Proceedings of Building Simulation 2011:
12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November.

UNDERSTANDING NET ZERO ENERGY BUILDINGS: EVALUATION OF LOAD MATCHING AND GRID INTERACTION INDICATORS

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ABSTRACT

Although several alternative definitions exist, a *Net-Zero Energy Building* (Net ZEB) can be succinctly described as a grid-connected building that generates as much energy as it uses over a year. The “net-zero” balance is attained by applying energy conservation and efficiency measures and by incorporating renewable energy systems. While based on annual balances, a complete description of a Net ZEB requires examining the system at smaller time-scales. This assessment should address: (a) the relationship between power generation and building loads and (b) the resulting interaction with the power grid. This paper presents and categorizes quantitative indicators suitable to describe both aspects of the building’s performance. These indicators, named *LMGI - Load Matching and Grid Interaction* indicators, are easily quantifiable and could complement the output variables of existing building simulation tools. The indicators and examples presented here deal only with electric generation and loads.

INTRODUCTION

This work presents quantitative indicators that can be used to describe load matching and grid interaction (LMGI) conditions in net-zero or near net-zero energy buildings (Net ZEBs). *Load matching* refers to how the local energy generation compares with the building load[1]; *grid interaction* refers to the energy exchange between the building and a power grid. These are independent, but intimately related issues. The main distinction made here is that *load matching* indicators measure the degree of overlap between generation and load profiles (e.g. the percentage of load covered by on-site generation over a period of time) whereas *grid interaction* indicators take aspects of the unmatched parts of generation or load profiles into account (e.g. peak powers delivered to the electricity distribution grid).

Net-zero energy buildings do not exist in isolation. Despite the multiple definitions of net-zero building (Torcellini et al. 2006, Marszal et al., 2011), the wording “*net*-zero” implies an interaction with a surrounding energy grid. It is expected that the accounting of the selected metric (e.g., primary energy) over a relatively long period (typically a year), will yield a net balance close to zero.

The “net-zero” concept is convenient and practical. However, it is insufficient to describe the energy performance of a building and its potential role as an active element in the energy network (Sartori *et al.*, 2010). If the building-grid interaction at smaller time-scales is not considered, Net ZEBs could have a detrimental impact on the performance of the grid at high penetration levels. For example, they may contribute to increasing peak loads, thus requiring additional generation and transmission capacity from utilities. They may also increase voltage variation in local distribution grids. This last factor needs to be taken into account when grids are designed or operated because some voltage characteristics of low and medium voltage electricity grid should be maintained (EN 50160, 1999).

To illustrate this point, solar powered net-zero homes in high latitudes usually have net energy consumption in winter, and net energy generation in summer. Excess solar power in summer may balance grid electricity (e.g, in an all-electric home) or even natural gas consumption in winter (fuel switching). In absence of other measures, Net ZEBs will contribute to the burden carried by the power grid, while supplying energy when the grid does not require it. If a net-zero building draws power during peak times, from the point of view of the grid there will be little difference between a net-zero building and a conventional one. If the load matching issues and grid interaction are not properly addressed, net-zero energy buildings might not reach their full potential in terms of energy conservation, promotion of renewable energy sources and global reduction of GHG emissions.

In view of these considerations, the issues of load matching and grid interaction have become part of the discussions of the IEA activity Task 40/Annex 52 “Towards Net Zero Energy Solar Buildings” (IEA, 2008). Several definitions, criteria and quantitative indicators for load matching and grid interaction were recently presented (Voss et al., 2010).

Quantitative indicators can be used to evaluate the impact of advanced control and energy storage strategies, such as batteries or thermal energy storage (TES) devices. The expected gradual adoption of

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[1] synonymous of gross load or energy use

"smart grid" features, and "smart meters" in advanced buildings, implies that new opportunities will be available for information exchange between buildings and the grid. It will be possible for the building to respond dynamically to price signals from the grid, and to take demand response actions. Load management is of foremost interest for utilities and could help in popularizing net-zero energy designs.

