Tool to evaluate the Energy Flexibility in Buildings – A short manual

A technical report from IEA EBC Annex 67 Energy Flexible Buildings

Tool to evaluate the Energy Flexibility in Buildings – A short manual

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Preface

This report is part of the IEA EBC Annex 67 project Energy Flexible Buildings. The report presents a manual for a worksheet to uniformly visualize, characterize and evaluate flexibility. The report accompanies the Flexibility-Evaluation-Tool (FET) that can be downloaded via the Annex 67 website (http://www.annex67.org/Publications/Software) and provides a short manual of how to use the tool and gives an overview of the calculation methodology.

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Nomenclature

A	The total amount of decreased energy demand [J];
B	The total amount of increased energy demand [J];
α	The time it takes from when the change in demand starts until it reaches the lowest level [s];
β	The total time of decreased electricity demand [s];
τ	The delay from adjusting the electricity price and seeing an effect on the electricity demand [s]
Δ	The maximum change in demand following the price change [W];
L_{ref}	Reference load without flexibility [kW/m²]
L_{flex}	Load with flexible operation [kW/m²]
C	Cost function [units/kWh, e.g. gCO_2/kWh, €/kWh, PE/kWh]
S	Savings [units/m², e.g. gCO_2/m², €/m², PE/km²]
E_{flex}	Efficiency of flexible operation [%]
S_{flex}	Shifted flexible loads [%]

1. Introduction

Within IEA EBC Annex 67 – Energy Flexible Buildings, a consistent framework that considers all the relevant aspects of characterizing Energy Flexibility in Buildings has been developed [1].

So far, a theoretical understanding has been established on this topic and is being disseminated. Within the dissemination a worksheet implementing energy-flexibility calculations for selected definitions has been developed.

The Flexibility-Evaluation-Tool (FET) is a tool to uniformly visualize, characterize and evaluate flexibility. The report accompanies the tool that can also be downloaded via the Annex 67 website (http://www.annex67.org/Publications/Software) and provides a short manual of how to use the tool and gives an overview of the calculation methodology.

The tool:

- Evaluates of energy flexibility with different timesteps, timespans, cost functions/penalty signals based on a reference load profile, a load profile with flexible operation and a penalty signal/cost function
- Includes a reduced number of energy flexibility evaluation criteria and indicators
- Provides a way to compare results from simulations.

2. Flexibility-Evaluation-Tool

The Flexibility-Evaluation-Tool (FET) is an Excel-based tool to uniformly visualize, characterize and evaluate flexibility for different data input sources. The tool has been developed within Microsoft Excel 2010, so there can be some incompatibilities with older excel versions. While opening the file, it is necessary to enable content and approve to make the file a trusted document.

The excel workbook comprises two worksheets:

- Energy Flexibility Evaluation
- Boundary Conditions

The worksheet "Energy Flexibility Evaluation" collects the input data and also reports results. For the evaluation at least three inputs are needed:

- Reference load without flexibility
- Load with flexible operation
- Cost function

Within the worksheet "Boundary conditions", boundary conditions for the entered data like outdoor temperature, global horizontal irradiation on horizontal plane, minimum comfort temperature, maximum comfort temperature e.g. can be documented. The inputs in this worksheet are for documentational purposes only and do not affect the results in the “Energy Flexibility Evaluation” worksheet but aims to make results more comparable.

