Energy Performance Certificate: a valuable tool for building-to-grid interaction?

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ABSTRACT: New challenges were opened with the recast of Energy Performance of Buildings Directive, requiring by 2020 that new buildings be "nearly Zero-Energy Buildings" (nearly ZEB). In addition to consumer buildings, Net ZEBs are also producers' by using as much renewable energy sources as possible to compensate the building energy load. Sustainable cities require energy-efficient buildings, i.e. buildings where the use of energy is minimized without compromising the occupants comfort, namely for heating, cooling, lighting and indoor air quality. But smart cities require energy-efficient 'interactive' buildings, which integrate multiple-carrier energy networks and provide up-to-date valuable information for their management, where buildings are simplified to single nodes characterized by their energy load, generation, storage and conversion, applying the load-generation approach. The information currently available in the Energy Performance Certificate is not relevant for estimating the time dependent building energy load, but it can be easily improved by including a few descriptive parameters.

1 INTRODUCTION

New challenges were opened with the recast of the Energy Performance of Buildings Directive, (EPBD-Recast, 2010), requiring by 2020 that new buildings be "nearly Zero-Energy Buildings" (nearly ZEB). But, for some of European Member States, nearly ZEB are not defined in detail. Therefore, a more consistent definition is the Net ZEB (Sartori et al., 2011), intended as on-grid ZEB's, meaning 'buildings connected to the grid' delivering as much energy to the supply grids as they use from the grids (Laudsten, 2008). Net ZEB's are energy producer buildings besides consumers and, therefore, they use as much renewable energy sources (RES) as possible to compensate the energy requirements of the building.

Sustainable cities require energy-efficient buildings, i.e. buildings where the use of energy is minimized without compromising the occupants comfort standards, namely for heating, cooling, lighting and indoor air quality. In order to increase the overall energy efficiency in cities and facilitate the integration of RES into urban energy networks, building-to-grid interaction should be reinforced, requiring, from the buildings' perspective, energy-efficient 'interactive' buildings (EeIB). Henceforth, EeIBs actively interact with multiple-carrier energy networks (e.g. electric grid, thermal network, gas pipelines) by providing up-to-date information, valuable for the energy networks management. Therefore, not only energy flows, from or to an EeIB, are important, but also the information flows, based on accessing and predicting time-dependent energy flows. This is the context that frames the work here developed, following the objectives of EERA Joint Programme on Smart Cities (2011).

The energy networks modeling of Niemi et al. (2012) is an example of simulating multi-carrier energy networks including renewable energy generation, where buildings are simplified to nodes in the grid. In the load-generation approach (Sartori et al., 2011), buildings are evaluated by their energy demand (consumption or *load*) and energy supply (production or *generation*).

But for energy networks modeling, energy *storage* potential should also be taken into account. It is noteworthy that in the Niemi et al. (2012) approach, geospatial and temporal loads data are required for running simulations, but they used instead an empirical simplified method to generate those data.

In European countries, building energy labeling was launched through Directive on Energy Performance of Buildings (EPBD, 2002), which attributed an energy performance scale to buildings. However, despite that, the Energy Performance Certificate (EPC) contains much more information about the building itself and energy systems, constituting the "identification card" of the building.

This paper aims at evaluating how relevant are the parameters available at EPC for residential buildings, considering the Portuguese example, for estimating the time-dependent building energy load required for multi-carrier energy networks modeling. Henceforth, the energy generation and storage are out of the scope of this paper, even if these terms are included in the formulation.

2 BUILDING-TO-GRID INTERACTION

2.1 *Building: Load-Generation-Storage-Conversion*

For modeling purposes, buildings are simplified to single nodes characterized by load (L), generation (G), storage (S) and conversion (C). It is noteworthy that the load-generation approach (Sartori et al., 2011) assumes as object boundary the building itself and, therefore, all the energy locally produced (generation term) and used in the building is included in its energy load. This consideration is different from the assumed by CEN/TR 15615 (European Committee for Standardization, 2008), where the energy produced on-site is deduced from the energy demand and delivered energy.

Since the design of the building is strictly connected to passive strategies/systems, such as solar heating, passive cooling or natural ventilation, for example a south oriented window is a direct gain system, the energy load is the energy required for heating, cooling, lighting, ventilation, etc. considering the use of all passive strategies/systems. The building energy storage is conceptually different from the natural building thermal capacity, which is included as a passive strategy; it identifies all forms of controlled storage of the energy carrier, such as hot water or ice tanks, for heat, and batteries, for electricity.