The indicators presented herein deal with buildings using electricity as their sole energy carrier (all-electric buildings). Electricity is the main priority in this analysis, since the technical challenges of storing electric energy highlight the relevance of the building-grid interaction. However, most of these indicators may also be applicable to buildings using other energy carriers (e.g., buildings connected to a district heating or cooling system).

The indicators presented here are intended only as assessment tools: there is no inherent positive or negative value associated with them. For this reason, we suggest avoiding the use of the term "mismatch" (used in some indicators), which may have a negative connotation. Matching the building's load with PV generation may or may not be appropriate depending on the circumstances.

The paper is structured as follows: first, target groups for different types of indicators are identified. Second, a literature review of previously suggested indicators is presented. Third, based on this review, a set of LMGI indicators chosen from the literature, as well as some new or modified indicators, are evaluated for an example Net ZEB. Finally, the findings are discussed and conclusions are drawn.

TARGET GROUPS FOR INDICATORS

Different target audiences will be interested in different kinds of quantitative indicators. The level of detail, the time resolution and technical complexity of the indicators must be adapted to the needs of different groups. The following potential target audiences have been identified:

Building designers and owners

When developing a Net ZEB, quantitative *load matching* indicators may guide the design team in comparing different design/project scenarios and selecting equipment. In particular, they could be useful in sizing energy storage devices and HVAC components as well as adjusting orientation and slope of solar energy systems or optimizing the control strategy for building integrated CHP systems. Load match indicators may also serve to assess the vulnerability of the building to natural catastrophes, weather events or a grid breakdown.

Building owners or operators could also use *grid interaction* indicators to better take advantage of time-of-use (TOU) electricity rates or feed-in tariffs (FIT) (Newsham et al., 2010). Indicators developed based on daily and hourly data may be of interest for this target audience, since energy storage in a building is usually possible only for periods of about one day or perhaps a few days.

Community designers and urban planners

LMGI indicators need not be limited to a single building: they could also be used to describe the performance of building clusters or larger communities. In this sense, LMGI indicators can work as descriptors of a generalized energy system. Building groups or communities may include centralized CHP, storage or district heating systems that could help in managing the load of the community over long periods. Designers of such a system could benefit from *load matching* indicators with low time resolution (for instance, monthly solar fraction).

Grid operators at a local distribution level

Operators of distribution grids at medium or low voltage (a few hundred to a few thousand volts) are interested in the load distribution on the grid, especially peak powers, because these are influential on losses and voltage profiles. Therefore, *grid indicators* with very high temporal resolution (i.e., time scales of at least hours, or even down to minutes or seconds), may help them in assessing and design the operation limits of the grid. For example, these indicators may help to improve voltage regulation in the case of high penetration rates of PV systems (Fechner, 2011). Indicators based on probability and statistical information could be useful for operators of distribution grids.

Grid operators at a national or regional level

Operators of national energy grids are familiarized with economic dispatch and planning the operation of generation plants and transmission lines based on expected loads. *Grid indicators* with low temporal resolution (daily or monthly) are useful for this target group, as they could be used to assess the impact of net-zero energy buildings in the grid. Aggregated *grid indicators* at hourly or even less resolution will help to manage national grids and to increase the penetration of renewables in the electric power system, especially if high daily peak/baseload ratios occur.

REVIEW OF LMGI INDICATORS

A literature survey of *load matching* and *grid interaction* indicators was carried out. When these two concepts are mentioned in the literature, it is not always obvious what the differences between them are. As it was stated in the introduction, the main distinction made here is that *load matching* indicators measure the degree of overlap between generation and load profiles whereas *grid interaction* indicators take aspects of the unmatched parts of generation or load profiles into account.