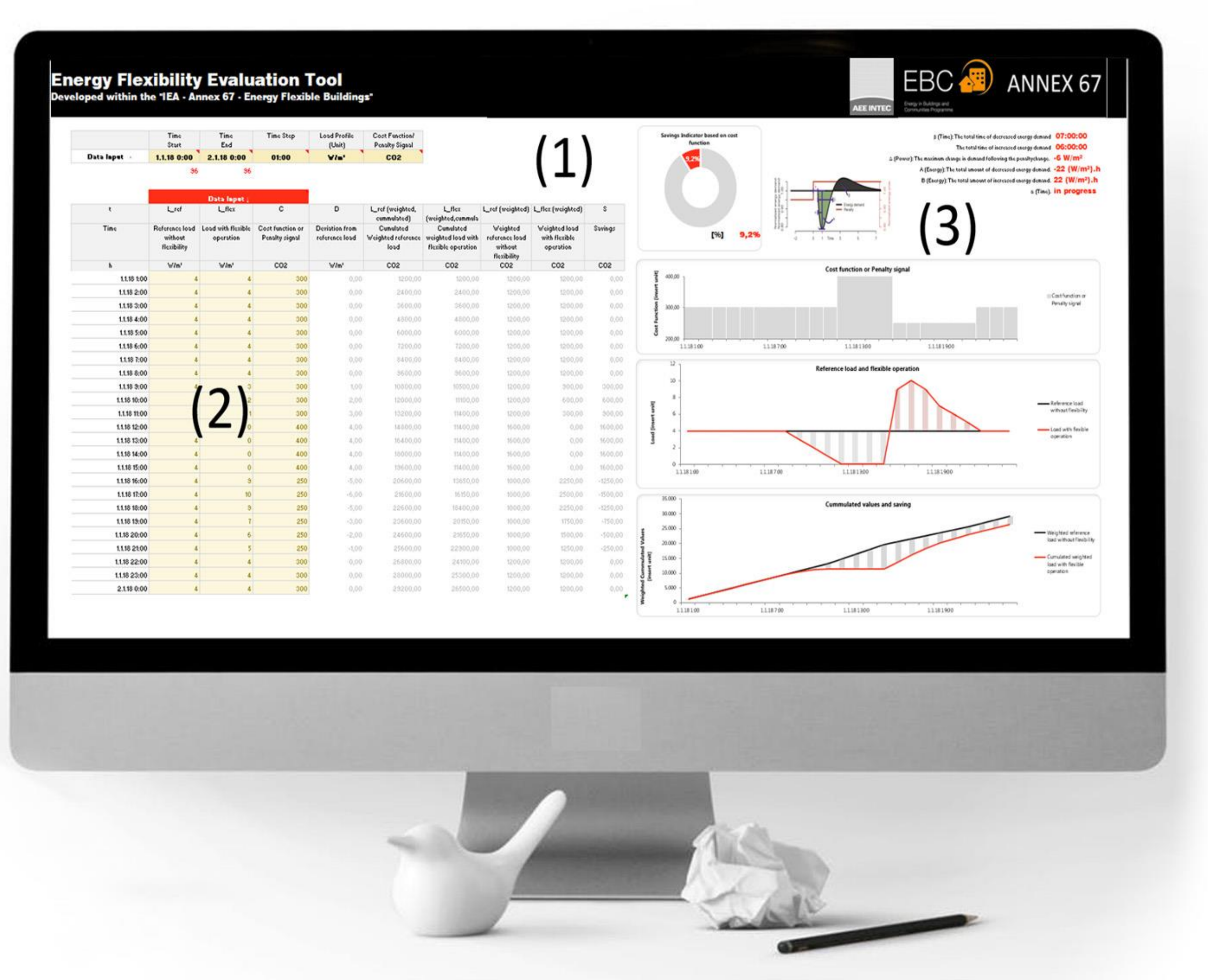


*Figure 1. Energy **F**lexibility **E**valuation **T**ool (FET)- Overview of the interface*

(1) Overall inputs for timespan, timesteps, cost-function/penalty function and units

(2) Input data about a buildings load profile, a flexible load profile and a cost function based on the timesteps, timespan and units

(3) Evaluation charts and characterization

2.1. Energy Flexibility Input Cells

Input data cells are yellow and orange. Also, the other cells of the excel tool are not protected and will allow modifications.

In the overall data input section at the top of the sheet (Table 1), input data concerning the considered time period, timestep, units and cost function need to be entered.

Table 1. Data input to define overall values for the considered time period, timestep, units and cost function.

	Time Start	Time End	Time Step	Load Profile (Unit)	Cost Function/ Penalty Signal
Data Input →	1.1.18 00:00:00	2.1.18 00:00:00	01:00:00	W/m²	CO_2

Please note that the formatting of the input fields needs to be maintained. Timespans can be chosen up to one year and hourly as well as sub-hourly timesteps (minutes, seconds) can be entered.

