

## NEW ENERGY PERFORMANCE INDEXES FOR ENERGY-EFFICIENT INTERACTIVE BUILDINGS

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**Abstract** *This paper argues that promoting energy supply by Renewable Energy Sources (RES) in buildings, namely residential, requires additional informative indexes to be included in buildings Energy Performance Certificates. The load-generation approach for the energy balance is here discussed, and compared with the current recommended by CEN/TR 15615, i.e. the delivered-exported approach. Besides the Energy Performance Index, which takes the same value for both approaches, other indexes are studied. From the analysis considering two variants for a single-family house with six solutions for energy systems, it is suggested to include: i) L/R (building load vs benchmark load) and ii) G/L (RES supply vs building load). On the one hand, L/R distinguishes the solutions where the building envelope is optimized from those where the driver to reduce EPI is the RES supply installation. On the other hand, G/L quantifies the RES share in the building demand and goes in line with what is recommended for the principles defining nearly Zero Energy Buildings. The breakdown of G/L into on-site and off-site RES will be also very helpful in differentiating local RES supply from imported renewables fuels, such as biomass. Moreover, considering smart cities, not only energy flows are important but also information flows (e.g. energy forecast, energy management), thus, new energy performance indexes are required for energy-efficient interactive buildings.*

## 1. INTRODUCTION

Sustainable cities require energy-efficient buildings, i.e. buildings where the use of energy is minimized without compromising of occupants life standards, namely for heating, cooling, lighting and indoor air quality. In 2002, in Europe, the European Energy Performance of Buildings Directive 2002/91/EC (EPBD) [1] required all member states (MS) the task of indexing buildings by their energy performance, which applies to new and, for some MS, also existing ones. Meanwhile, most of the MS implemented the Energy Performance Certification (EPC), but new challenges were open with the recast of EPBD (Directive 2010/31/EU) [2], requiring by 2020 that new buildings be as “nearly Zero-Energy Buildings”, defined as “*a building that has a very high energy performance (...). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy produced on-site or nearby*” [2].

The Energy Performance Index (EPI) is connected with the goal of promoting the *Low Energy Buildings* and, therefore, quantifies the energy performance of a specific building compared to a defined standard (*benchmark*).

However, a step forward seems to be needed in order to reach the goal of *Net Zero-Energy Buildings*, intended as *on-grid* (=connected to grid) buildings, by using as much renewable energy sources (RES) as possible to compensate the energy requirements of the building (building energy *load*). It is noteworthy that the building energy *load* can be low, but hardly zero.

In the framework of a sustainable city, this paper discusses that a single index, as EPI, is not enough to characterize the flow of energy carriers crossing the building boundary. Moreover, considering *smart* cities, not only *energy* flows are important but also *information* flows (e.g. energy forecast, energy management), thus, new energy performance indexes are required for energy-efficient *interactive* buildings.

## 2. DEFINING BOUNDARIES

The first law of Thermodynamics states that the change in the internal energy of a closed system is equal to the amount of energy exchanged in the system’s boundaries, namely by heat and work. Therefore, assuming the building as a closed system where heating, cooling, lighting and air quality requirements apply, the first and obvious boundary of the building is its ‘skin’, i.e. the building envelope composed by walls, windows, roofs and floors, which are not adiabatic surfaces. The heat supplied to or extracted from the building in order to keep its internal energy constant, correlated with temperature, are the building energy needs, heating or cooling, respectively.

However, supplying heat is possible by different energy transformation processes, such as combustion, Joule effect, etc. Therefore, energy carriers are either a substance (energy forms such as fuels) or a phenomenon (energy systems such as electricity) that can be used to produce mechanical work or heat or to operate chemical or physical processes [3]. CEN/TR 15615 [4] recommends calculating EPI’s using an import-export approach (=delivered-exported, *D-E*) of energy carriers, assuming that the energy from RES

(e.g. solar, wind), transformed and used locally, is neither imported nor exported. Otherwise, fuels, including those renewable, are considered as imported energy carriers.

The *boundary* of the aforementioned import-export approach goes beyond the physical boundary of the building ‘skin’, because it encloses the renewable energy systems, most of the time located above the building or in its proximity.