Load, generation, storage and conversion (Figure 1) apply to different energy carriers, i, and vary with time, t, so they are generically represented as $L_i(t)$, $G_i(t)$, $S_i(t)$ and $C_i(t)$, respectively. $L_i(t)$ and $G_i(t)$ are always positive, even if when they refer to 'cooling'. $S_i(t)$ can either be negative (for charge) or positive (for discharge). $C_i(t)$ takes negative values for the energy carriers that are used in the conversion and positive otherwise.

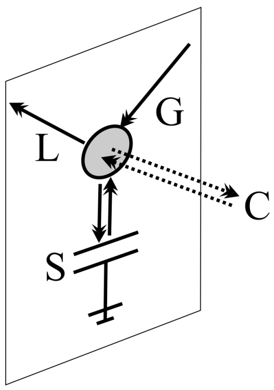

Figure 1. Building single-node representation: Load-Generation-Storage-Conversion

The energy systems of the building convert energy carriers into each other. The $C_i(t)$ term is the conversion energy balance for each energy carrier i:

$$C_i(t) = \sum_{k \neq i} c_{ki}/\eta_{k \to i} - c_{ik} \quad (1)$$

where $\eta_{k\rightarrow i}$ is the conversion performance from energy carrier k to i and c_{ki} is the energy carrier k transformed into energy carrier i.

The overall energy balance of a single node, for each energy carrier i, corresponding to the delivered or exported energy if it is negative or positive, respectively, is calculated by:

$$\phi_i(t) = G_i(t) + S_i(t) + C_i(t) - L_i(t) \quad (2)$$

It is noteworthy that the on-grid Net ZEB, could be achieved by considering all energy carriers $\phi_i(t)$ and integrating over a period of time, so that the overall primary energy, Φ, calculated by Equation 3 should be zero.

$$\Phi = \sum_t \Phi(t) = \sum_t \sum_i w_i \phi_i(t) \quad (3)$$

The w_i in Equation 3 are the weighted primary energy indexes or factors.

Henceforth, the off-grid Net ZEB, i.e. not connected to the grid, should achieve the goal of zero energy balance for each time-step t ($\Phi(t) = 0$), by supplying its overall load with energy generation and/or energy stored, considering conversion among different energy carriers.

A final note about possible restrictions applied to different terms: i) when there is a physical conversion restriction (e.g. no system converting electricity into fuel) the null energy performance is assumed; ii) the terms S_i and c_{ki} can be lower or higher limited, for example, by the systems power and the $\eta_{k\rightarrow i}$ can be expressed as a function of c_{ki} and iii) the building energy load is different from zero only for electricity, heat and cool energy carriers.

It is noteworthy that, thermodynamically speaking, the heat energy carrier includes heating and cooling energy needs. However, considering that the conversion performance can be significantly different for the same system or even systems that provide heating or cooling are different, they are assumed as two separated energy carriers.

2.2 *Networks: energy carrier and information flows*

Buildings represented as single nodes are interconnected among them, or with energy connectors, e.g. transformers for electricity grid or heat substation (see squares in Figure 2). Commonly, energy networks correspond to different overlapping levels for each energy carrier, namely electricity, heat, cool and fuels, considering in the nodes the possibility of energy carrier conversion. For example, heating requirements can be supplied by energy systems with different energy carriers such as a heat pump, boiler or solar collector. This consideration is possible by including energy carrier networks connections (dashed lines in Figure 2).

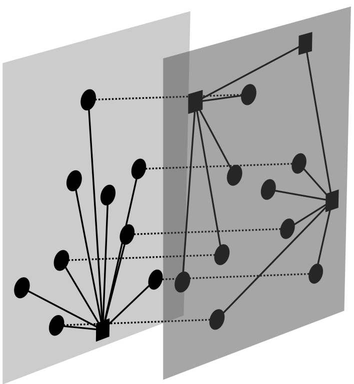

Figure 2. Two energy carrier networks connected by energy conversion.

For the energy network management, the knowledge of L, G, S, and C, which typically vary with time, is important. The smart management consists in deciding about the S energy flow (no use, charge or discharge), the C energy flow (conversion systems to be used) and grid interconnection energy flows.

3 BUILDING LOAD

3.1 *EPC data*

The building-to-grid representation requires the knowledge of the building load term, for a time-step considerably low, in order to provide valuable information for energy networks management.