Another important distinction to make regards the information needed for evaluation of the indicators. Some indicators use only the on-site load and generation profiles, while others also use additional information such as energy market prices or information on a whole set of buildings in an area. Given their lower dependency on data, it is evident that indicators of the former type are easier to both evaluate and generalise, while the latter type becomes more specific in both time and place.

Table 1 shows a categorisation of the indicators, or types of indicators, found in the available literature. A short summary of the findings is given below.

Table 1. Summary of LMGI indicators.

		Indicator category	
		Load matching	Grid interaction
Data requirements	On-site load and generation	**I** Load match index[1] Solar fraction[2] Cover factor[4] Self-consumption factor[7] Loss-of-load probability (LOLP)[4]	**II** Grid interaction index[1] Capacity factor[4] Peak power indicators[4] Dimensioning rate[4] Grid citizenship tool[8]
	Additional data	**III** Mismatch compensation factor[5] Market matching[3]	**IV** Profile addition indicators[3] Coincidence factor[6]

[1]Voss et al. (2010), [2]Widén et al. (2009), [3]Widén and Wäckelgård (2010), [4]Verbruggen et al. (2011), [5]Lund et al. (2011), [6]Willis and Scott (2000), [7]Castillo-Cagigal et al. (2010), [8]Colson and Nehrir (2009).

Category I

This category encompasses load matching indicators that do not need any additional information besides the load and generation profiles. The first four, namely the *load match index*, the *solar fraction*, the *cover factor* and the *self-consumption factor*, contain essentially the same information; the fraction of the load covered by on-site generation.

The actual concept of a 'solar fraction' is of course only applicable for on-site solar technologies, while the three others are more general. These four indicators are, as an example, well suited for describing how much of the demand can be saved by on-site energy supply and how much energy must be bought from the grid by the building owner. The fifth indicator, the *loss-of-load probability* (LOLP) index, instead shows how *often* the on-site supply is not enough to cover the demand.

Category II

This category collects indicators that can be used to show different aspects of the grid interaction of a building, without any need for additional data besides load and generation profiles. The *grid interaction index* shows the variability of the amount of purchased or delivered energy for a given time resolution, normalised by the highest absolute value.

The *capacity factor*, as formulated by Verbruggen et al. (2011), shows the total energy exchange with the grid divided by the exchange that would have occurred at nominal connection capacity, i.e. a measure of the utilisation of the grid connection.

Another aspect to be considered is the distribution of power peaks for delivered or demanded energy. These are called *peak power indicators* here and could simply be the maximum peak power or the time duration or mean value of the highest peaks. For grid connections and distribution grids with a large number of buildings that are both net users and exporters of energy, the latter indicators could provide basic information for dimensioning and design, using for example *dimensioning rate*. Colson and Nehrir (2009) introduced a qualitative tool, namely the *microgrid citizenship tool*, based on key microgrid characteristics of nominal generation capacity, installed storage, and load. The concept of the tool can be adapted to grid- connected buildings. The tool is composed of three ratios. The *component ratio (CR)* offers a qualitative scale (from -1 to +1) for the degree of generation to load. The *storage ratio (SR)* gives a measure of how well the installed generation is supported by its own storage. Finally, the *intermittency ratio (IR)* is intended to give a qualitative indication as to how "dependable" the microgrid (building) is at supplying power.

Category III

This category contains indicators that use additional data to show aspects of load matching that cannot be shown with only load and generation data. The *mismatch compensation factor* (MMCF) is the quotient between the on-site generation capacity that meets the annual demand and the capacity that compensates for the mismatch (i.e. the capacity that makes total generated electricity worth as much as demanded electricity on an annual basis). A MMCF > 1 means that the system that compensates for the mismatch is smaller than the system that gives a net zero energy balance because generated electricity is, on average, worth more than demanded electricity (Lund et al., 2011). The *market matching* indicator is similar to the MMCF and shows the difference between the market value of bought and delivered energy (Widén and Wäckelgård, 2010).