- Input field "Start/ End Time": manual input (dd.mm.yy hh:mm:ss) ,
- Input field "Timestep": manual input (hh:mm:ss),
- Input field "Load Profile (Unit)": dropdown list (W/m²; kW/m²; W; kW)
- Input field "Cost Function/Penalty Signal (Unit):" dropdown list (CO_2 emissions per unit; € per unit; PE – Primary Energy per unit; Residual load)[1]

Further information on how to complete the tables is available in the tooltips within the worksheet. Definitions and terminology are available in info boxes.

The input list for the data input section below the table in the tool as well as the charts will be automatically updated once the input fields in Table 1 are changed.

In the main data input section (Table 2) input data about a buildings load profile, a flexible load profile and a cost function need to be entered based on the timesteps, timespan and units that have been entered in Table 1.

Table 2. Data input section of " reference load without flexibility (L_ref)", "load with flexible operation (L_flex)" and "cost function (C)".

t	**L_ref**	**L_flex**	**C**	**D**	**L_ref** **weighted**	**L_flex** **weighted**	**L_ref** **weighted, cummu-lated**	**L_flex** **weighted, cummu-lated**	**S**
Time	**Reference load without flexibility**	**Load with flexible operation**	**Cost function**	**Deviation from reference load**	**Weighted reference load without flexi-bility**	**Weighted load with flexible operation**	**Cumulated Weighted reference load**	**Cumulated weighted load with flexible operation**	**Savings**
h	**W/m²**	**W/m²**	**CO_2**	**W/m²**	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**
1.1.18 1:00	4	4	300	0	1200	1200	1200	1200	0
1.1.18 2:00	4	4	300	0	1200	1200	2400	2400	0
1.1.18 3:00	4	4	300	0	1200	1200	3600	3600	0
1.1.18 4:00	4	4	300	0	1200	1200	4800	4800	0
1.1.18 5:00	4	4	300	0	1200	1200	6000	6000	0

[1] If the dropdown list does not include a specific unit for the cost function or the load profile the inputs can be changed in cells (H2:O2). Please note that the text in these cells is formatted in white color.

As can be seen in Table 2 "reference load without flexibility (L_ref)", "load with flexible operation (L_flex)" and "cost function (C)" need to be entered in column C, D and E. The cost function/penalty signal (C) can be chosen according to the conditions: often the penalty signal is a price signal, but can also be a CO_2 or a RES signal. For these signals, the controller should minimize the price or CO_2 emission or maximize the utilization of RES. The cost function/penalty signal is considered as a temporal signal varying over the year according to the requirements of the energy grid in specific time periods.

The input for "reference load without flexibility (L_ref)" and "load with flexible operation (L_flex)" is needed for the comparison of a flexible operation based on the cost function/ penalty signal with the reference case, where no flexibility would have been received. The data for both inputs is derived usually from simulation results but can also be based on measured operational data.

The calculation of the indicators in the neighboring columns (F-K) as well as the visualization of charts starts automatically once the data is entered according to the methodology described in chapter 3.2.

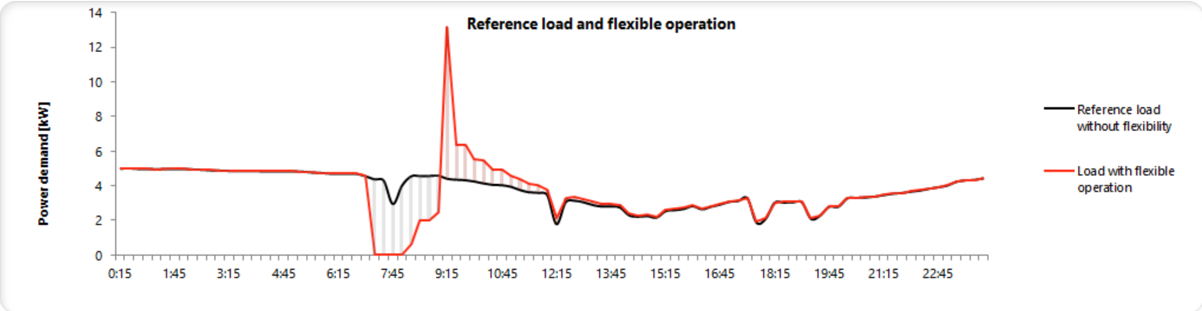


Figure 2. Example of a single downward flexibility event – Result chart.