For residential buildings, Portuguese EPC contains data of the thermal load for heating, cooling and domestic hot water (DHW) calculated for an annual time basis, which in the formulation here assumed are the time integrated L_1 and L_2, respectively, the heating energy load (space heating and DHW) and cooling energy load. Energy systems performance is also accessible from EPC, even if they are defined as constant values defined for nominal loads.

One of the requirements for building-to-grid interaction would be accessing time-dependent variables. Furthermore, the thermal loads are calculated for standard use conditions, which cannot be representative of the real use profiles.

The main conclusion of this brief analysis is that the current format of the EPC does not contain valuable data for building-to-grid interaction. Making the EPC a valuable tool for building-grid interaction is, therefore, the main goal of the following sections.

3.2 *Measuring and predicting*

In order to enable the use of EPC data, it would be required further information about the building itself. The main objective would be accessing the time-dependent energy loads, using a few descriptive parameters.

For heating and cooling energy needs, the method currently adopted in EPC is the quasi-steady state seasonal approach. However, the input data required to apply that method are very similar to other calculations methods, with different time-basis, such as the resistance-capacitance (RC) method of EN ISO 13790 (European Committee for Standardization and International Organization for Standardization, 2008), which is a simplified hourly method to compute heating and cooling energy needs. This method uses very few descriptive parameters of the building envelope (see Table 1). It is noteworthy that some of the variables required for running the method are user dependent, besides climate dependent. For example, the ventilation heat transfer coefficient varies with windows opening and/or ventilators use; effective solar collecting area varies with movable shading operation. The aforementioned variables could be included in EPC by defining the corresponding parameters related to each use operation profile, such as ventilators on and off, shading active and inactive.

The user plays an important role on the thermal energy loads, not only for the building main variables already discussed, but also for the real use of energy systems. That is why measuring data is complementary to EPC data, in order that user behavior be also taken into account in energy predictions.

The process of feeding the model with EPC and monitoring data enables to predict building thermal loads by taking into account the local weather forecast (climate data).

Table 1. Building envelope description for RC model.

Main variables	Total values	Specific values
Net floor area	A_f (m^2)	-
Transmission heat transfer coefficient for heavy elements (walls, roofs, floors, etc.)	$H_{tr,op}$ (W/K)	$H_{tr,op}/A_f$ (W/K.m^2)
Transmission heat transfer coefficient for light elements (windows, curtain walls, etc.)	$H_{tr,w}$ (W/K)	$H_{tr,w}/A_f$ (W/K.m^2)
Ventilation heat transfer coefficient	H_{ve} (W/K)	H_{ve}/A_f (W/K.m^2)
Internal thermal capacity	C_m (J/K)	C_m/A_f (J/K.m^2)
Effective solar collecting area by orientation	A_{sol} (m^2)	-

4 CASE-STUDY

4.1 *Description*

Assuming an apartment located in Lisbon, with 105 m^2 of net floor area, the transmission heat transfer per unit of floor area is 1.23 and 0.54 $W/K.m^2$, respectively, for heavy and light thermal capacity elements. The ventilation heat transfer takes an average value of 0.53 and 0.70 $W/K.m^2$, for winter and summer seasons, respectively. Internal thermal capacity is 260 $MJ/K.m^2$, corresponding to heavy thermal inertia. Effective solar collecting area for each one of the three orientations – north, south and west - is 3.31 m^2 only for windows glazing and 0.44 m^2 with shading devices. For a horizontal orientation the effective solar collecting area is 0.58 m^2, which is due to roof solar gains. For supplying heat to the apartment net floor area, a natural gas heat boiler with an efficiency of 0.89 is considered. Alternatively, a heat pump provides heating and cooling with 3.6 and 3.2, respectively, the equipment COP and EER. There are no local renewable energy sources or storage energy systems.

For the sake of simplicity DHW is not included in the case study. Heating season starts at November 29th and ends at May 6th, approximately 5.3 months. Cooling season lasts from June 1st to September 30th.

User profiles are defined as permanent heating/cooling during heating/cooling seasons. The activation of shading devices is assumed whenever façade solar irradiation exceeds 300 W/m^2.

4.2 *Results*

Running a simulation for one year, using 'Grande Lisboa' TMY (Aguiar et al., 2013), the hourly thermal loads for heating and cooling are plotted in Figure 2. Annual thermal loads are 17.1 and 10.9 kWh/m^2, respectively for space heating and cooling.