However, assuming the boundary as the building ‘skin’, the new energy balance differs from *D-E* because it compares the building energy *load* with the renewable energy locally transformed (locally used or exported). The new approach introduced by Sartori et al. [5] is called *load-generation*, *L-G*. It can be correctly argued that energy is transformed and not generated, however, the term *generation* is still used to give continuity to what authors have defined. It is noteworthy that even if EPI is quantified by a delivered-exported approach, it does not change for a load-generation approach due to the fact that, in both approaches, it accounts for the net of energy required from outside the boundaries.

### 3. NEW ENERGY PERFORMANCE INDEXES

The main advantage of a *D-E* approach is the fact that it easily quantifies, for an annual basis (or a even smaller period), the amount of energy delivered to the building and the energy exported. Unless dedicated measuring is performed, quantifying the building energy load and the RES energy generation could be difficult when RES energy systems are installed.

For example, for a residential building with thermal solar collectors installed in the roof for domestic hot water (DHW) and heating, the user does not know the part of the energy load that is supplied by the solar system, but knows how much energy is used (through its payment) for the complementary system (e.g. gas, electricity). Therefore, in operative terms, *L-G* is of difficult application.

However, in terms of design, *L-G* energy balance is preferred relatively to *D-E*, because it contains additional information regarding RES supply, locally used or exported. EPI is a one-dimension scale that typically varies from G (the worst) to A (the best). Therefore, the following section argues about the need of additional indexes when the *L-G* approach is used.

#### 3.1. *L-G* graphical representation

The *L-G* graphical representation is typically a *x-y* Cartesian system where the *x*-axis represents the energy load and the *y*-axis represents the energy generation. The EPI is obtained by subtracting the energy generated to the energy load, normalized by a benchmark energy value (*R*). The EPI ‘isoline’ is represented by the *b* straight line, designated henceforth as the EPI-line, parallel to  $x=y$  where the energy generation and load are equal.

However, a second dimension is needed to define a 2D system. For example, a pair of coordinates for latitude and longitude determines more precisely a position in the terrestrial surface. Following what has been learned from EPC, it would be desirable to keep the EPI as the first dimension.

There are some possibilities to the second dimension, which are represented in Figure 1, namely:  $L/R$ , the load generated energy normalized by the benchmark ( $x_1$ );  $G/R$ , the generated energy normalized by the benchmark ( $x_2$ ); and, finally, the  $G/L$ , the ratio between the RES energy generation and the energy load. The latter option mathematically expresses the tangent of an angle, identified by  $\xi$ , as  $\tan \xi = G/L$ . From these three possible dimensionless quantities, the last is the only not normalized by the benchmark.

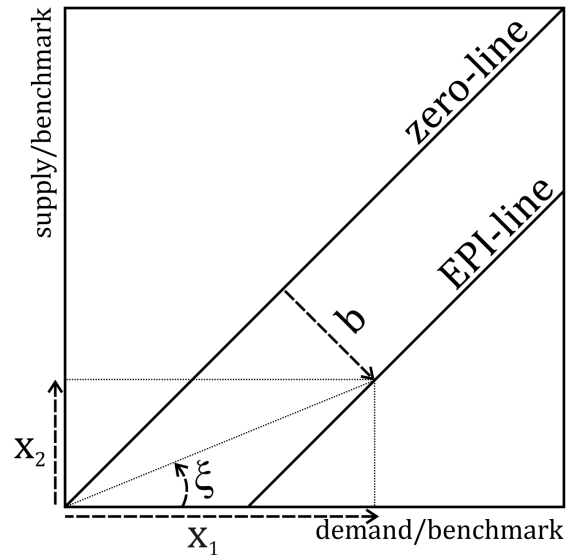


Figure 1. Two-dimensional coordinates system adapted for L-G energy balance:  $(b, x_1)$ ,  $(b, x_2)$  or  $(b, \xi)$ .

### 3.2. Load-generation primary energy

The calculation of building load primary energy is the weighted sum of the final energy  $Q_{ij}$ , by energy carrier  $i$  and end use  $j$ :

$$L = \sum_i \sum_j \omega_i Q_{ij} \quad (1)$$

with  $\omega_i$  as the total primary energy factor or index ( $PEI_t$ ) of energy carrier  $i$ .