2.2. Energy Flexibility Evaluation and Charts

Results of are shown in the same sheet on the right side and are seen in Figure 3.

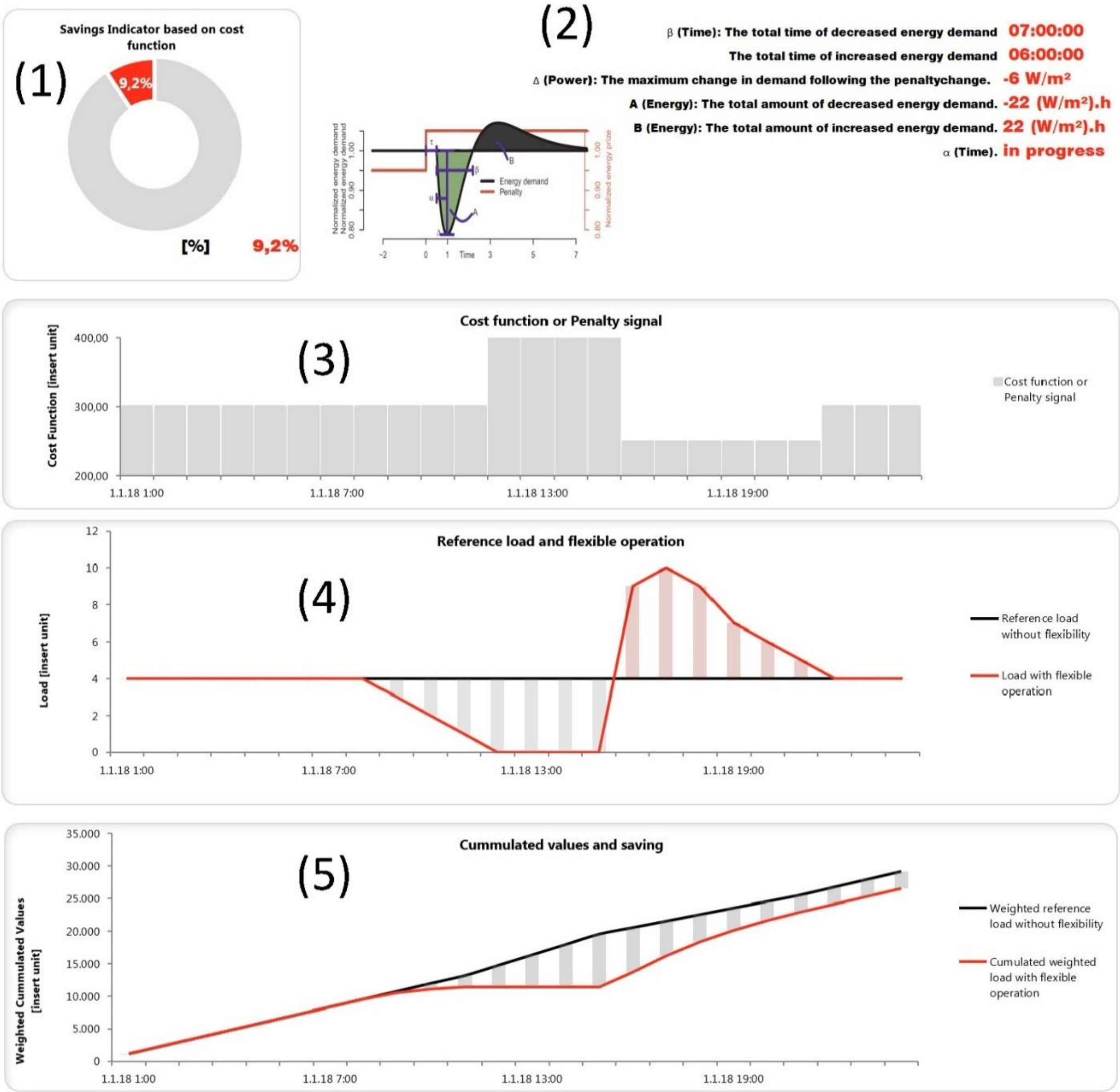


Figure 3. Evaluation of Energy Flexibility – Result charts

(1) This chart shows the “savings indicator”, which is based on the cost function. It gives a percentage value of the savings based on the cost function (CO_2 or primary energy, cost, e.g.). The calculation methodology is explained in detail in chapter 3.2.