The main advantage of these indicators is that they can value the load matching of the building from the electricity market's viewpoint. If there is a need for electricity on the market, the MMCF will be greater than 1 and the market matching index positive, indicating that the "mismatch" in the building is generally positive from the system's point of view. Electricity market prices for the studied location are an important additional piece of information needed to evaluate these indicators.

Category IV

Although the energy needs of the whole market may coincide with an energy surplus from the building, there may also be unfavourable consequences of electricity overproduction levels in the local distribution grid. Category IV lists a few indicators for identifying such situations. The *profile addition indicators* are evaluated for the aggregate load of a local distribution grid to show the effect on the margin of adding a Net ZEB profile. For example, the actual indicator evaluated could be one of those listed in category II. This approach needs information about the aggregate load on the studied grid. The *coincidence factor* is, in general, the fraction between the observed peak of a customer group and the sum of the individual peaks of each customer. It shows the degree of random coincidence between individual peaks and the degree of smoothing when aggregating a large number of buildings. For a grid company, a typical coincidence factor for different types of Net ZEBs would probably be interesting, as it can be used to size grid components (Willis and Scott, 2000). This indicator needs a set of Net ZEB grid interaction profiles to be evaluated. The *covering index* is the ratio between the available conventional power in the system and the peak power demand. This indicator is of interest for energy operators at national level (REE, 2010).

All of these indicators attempt to summarise a large dataset of generation and load profiles (and possibly additional information) into one number or a small set of numbers. Graphs can also be used to visualise a larger range of values (e.g., the variability in the grid interaction). Some examples are *sequence graphs* that show profiles in sequence, time step by time step, *cumulative graphs* that show cumulative generation and load time step by time step to show the temporal asymmetry, and *duration curves* that sort data in decreasing order. Various numerical indicators can be determined from the duration curve.

EVALUATION OF LMGI INDICATORS

As an example of what LMGI indicators show and as a test of their relevance, some of the reviewed indicators, as well as some modified or alternative ones, were applied to a test building. First, the terminology is stated. Then, mathematical definitions for reviewed indicators and alternative indicators are presented. Finally the computed values for a test case are shown.

Terminology and balance

The sketch depicted in Figure 1 provides an overview of relevant terminology addressing the energy use in buildings and the connection between buildings and the power grid. The sketch is not an energy balance graph and is only valid for buildings using electricity as their sole energy carrier.

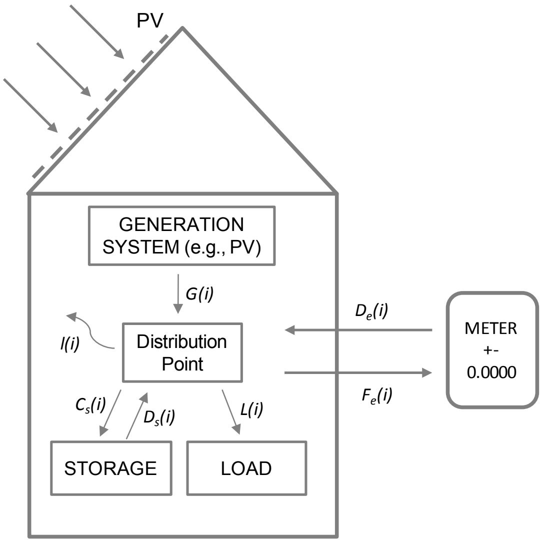

Figure 1 Schematic view of the energy flows in an all-electricity Net ZEB

Let us assume that the building performance is evaluated at relatively short time intervals (e.g., 15 min, 1 hour), which we will call “sampling interval” and represent by Δt. The index i will be used to identify the value of a variable measured between the times t_i and $t_{i+1} = t_i + \Delta t$. For example, the total energy generated in the interval Δt will be obtained by integrating the generation rate over this interval:

$$G(i) = \int_{t_i}^{t_{i+1}} g(t)dt \qquad (1)$$

At a given time step identified with the index *i*:

$$G(i) = L(i) + S(i) + l(i) + E(i) \qquad (2)$$

where: $$E(i) = F_e(i) - D_e(i) \qquad (3)$$

and $$S(i) = C_s(i) - D_s(i) \qquad (4)$$

Definition of LMGI indicators

A selected set of the reviewed LMGI indicators are mathematically defined below. These indicators correspond to category I and II, because the available data to compute them are the on-site load and generation. The selection criterion has been to choose the ones that could represent as best as possible the behaviour of the same Net ZEB with different grid-connection strategies.