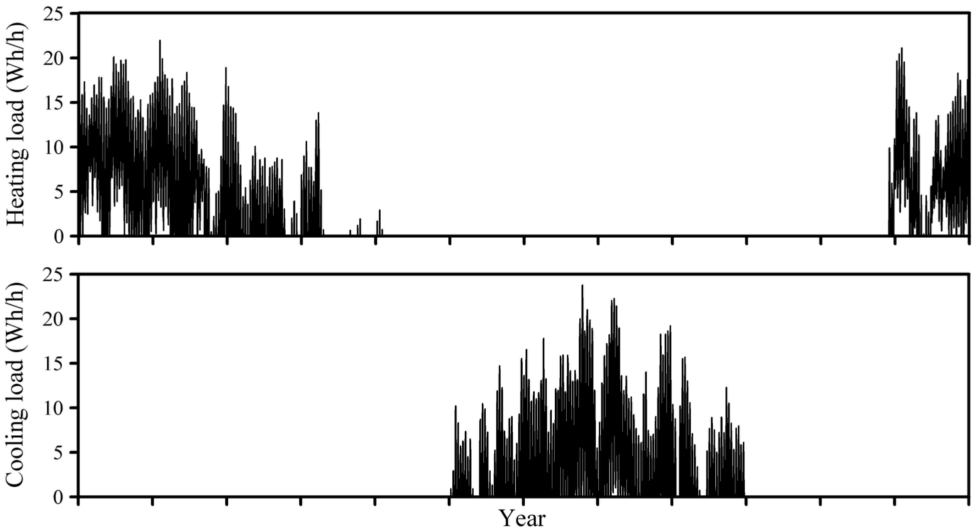

Figure 2. Thermal load for heating and cooling for the case study.

Regarding building-to-grid formulation, there are four energy carriers: 1) heat, 2) cool, 3) electricity and 4) natural gas. Systems energy performance assume the following values: $\eta_{3\to1} = 3.60$, $\eta_{3\to2} = 3.20$ and $\eta_{4\to1} = 0.89$. For each time-step and energy carrier, the energy balance is given by Equations 4 to 7.

$$\phi_1(t) = C_1(t) - L_1(t) = c_{31} + c_{41} - L_1(t) \quad (4)$$

$$\phi_2(t) = C_2(t) - L_2(t) = c_{32} - L_2(t) \quad (5)$$

$$\phi_3(t) = C_3(t) = -c_{31}/\eta_{3\to1} - c_{32}/\eta_{3\to2} \quad (6)$$

$$\phi_4(t) = C_4(t) = -c_{41}/\eta_{4\to1} \quad (7)$$

Since the building is neither connected to a thermal energy network, nor has local RES production, $\phi_1(t)$ and $\phi_2(t)$ should be null. Therefore, $L_2(t)$ is totally supplied by electricity conversion (heat pump). Otherwise, $L_1(t)$ is supplied by one or both of the systems using natural gas combustion (boiler) or electricity conversion (heat pump). The energy network management includes the decision about which heating system should be used by adopting decision criteria such as costs, avoiding peak electricity loads or, alternatively, using one of the systems as back-up whenever heating power exceeds the maximum thermal power of the main system.

For a scenario of solar collectors to produce heat, $G_1(t)$ and $S_1(t)$ would be alternatives for conventional energy systems, as Equation 8 shows. Henceforth, additional criteria should be defined, such as the priority of using heat from solar collectors or stored heat.

$$\phi_1(t) = G_1(t) + S_1(t) + C_1(t) - L_1(t) \tag{8}$$

The complexity would increase if the building with solar collectors is integrated in a thermal energy network. In this new scenario, besides heat and cool, there are no other energy carriers and $\phi_1(t)$ can assume positive values being a supplier to the heat energy network or negative being supplied from the energy network.

5 CONCLUSIONS

The current Portuguese EPC is oriented to give information about the building energy performance for an annual basis, which is not adapted for the required building-grid interaction. The main issue here discussed is how to achieve the time-dependent building thermal load by a few descriptive parameters, to be included in future versions of EPC.

The formulation for the multi-energy carrier networks is based on the Niemi et al. (2012) approach, but adapted in order to evidence for the EPC main object: the building. Its versatility allows considering different options for the management of energy networks: minimizing costs or primary energy, prioritizing RES, etc. Furthermore, the formulation is also very adapted for the on-grid NEB concept, since the primary energy integrated over a period of time, typically one year, but it can be higher (e.g. building lifetime) or lower (e.g. month), which should be null for those buildings, is a direct output of the energy networks modeling.

Finally, it is noteworthy that this study is still exploratory. Given that building-grid formulation is defined and the essential building parameters are chosen, it should be tested with multi-carrier energy networks, which constitutes future work.

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