(2) This section characterizes the energy flexibility as a series of step-changes in relation to a change in a penalty signal/cost-function as described by Junker et. al [2] (see also chapter 3.1 in this report). Further details on the methodology are given in the Annex 67 report “Principles of Energy Flexible Buildings” on the Annex 67 website (http://www.annex67.org/Publications/deliverables).

(3) The chart shows the variation of the cost function/penalty signal over the given timespan

(4) The chart compares the behavior of the flexible operation of a reference building to a so-called baseline load profile without flexibility

(5) The ratio between the two accumulated load profiles weighted with the cost function tells how large the deviation and savings are.

3. Methodology

3.1. Characterization of Energy Flexibility

To characterize the energy flexibility of a system a methodology has been developed, which captures flexibility as a step-response function to a change in a penalty signal/cost-function. The approach thereby assumes that the flexible system in consideration has a certain penalty-aware control and that flexibility is offered by responding to a change in the penalty signal/cost-function [3].

A full description of how to characterize energy flexibility is given in "Principles of Energy Flexible Buildings" [4] on how to get the Impulse-Response function for penalty-controlled buildings", is available in "Principles of Energy Flexible Buildings" and in the paper "Characterizing the Energy Flexibility of Buildings and Districts" [2] by Annex 67. Due to the variation of the conditions for obtaining Energy Flexibility the focus is on a characterization methodology rather a single indicator.

The figure below briefly summarizes the developed methodology and provides the characterization framework of the tool.

Figure 4 shows a theoretical response of a system to a step-change in the penalty signal based on which the following flexibility characteristics are defined:

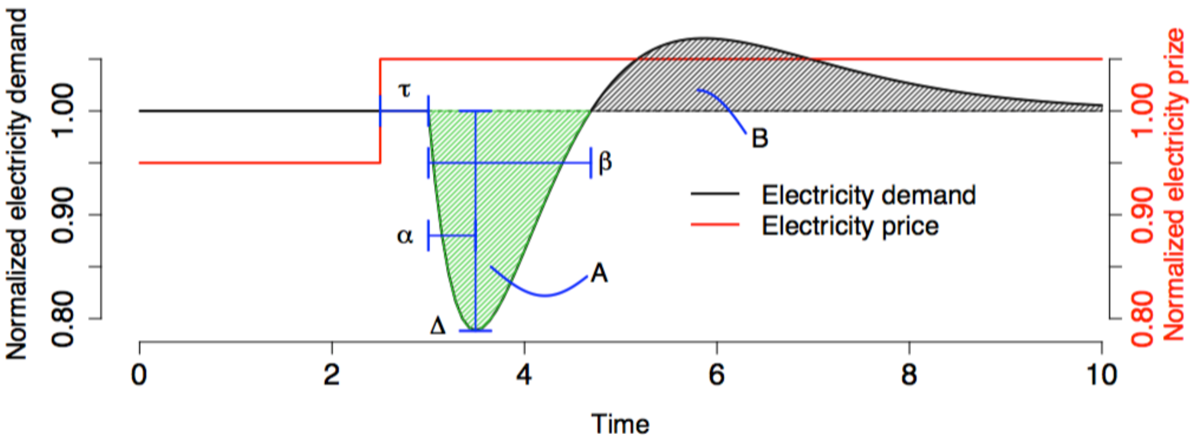


Figure 4. Response of a system to a step-change in the penalty signal *in case of an all-electric system* [2].

τ	The delay from adjusting the electricity price and seeing an effect on the electricity demand [s]
Δ	The maximum change in demand following the price change [W];
α	The time it takes from when the change in demand starts until it reaches the lowest level [s];
β	The total time of decreased electricity demand [s];
A	The total amount of decreased energy demand [J];
B	The total amount of increased energy demand [J].