Load match index over evaluation period T:

$$f_{load,T} = \overline{\min\left(1, \frac{G(i) - S(i) - L_o(i)}{L(i)}\right)} \qquad (5)$$

Load cover factor over evaluation period T:

$$\gamma_{load,T} = \frac{\sum_{i}^{i+N} \min\left[G(i) - S(i) - l(i), L(i)\right]}{\sum_{i}^{i+N} L(i)} \qquad (6)$$

in which the number of samples, N, is given by $T/\Delta t$

Capacity factor over evaluation period T

$$CF_b = \frac{\sum_{i}^{i+N} |E(i)|}{E_{des} \cdot T} \tag{7}$$

Loss of load probability

$$LOLP = \frac{time_{L(i)>[G(i)-S(i)-l(i)]}}{T} \tag{8}$$

Peaks above certain barrier (L_{lim})

$$E_{>L_{\lim}} = \frac{time_{|E(i)|>L_{\lim}}}{T} \tag{9}$$

Dimensioning rate

$$DR_b = \frac{\max\left[|E(i)|\right]}{E_{des}} \tag{10}$$

Grid interaction index over period T

$$f_{grid} = STD\left(\frac{E(i)}{\max\left(|E(i)|\right)}\right) \tag{11}$$

The following three indicators are part of the microgrid citizenship tool.

Component Ratio

$$CR = \frac{G_{des} - L_{des}}{G_{des} + L_{des}} \tag{12}$$

Storage ratio

$$SR = \frac{G_{des} - S_{des}}{G_{des} + S_{des}} \tag{13}$$

Intermittency ratio

$$IR = \frac{G_{daily\ avg} - S_{des}}{G_{des} + S_{des}} \tag{14}$$

Alternative LMGI indicators

Alternative indicators are proposed in this section. Some of them consist of minor modifications of the indicators described in the previous section, in order to enrich the information they give. Others are inspired by other kind of systems, such as solar power plants. Finally, the authors propose indicators aimed at better describing the flexibility of Net ZEB.

A modified method to compute the capacity factor is proposed, taking into account the path of the energy exchange with the grid. A positive value means that the building is exporting energy to the grid over the evaluation period.

Capacity factor over evaluation period T

$$CF_{b,E} = \frac{\sum_{i}^{i+N} E(i)}{E_{des} \cdot T} \tag{15}$$

The *connection capacity credit* or power reduction potential can be defined as the percentage of grid connection capacity that could be saved in comparison with the design connection capacity for a building with no local energy supply. It has been inspired by the kVA credit indicator proposed by Verbruggen et al. (2011).

Connection capacity credit

$$E_{c,des} = 1 - \frac{E_{des}}{L_{des}} \tag{16}$$

The two following proposed indices take advantage of some concepts used in the design of CSP parabolic trough systems and could be useful for determining optimal designs. The *generation multiple* relates the size of the generation system with the design capacity load. The *equivalent hours of storage* corresponds to the storage capacity expressed in hours. Both indicators can be used to compare different Net ZEB designs.

Generation Multiple

$$GM = \frac{G_{des}}{L_{des}} \tag{17}$$

Equivalent hours of storage

$$N_{h\_S} = \frac{C_S}{L_{des}} \tag{18}$$

The following indices are grid interaction indices or peak power indicators normalized by the design capacity load. These indices are better suited for comparing different Net ZEB design proposals.