For a single-family house with 165 m<sup>2</sup> of floor area ( $A_f$ ), consider two variants A and B, where the second corresponds to an improved solution regarding thermal insulation and windows solar protection: A) specific heat loss coefficient of 2.94 W/(Km<sup>2</sup>) and g-value of 0.45 and B) specific heat loss coefficient of 2.35 W/(Km<sup>2</sup>) and g-value of 0.04. Both variants adopt natural ventilation. The six solutions here assumed for the set of energy systems supplying heating, cooling and DHW are shown in Table 1, as well as their overall efficiency.

Solution	Heating	Cooling	DHW
1	Electrical resistance ( $\eta=1$ )	Heat pump (EER=2.8)	Electric heater ( $\eta=0.95$ )
2	Heat pump (COP=3.2)	Heat pump (EER=2.8)	Gas heater ( $\eta=0.82$ )
3	Gas boiler ( $\eta=0.86$ )	Heat pump (EER=2.8)	Gas boiler ( $\eta=0.86$ )
4	Gas boiler ( $\eta=0.86$ )	Heat pump (EER=2.8)	Solar collector + Gas boiler ( $\eta=0.86$ )
5	Biomass boiler ( $\eta=0.75$ )	Heat pump (EER=2.8)	Biomass boiler ( $\eta=0.75$ )
6	Biomass boiler ( $\eta=0.75$ )	Heat pump (EER=2.8)	Solar collector + Biomass boiler ( $\eta=0.75$ )

Table 1. Energy systems supplying building energy needs

Specific energy needs for heating and cooling are, for the first variant (A), 19.4 and 6.7 kWh/m<sup>2</sup>, respectively. The specific energy needs for the improved variant (B) for heating and cooling are 12.1 and 3.9 kWh/m<sup>2</sup>, respectively. Specific energy needs for DHW are, for both variants, 14.1 kWh/m<sup>2</sup>.

### 3.3. Results discussion

Table 2 compiles the results obtained for each variant A and B with the six energy systems options, considering the following theoretical PEI<sub>i</sub>: electricity 2.5, natural gas 1, biomass 1 and solar 1.

Solution	L [kWh/m <sup>2</sup> ]	G [kWh/m <sup>2</sup> ]	R [kWh/m <sup>2</sup> ]	(L-G)/R (EPI or b)	G/R (x <sub>1</sub> )	L/R (x <sub>2</sub> )	G/L (tan ξ)
A1	92.5	-	103.3	0.89	-	0.89	-
A2	38.7	-	48.5	0.80	-	0.80	-
A3	45.3	-	56.0	0.81	-	0.81	-
A4	43.7	10.1	56.0	0.60	0.18	0.78	0.23
A5	51.1	45.1	56.0	0.11	0.81	0.91	0.88
A6	47.7	41.7	56.0	0.11	0.75	0.85	0.87
B1	45.0	-	103.3	0.72	-	0.72	-
B2	18.2	-	48.5	0.63	-	0.63	-
B3	22.5	-	56.0	0.61	-	0.61	-
B4	32.6	10.1	56.0	0.40	0.18	0.58	0.31
B5	38.7	35.5	56.0	0.06	0.69	0.69	
B6	35.4	31.9	56.0	0.06	0.57	0.63	0.90

Table 2. Energy Performance Indexes for different solutions.

The cases A1 to A3 and B1 to B3 have no renewable energy supply and, therefore, EPI's follow the common energy scale. B performs better than A and, probably, they have different energy rating. In Portugal, for example, the first would be B<sup>-</sup> ( $0.75 < \text{EPI} \leq 1$ ) and the former

B ( $0.50 < \text{EPI} \leq 0.75$ ).

When renewable energy supply is included in the analysis, as depicted in Figure 2, it is observed that A4 and B3 have roughly the same EPI, but they are significantly different: the thermal envelope of B is improved compared to A, and no RES supply exists in B. For similar cases, the need of a second index is justified.  $L/R$  index ( $x_1$ ) expresses that the building energy load is 28% higher for variant A. Otherwise,  $G/L$  informs that A4 has more than 20% of RES supply.  $G/R$  is the less interesting index ( $x_2$ ) in terms of useful information because it compares the building RES supply to the benchmark energy load. Therefore, from this analysis, it can be concluded that one or both indexes  $L/R$  or  $G/L$  would be useful as complementary information to include in EPC. It is noteworthy that BPIE [6] recommended, for principles defining a nZEB, a minimum renewable energy share (the equivalent of  $G/L$ ) of, at least, 50%.