3.2. Indicators for Energy Flexibility S-flex and E-Flex

When quantifying the flexibility of a whole building in operation, it is necessary to compare the behavior of the building with the flexible operation with a reference case – a so-called baseline load profile without flexibility. The idea is to rate the different load-patterns of the same building in standard operation in comparison to a building that shifts or stores energy according to a signal or control strategy. In order to see the difference, it is necessary to compare two cases with different strategies. It should be noted that this approach is possible in this tool but typically not available in practice for real buildings in operation. Usually this approach is used when simulating a building during the design phase. Two different variants of the control is simulated, one with flexible operation and one reference case without.

The ratio between these two resulting load profiles states how large the deviation and the relative savings are. The use of flexibility in a building is based on a signal that is depending on the objective, e.g., minimizing costs, grid stabilisation, minimising CO_2 or renewable self-consumption. Therefore, in this tool, flexibility is also rated depending on its objective and not just on a single signal as can be seen in the characterization approach of the previous chapter.

In the following all steps for the evaluation procedure for energy flexibility within the tool as be seen in Figure 5 are explained:

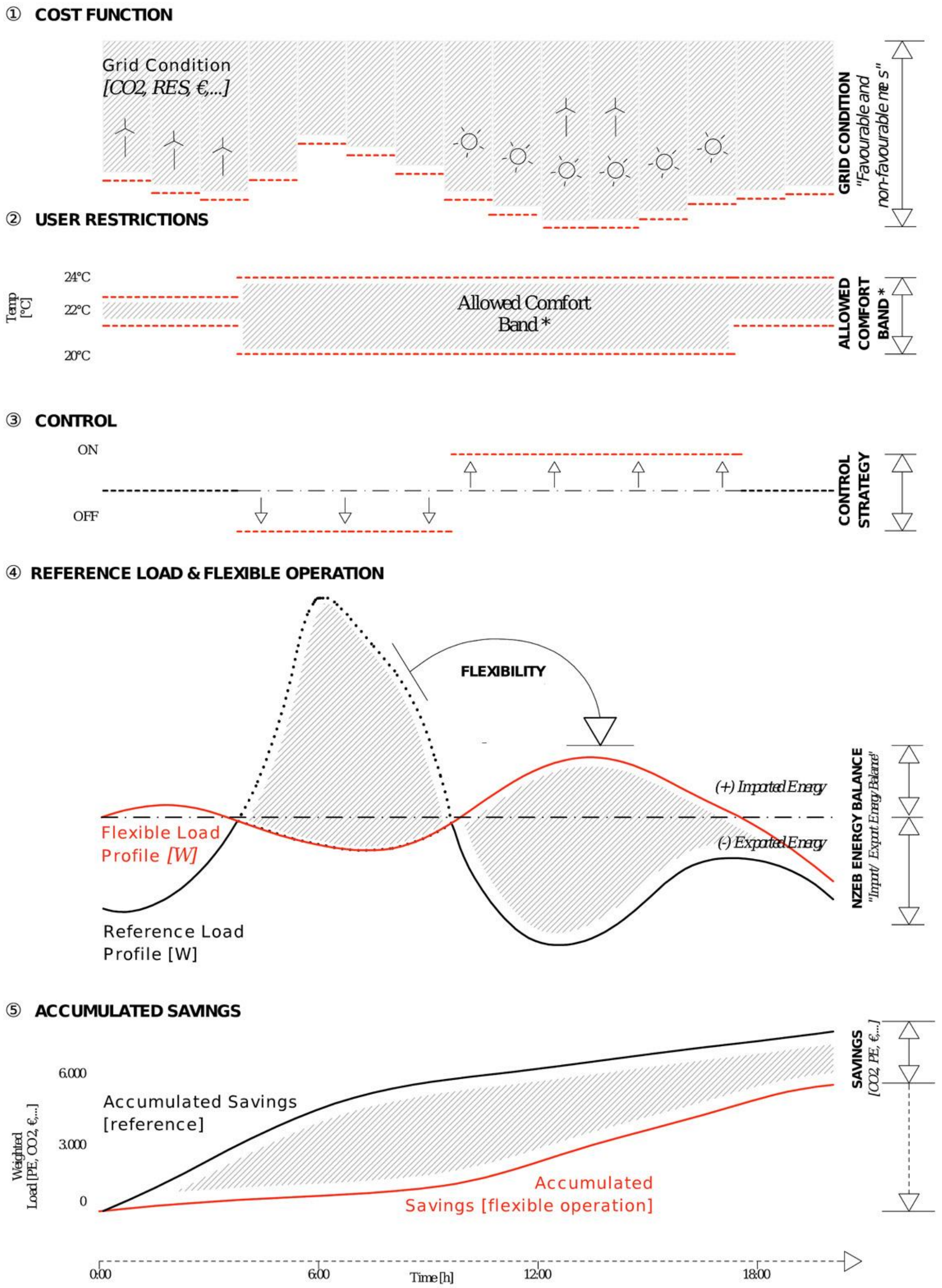
① Cost function:
Definition of the cost function based on the objective - e.g. external signal: carbon emissions gCO_2/kWh), costs (€), residual load (MW)