Relative Feed-in Peak Power

$$PP_{r,f\_e} = \frac{\max\left[E(i)\right]}{L_{des}} \tag{19}$$

Relative Delivered Peak Power

$$PP_{r,d\_e} = \frac{\min\left[E(i)\right]}{L_{des}} \tag{20}$$

Relative grid interaction amplitude

$$A_{grid,r} = PP_{r,f\_e} - PP_{r,d\_e} \tag{21}$$

Relative grid interaction index

$$f_{grid,r} = STD\left(\frac{E(i)}{L_{des}}\right) \tag{22}$$

The last proposed index is the no-grid interaction probability, which means the probability that the building is acting autonomously of the grid. In that case, the entire load is covered by the direct use of renewable energy system or by the stored energy.

No grid interaction probability

$$P_{E\approx 0} = \frac{time_{|E(i)|<0.001}}{T} \tag{23}$$

Results for LMGI indicators in a test case

Hourly data set from simulations for an experimental house have been used to test the LMGI indicators. The data are from the Bergische Universität Wuppertal team participating in the Solar Decathlon Europe competition in 2010 (Team Wuppertal, 2010). The building is a Net ZEB, using solar energy as the only energy source and equipped with technologies that permit maximum energy efficiency. PV generator systems on the roof and the south façade contribute, respectively, with about 6.4 and 3.8 kWp of installed capacity. The system is equipped with a 6 kW·h battery, enabling different modes of operation (grid connected, battery-buffered and occasionally stand-alone). Table 2 summarizes relevant design parameters used to compute LMGI indicators. Table 3 shows results of computed LMGI indicators.

Table 2. Test case design specification parameters

PARAMETER	VALUE
G_{des}, installed PV Capacity	10.2 kWp
L_{des}, Design load capacity	15 kW
E_{des}, Design connection capacity	15 kW
S_{des}, Storage capacity (fully charged to discharged, 1 hour)	2.91 kW
C_s, Storage capacity (total)	6 kW·h

Detailed hourly data from a simulation of the building located in Madrid are available. Simulations have been performed in cooperation with Fraunhofer ISE with the DYMOLA simulation environment. One set of data corresponds to a system without storage. The other data set corresponds to a system with battery, where the battery use is optimized so that to preferably match the electricity demand of the house with its own solar energy generation. Results in Figure 2 and Figure 3 shows that over 9,000 kWh/year are fed-in to the grid for both cases, while grid import is nearly zero in the summer period with a storage system.

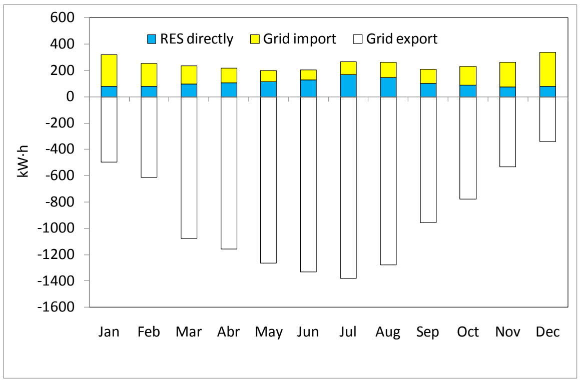

Figure 2. Load distribution from energy sources and electricity feed-in to the grid for the test case without battery

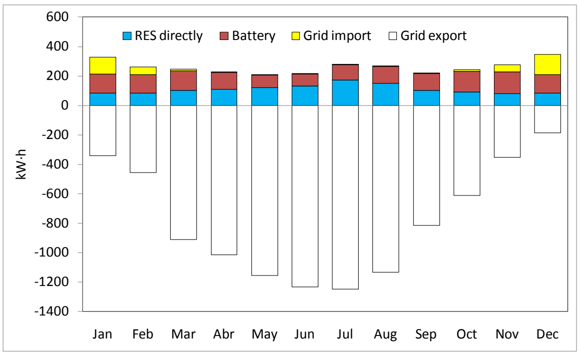

Figure 3. Load distribution from energy sources and electricity feed-in to the grid for the case with battery