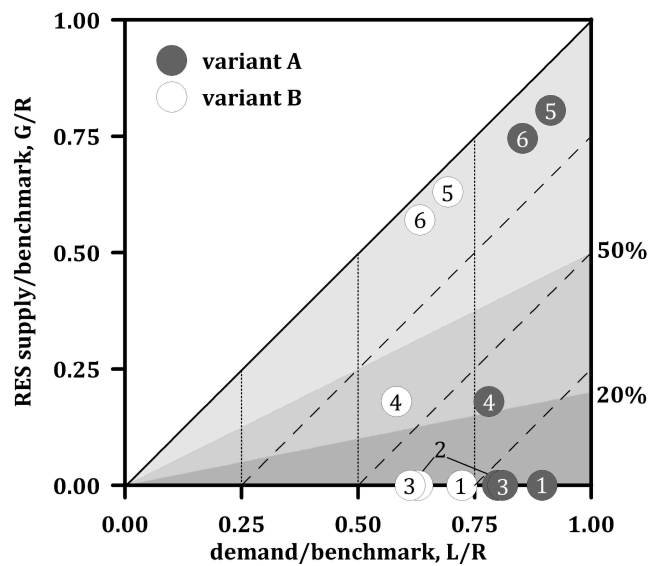


Figure 2. Energy performance Index (dashed lines),  $G/L$  index (gray scale) and  $L/R$  index (dotted lines) for the different energy systems solutions and the two variants.

A further analysis concerns solutions 5 (only biomass) and 6 (solar and biomass). From the building user perspective, it is important to distinguish the solutions with solar thermal collectors, which do not constitute a direct energy cost besides maintenance, from the solutions based only on biomass. Despite the fact that A5, A6, B5 and B6 are very similar in terms of EPI (0.11 for A's and 0.06 for B's), they are very different in terms of energy loads, varying from 35.4 to 51.1 kWh/m<sup>2</sup>. Moreover, for solutions A5 and B5, part of that energy load (10.1 kWh/m<sup>2</sup>) comes from solar collectors.

From this discussion, it would be helpful a breakdown of  $G/L$  index into on-site (e.g. solar, wind) as well as off-site RES (e.g. biomass) and, therefore, *on-site*  $G/L$  and *off-site*  $G/L$ .

### 3.4. Final considerations

At this point, energy flows were discussed, but an interactive *building* is more than an energy consumer/supplier. The concept of smart-cities and smart energy networks [7] presupposes the strict interaction between buildings and grids. The applicability of the *L-G* approach and the discussed indexes could be extended to shorter periods, rather than annual. The interest of condensing building information into physical indexes, defined for a specific time-scale (e.g. hourly, daily), is certainly an emerging research issue to be developed in the near future.

## 4. CONCLUSIONS

This paper argues that promoting RES energy supply in buildings, namely residential, requires additional informative indexes to be included in buildings Energy Performance Certificates. The load-generation approach for the energy balance is here discussed, and compared with the current recommended by CEN/TR 15615 [4], i.e. the delivered-exported approach. Besides the Energy Performance Index, which takes the same value for both approaches, there are three other indexes that could be considered: *L/R* (building load vs benchmark load), *G/R* (RES supply vs benchmark load) and *G/L* (RES supply vs building load).

From the analysis considering two variants for a single-family house with six solutions for energy systems, two of the three indexes are suggested to be included:

- *L/R* distinguishes the solutions where the building envelope is optimized from those where the driver to reduce EPI is the RES supply installation;
- *G/L* quantifies the RES share in the building demand and goes in line with what BPIE [6] recommends for principles defining nZEB. The breakdown of *G/L* into *on-site* and *off-site* RES will be also very helpful in order to differentiate local RES supply from renewables fuels, such as biomass.

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