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Assessing the performance of Positive Energy Districts: The need for innovative methods

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Abstract. Positive Energy Districts (PEDs) are potential high-impact climate change mitigation actions towards low carbon or even climate neutral cities. This implies that the energy performance and greenhouse gas emissions of PEDs need to be assessed. To this end, an accounting methodology, metrics, supporting (accounting) tools, and reporting are necessary that capture the full energy and climate impact of PEDs. The European Commission's Building Energy Specification Table (BEST) provides a methodological approach for calculating the energy balance of PEDs. The BEST is a formal requirement of the European Commission's proposal process, with respect to the Horizon 2020 funding program. An improved methodology for calculating the annual energy balance of a of PED, based on the international standard ISO52000, was developed by the Making City project in 2020. In this paper, we evaluate and compare accounting methods for assessing the energy performance of PEDs and conclude on their use and shortcomings. The hypothesis to be explored is that current accounting practices are based on accounting at a building level and alternative methodologies are needed to capture the full impacts at a district level. To this end, we apply the current approaches on the ATELIER project's PED pilot in Buiksloterham, Amsterdam, which will serve as a case study to illustrate the differences in outcomes and in the use of the results in evaluation and policy making. Consequently, we reflect and recommend on improved approaches and methodologies.

1. Introduction

In Europe, near zero energy buildings are becoming the standard for new construction, often mandated by building regulations. In existing building stock, the roll-out of energy efficiency measures and building retrofit remains a huge challenge. The next step towards positive energy buildings is being piloted and explored extensively [1]. However, there is increasing attention for the potential of optimizing the energy system in the wider context (district or neighborhood) [2]. The concept of Positive Energy Districts (PEDs) and Neighborhoods (PENs) is currently being tested across Europe.

The European Union's PED Program supports the planning, design, deployment and replication of 100 'Positive Energy Districts' across Europe by 2025 [3]. JPI Urban Europe's PED Booklet describes 29 PED and 32 towards-PED projects providing insights into factors relevant to the assessment of PEDs and highlighting a wide range of approaches towards the implementation of PEDs across Europe [3]. Almost all PED projects include mobility, and some include public infrastructure such as smart street lighting. PEDs contribute to the energy transition by moving from centralized to decentralized energy supply systems where local micro-grids manage dynamic exchanges with the regional energy system. Smart control and energy flexibility are needed for optimisation to limit the reliance on wider networks.

PEDs are also testing grounds for innovation, increasing the level of complexity in an already complex system.

PEDs are considered as a potential high-impact climate change mitigation action towards low carbon or even climate neutral cities. This implies that the performance of energy and greenhouse gas (GHG) emissions reduction will be assessed. To this end, an accounting methodology, metrics, supporting (accounting) tools, and reporting are necessary with the following requirements:

- Capture the full energy and climate impact of PEDs with all sources of energy supply and demand included if they have significant impacts on the energy and climate performance of a PED.
- Allow for the adaption of main assumptions and input parameters for local circumstances.
- Allow for comparison of the results of different PEDs (harmonization).
- Allow for the integration of new sources of supply and demand in the case of upscaling of the original PED, for instance inclusion of additional buildings.
- Be transparent and reproduceable in the reporting of data inputs, methodology and assumptions.

The hypothesis to be explored in this paper is that the current accounting practices for assessing PED performance, in particular the Building Energy Specification Table (BEST) [7], are based on accounting at building level, and do not meet the requirements. We evaluate the current approaches and methodologies and conclude on their use and shortcomings. To this end, we apply the approaches on a PED pilot as a case study to illustrate differences in outcomes and in the use of the results in evaluation. Consequently, we recommend an improved approach and methodology.

2. PED Assessment Methodologies

Building energy performance simulation, using commercially available tools, is widely used to predict the energy demand of buildings and support compliance with EU building standards. However, there is no common approach established to model energy performance at a district level. The assessment of performance at a district level is inherently complex with energy demand sources outside the traditional scope of ‘building bound’ energy, integration of multiple energy supply systems and complex interactions between on and off-site renewable energy generation and stationary energy storage systems together with the application of smart-grids and advanced energy management systems.

District and urban building energy modeling is an emerging field with the capability to cover spatial scales from building blocks to district scale to an entire city [4]. Established methodologies and frameworks are needed to support the transition to low-carbon cities together with flexible and adaptable tools to support the selection of the most convenient scenario to attain reliable predictions and effectively communicate patterns of energy consumption, availability of resources and optimal energy systems configurations to local stakeholders and decision makers [5].

In this paper, the following three accounting methods for PEDs are compared:

1. Building Energy Specification Tables (BEST) used in combination with the SCIS self-reporting guidelines [7]
2. ISO52000 standards for calculating the annual total (and non-renewable) primary energy balance and the methodology developed by the MAKING-CITY project [6] [12]
3. Open simulation tool City Energy Analyst an integrated approach using open accounting and simulation tools that are flexible in including energy need and use categories.