Table 3. Computed LMGI indicators

INDICATOR	WITHOUT BATTERY	WITH BATTERY
Load matching indicators		
$f_{load,h}$	44.5 %	93.6 %
$f_{load,m}$	100.0 %	100.0 %
$f_{load,y}$	100.0 %	100.0 %
$\gamma_{load,h}$	42.2 %	87.2 %
$\gamma_{load,m}$	100.0 %	100.0 %
$\gamma_{load,y}$	100.0 %	100.0 %
$LOLP_b$	57.6 %	17.7 %
GM	0.68	0.68
N_{h_S}	0.0 h	0.5 h
Grid interaction indicators		
CF_b	9.8 %	7.5 %
$CF_{b,E}$	7.2 %	6.9 %
OPP	6.82 kW	6.66 kW
$E_{>L_{lim}=5kW}$	8.93 %	7.63 %
DR_b	49.1 %	47.8 %
$E_{c,des}$	0.0 %	0.0%
CR	-0.190	-0.190
SR	1.000	0.556
IR	0.262	0.426
$G_{daily\ avg}$	2.7 kW	2.7 kW
PP_{r,f_e}	0.49	0.48
PP_{r,d_e}	-0.10	-0.10
$A_{grid,r}$	0.59	0.58
f_{grid}	0.29	0.26
$f_{grid,r}$	0.14	0.13
$P_{E\approx 0}$	0.0 %	56.8 %

DISCUSSION

Some points of discussion can be derived from the test case results. Since the size of the PV system and the connection capacity are the same for both scenarios, the values for the indicators *GM, CR,* $E_{c,des}$ are the same. These indicators might be useful to compare differences in design options, apart from those due to different energy storage capacities.

There is a group of indicators –peak power (PP_{r,f_e}, PP_{r,d_e}, $A_{grid,r}$, OPP), grid interaction (f_{grid}, $f_{grid,r}$) or others which computes maximum values of certain variables (DR_b, $E_{>lim}$)– which show slight differences between the two test case scenarios. Looking at the building energy use results, the peak power is about 1.5 kW. This figure is far from the expected peak values, which led to a design connection capacity of 15 kW. The recorded peak power for energy consumption during the Solar Decathlon in Madrid (summer 2010) was 5 kW. We conclude that sub-hourly resolution, probably less than 10 minutes, is needed to capture more accurately the behaviour of the building when a dynamic simulation is used.

For the test case considered above, it is evident that some indicators show better the impact of using a battery. For example, both the hourly load match index ($f_{load,h}$) and the load cover factor ($\gamma_{load,h}$) are considerably higher when using the battery. The loss of load probability ($LOLP_b$) is significantly reduced when the battery is used, from 57.6% to 17.7%, which reflects an increase in reliability. The no-grid interaction probability ($P_{E\approx 0}$) increases from 0% to 56.8%, which means that the introduction of the battery increases dramatically the time when no interaction is registered. This effect can be clearly appreciated in Figure 4.

Some modifications of existing indicators are proposed by the authors. That is the case of the capacity factor (CF_b and $CF_{b,E}$). Different values for the same scenario (CF_b=9.8% and $CF_{b,E}$=7.2%, for the case without battery) are derived from the different formulation. The CF_b indicator computes absolute values of exchanged energy with the grid, treating exported and imported energy in an equivalent manner, while $CF_{b,E}$ differentiates between them. Consequently, $CF_{b,E}$ could take negative values if the delivered energy is higher than the feed-in energy.