② Boundary Conditions/User Restrictions:
Definition of boundary conditions – e.g. times of flexible operation, expected comfort requirements, battery storage capacity

③ Control strategy:
Definition of the controller’s ability to respond to the cost function/external signal.

④ Reference Load & Flexible Operation - Simulation:
L_{ref}: Simulation of the buildings without flexibility, which means a simulation without considering a flexible control strategy – reference load profile
L_{flex}: Simulation of the buildings load over a given time with flexibility - simulation where the new control strategy is considered – flexible load profile
The deviation of the two resulting profiles will be referred to as »flexibility« in the following definition of the indicator.

⑤ Accumulated Savings:
The load profiles (L_{ref}) and (L_{flex}) are weighted and accumulated over time with the values derived from the cost function, e.g. external signal: carbon emissions (gCO_2/kWh), costs (€). The difference between the cumulated results of the two weighted cases at the end of the simulation period are called »savings«.



**User restrictions could also be defined as allowed hot water temperature, thermal comfort, demand management times for flexible services, etc.*

Figure 5. Evaluation procedure for energy flexibility within the tool.

An indicator which defines the «efficiency of flexible operation« (E_{flex}) based on an objective is introduced in the equations below. It gives a percentage value of the savings in terms of costs, CO_2 or primary energy, which can be achieved, compared to a baseline load profile without flexibility.

The flexibility itself is defined as the deviation of a flexible load profile from a baseline profile without flexibility. The output is the percentage of shifted flexible loads over time – the deviation in energy consumption from the second indicator: S_{flex} . This indicator is a non-weighted indicator based on the deviations of a building's final energy demand (see also Figure 6).

$$\mathrm{S}\ \ (t) := C(t)\ \cdot \left(L_{ref}(t) - L_{flex}(t) \right)$$

$$E_{flex} := \frac{\int S(t)\,dt}{\int\ C(t) \cdot L_{ref}(t)\,dt} = \frac{\int C(t)\ \cdot \left(L_{ref}(t) - L_{flex}(t) \right) dt}{\int\ C(t) \cdot L_{ref}(t)\,dt}$$

$$S_{flex} := \frac{\int \max\left\{ L_{ref}(t) - L_{flex}(t), 0 \right\} dt}{\int\ L_{ref}(t)\,dt}$$

in discrete time steps

$$\mathrm{S}_i := C_i\ \cdot \left(L_{ref,i} - L_{flex,i} \right)$$

$$E_{flex} := \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} C_i\ \cdot L_{ref,i}} = \frac{\sum_{i=1}^{n} C_i\ \cdot \left(L_{ref,i} - L_{flex,i} \right)}{\sum_{i=1}^{n} C_i\ \cdot L_{ref,i}}$$

$$S_{flex} := \frac{\sum_{i=1}^{n} max\left\{ L_{ref,i} - L_{flex,i}, 0 \right\}}{\sum_{i=1}^{n} L_{ref,i}}$$

