or reversible work in any form of energy is also defined as exergy. Considering the example of Figure A.2, the maximum or reversible work  $W_{\max1} = W_{\text{rev}1}$  is equal to the exergy  $E_1$  of the heat  $Q_1$ . Exergy thus defines the thermodynamic potential. The general definition of exergy automatically integrates the ambient conditions into thermodynamic considerations.

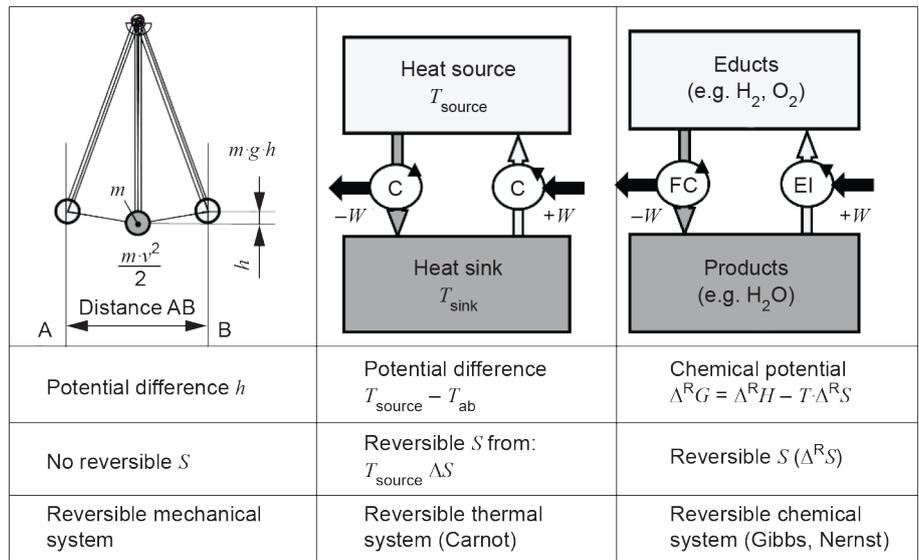
Generally, entropy can be explained as a measure for order or disorder of systems as more generally explained in statistical thermodynamics. Other important technical issues that are influenced by entropy are mixing of substances or information by the specially defined information entropy. The determination of chemical processes is a consequence of the so-called reaction entropy that is a result of the differences of the specific heat constants between the reactant and the product side. Thermal and chemical processes are characterized by a certain amount of entropy that can be reversibly exchanged with the environment under ideal conditions. Although reversible processes are not feasible, they are the important border case of any real process defining also its thermodynamic potential.

## A.5 Reversible processes as reference processes

A high number of technical systems can be synthesized by three principal basic reversible systems: a reversible mechanical system, a reversible thermal system and a reversible chemical system as shown in Figure A.3. The reversible mechanical system delivers no reversible entropy and all entropy production of a mechanical system is irreversible ( $KPI < 1$ ). Therefore electrical systems can be treated like mechanical systems in terms of this consideration [3]. As already shown, heat is always connected with a certain amount of entropy depending on its temperature (see above).

Exactly this amount of entropy necessarily needs to be released to the environment if the heat is used to produce its reversible work by operating an energy converter in the power machine mode (e.g. combustion engines). This entropy transport is assumed to be reversible (temperature difference  $\rightarrow 0$  or  $T_{\text{min.converter}} = T_0$ ) because we need exactly this amount of entropy again if we supply the energy converter with the reversible (maximum) work to generate again the original heat at the starting temperature. The energy converter is then operating in a work machine mode (as heat pump).

Usually the entropy of a chemical reaction system changes because any chemical reaction changes substances and entropy is a property of substances. This entropy difference is called reaction entropy  $\Delta^R S$  and is the reason for a reversible heat exchange with the environment. Chemical reactions may operate in a power machine mode (e.g. fuel cells) or in a work machine mode (e.g. electrolyser) as the reverse form of operation. The definition of entropy has a great importance in science generally far beyond the examples from continuum thermodynamics discussed here. Although we consider here clear engineering issues, it should be noted that the further work on entropy opened new insights into neighbouring disciplines that are seen as important also for an overall understanding of sustainability. For further reading we supply some references to show the importance of entropy in science generally. The development of statistical thermodynamics [4] already opened the connection to information theory [5], and finally consideration of self-organizing processes [6] led to descriptions of biological systems [7].



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**Key**

- C      converter
- FC     fuel cell
- EI     electrolyzer
- $G$     Gibbs free energy
- $H$     enthalpy
- $W$     work

**Figure A.3 – Overview of reversible processes**

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