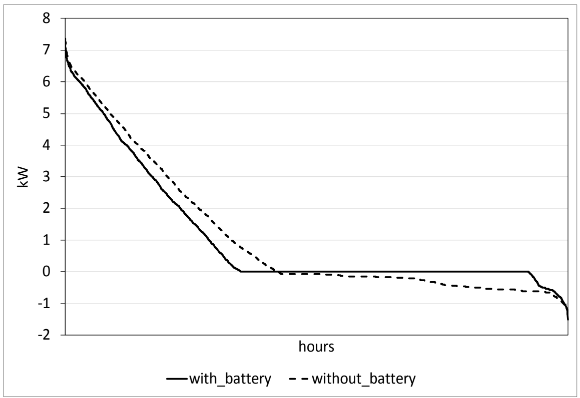

Figure 4. Duration curves for the net energy export to the grid exchange. Comparison of the test case with and without battery. Positive values means energy is feed-in to the grid while negative values means delivered energy from the grid.

Further research is needed to test LMGI indicators using both measured values from actual Net ZEB or results from simulation. This should include not only all-electrical buildings. Suitable indicators are important to take advantage of the significant potential of dynamic building simulation to guide the design process.

One of the most important features that LMGI indicators may grasp is the *flexibility* of a building. A building’s flexibility can be described as the ability to respond to signals from the grid (smart grids), price signals or to some action taken by the residents, and consequently adjust load, generation and storage control strategies in order to serve the grid, the building needs, or adjust to favourable market prices for energy exports or imports. Such opportunities could act on instantaneous values and be implemented automatically by devices such as a smart-meter. What is in the hands of designers at the design table – and what is of interest to the various target groups, e.g. building designers and utility operators – is to design the building and its energy systems to enhance flexibility.

The flexibility could be quantified using suitable indicator(s), especially those indicators that provide significantly different values in extreme situations. An extreme situation for an all-electric building is a feed-in priority strategy (maximum feed-in): the generation system feeds power into the grid regardless of the building’s load or storage possibilities. The opposite extreme situation is a load matching priority strategy: (maximum load match); storage system and load shifting strategies – if any – provide maximised self-consumption of the generated electricity. The difference between the two values tells how flexible a building is in terms of load matching and of grid interaction. The higher the flexibility, the better the building will be able to adapt to signals from the grid.

CONCLUSION

This work has presented and categorised the LMGI indicators most commonly mentioned in the literature. An example of their application has also been presented. Although the usefulness of each indicator depends on the final objective, LMGI indicators could add significant value to the output of building performance simulation tools, and give a more complete picture of net-zero energy buildings.

Although there are no “good” or “bad” values, LMGI indicators enable assessing of the effect of load management strategies (storage, predictive control, orientation, demand response, etc.). In consequence, they can be used to gauge the flexibility of a building’s design to respond to variable generation, loads and grid conditions, and to take advantage of smart grid features.

NOMENCLATURE

CF_b	Capacity factor for buildings

C_s	Charging energy to the storage
C_S	Total storage capacity
D_e	Delivered energy from the grid
D_s	Discharge energy from the storage
DR_b	Dimensioning rate
E	Net energy export to the grid
E_{des}	Nominal / Design connection capacity between building and grid
f_{grid}	Grid interaction index
$f_{load,i}$	Load match index
$\gamma_{load,T}$	Load cover factor
F_e	Feed-in energy to the grid
G	Generation (e.g., on-site PV)
$G_{daily\ avg}$	Average amount of generated energy divided by the average number of hours the system is generating power per day
i	time interval (m=month; y=year)
L	Building Load
l	Energy looses
L_{des}	Nominal / Design capacity load (connection capacity for building with no system generation)
$LOLP_b$	Loss of load probability
OPP	One percent peak power
S	Net energy exchange with the storage system
T	Evaluation period

ACKNOWLEDGEMENT

The work presented in this paper has largely developed in the context of the International Energy Agency (IEA) joint programme Solar Heating and Cooling (SHC) Task40 and Energy Conservation in Buildings and Community Systems (ECBCS) Annex52: Towards Net Zero Energy Solar Buildings.

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