L_{ref}	Reference load without flexibility [kW/m²]
L_{flex}	Load with flexible operation [kW/m²]
C	Cost function [units/kWh, e.g. gCO_2/kWh, €/kWh, PE/kWh]
S	Savings [units/m², e.g. gCO_2/m², €/m², PE/km²]
E_{flex}	Efficiency of flexible operation [%]
S_{flex}	Shifted flexible loads [%]

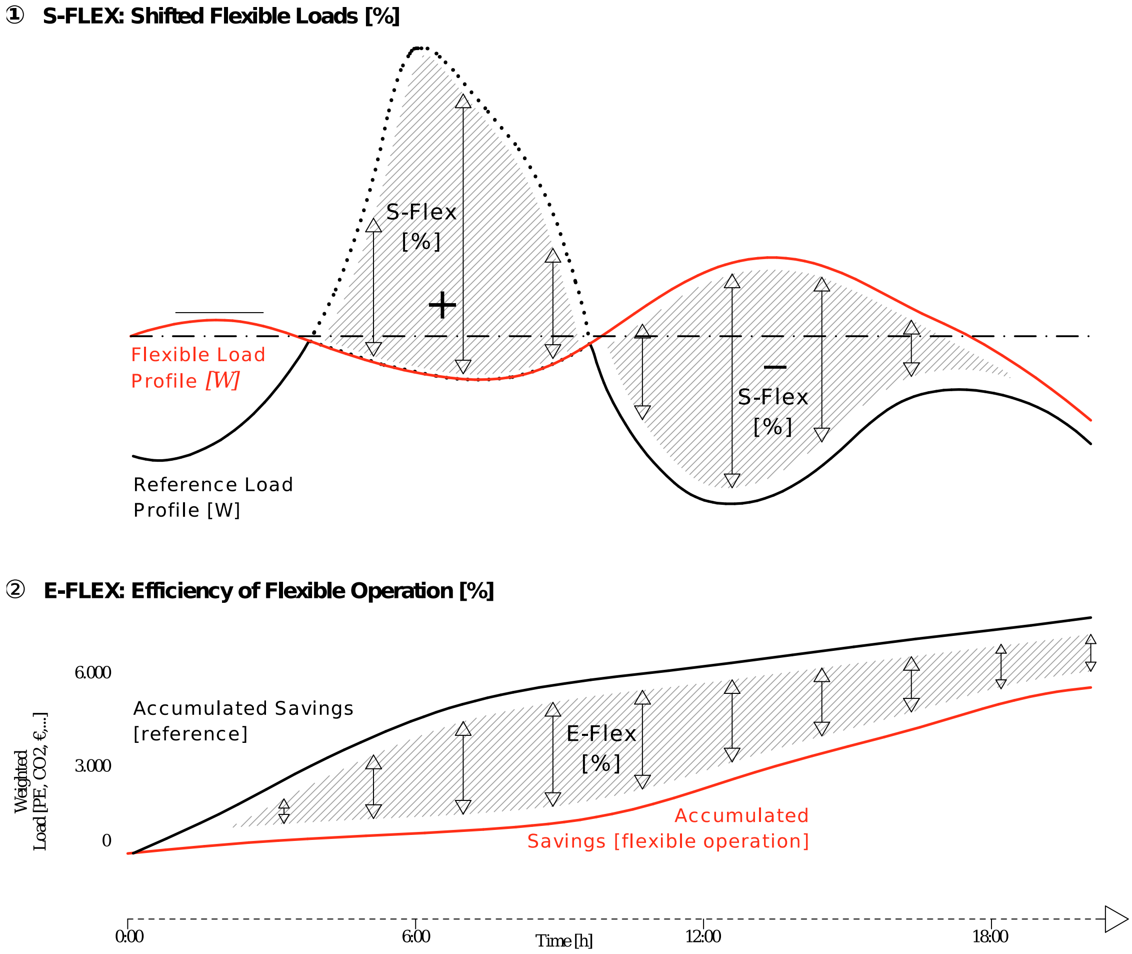


Figure 6. Graphical representation of indicators: E_{flex} - Efficiency of flexible operation and S_{flex} - Shifted flexible loads

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References

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[2] R. G. Junker *et al.*, “Characterizing the energy flexibility of buildings and districts,” *Appl. Energy*, vol. 225, pp. 175–182, 2018.

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