2.1 Building Energy Specification Table (BEST)

The European Commission's (EC) Building Energy Specification Table (BEST) provides a methodological approach for calculating the energy balance of PEDs [7]. The application of the BEST methodology, as an ex-ante assessment, is a formal requirement of the EC’s ‘call for proposal’ process, with respect to the Horizon 2020 funding program. In the case of new developments, BEST calculations are typically performed prior to undertaking detailed design and engineering calculations required for building permit approval and can therefor result in uncertainty and a lack of transparency in the BEST calculations.

The BEST calculation methodology has its origins in the Energy Performance of Buildings Directive (EPBD) [8], the main legislative instrument driving the improvement of energy performance of buildings in the EU. The BEST calculation methodology follows five steps (figure 1) resulting in the calculation of an annual positive energy balance also known as the primary renewable energy exported outside the PED boundaries. Limitation is the focus on building level rather than a district level.

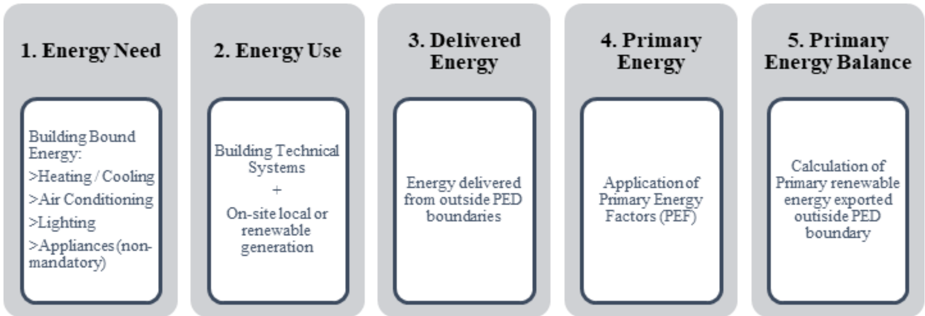

Figure 1. BEST calculation methodology

The EU Smart Cities Information System (SCIS) – Self-reporting Guide, provides more targeted guidance to support a district level assessment [10]. SCIS guidance addresses the complexities of a district level system, for example, multiple supply systems across multiple buildings, the contribution of on and off-site renewable energy generation and presence of energy storage. However, the scope of the assessment is still confined to 'building bound' energy use. Energy use from mobility and appliances is not considered.

2.2 ISO52000 Energy Performance of Buildings and MAKING-CITY PED Calculation Methodology

The revised EPBD introduced a common framework to support the calculation of building energy performance [11]. The framework seeks to harmonize calculation methodologies across EU Member States whilst supporting flexibility at a national level. The revised EPBD requires Member States to describe their calculation methodologies with a consistent set of standards [11]. These are known as the Energy Performance of Buildings (EPB) standards delivered through the ISO52000 standards.

ISO52000-1 enables an overall assessment of building energy performance to be calculated irrespective of the technologies used. The standards follow specific rules to ensure consistency, unambiguity, and transparency. ISO52000-1 has potential applicability as an accounting methodology for the calculation of PED energy performance. However, the scope of the ISO assessment omits energy use from appliances and mobility. Furthermore, public sources of energy use, such as street lighting are out of scope. Also, energy storage cannot be included. So, balancing and self-consumption of renewable energy, critical in the PED energy system, is not evaluated.

In the PED demonstration project MAKING-CITY, a calculation methodology and guidelines to calculate the positive energy balance of a PED was developed [6] [12]. The MAKING-CITY calculation methodology follows the same general approach as BEST and ISO52000-1 (figure 2) with the addition of intermediate steps to define the PED boundary, calculation of on-site generation and an energy balance. The MAKING-CITY guidelines fulfil a need for a clear, consistent, and harmonized approach to the PED energy performance assessment. However, the limitations of the ISO52000-1 approach, with its focus on building related energy sources, are not addressed.

Figure 2. MAKING-CITY methodology to calculate primary energy balance of a PED [6]

2.3 Open simulation tool City Energy Analyst

Existing approaches for calculating PED energy performance are restricted by their origin in the EPBD, with its focus on building level assessment [9]. So how can the current methodologies evolve to reflect the complexities of a district-level energy system? The first step in developing an integrated approach is to broaden the scope of the assessment boundary to include demand, supply, storage, and flexibility at a district-level, rather than restricting the scope to 'building-bound' energy sources.

Also, models need to be able to include energy system and building (use) specifics. One of the main challenges identified in simulating PED energy performance is limited access to reliable input data [13]. A source of input data that can support transparency is the Energy Performance Certificate (EPC) calculation. The EPC sets the standard for the maximum allowed energy performance for new buildings in the EU and is mandatory for building permits [14].

A further challenge in PED modeling relates to the complexity of tools and the time needed to accurately model PEDs [13]. For the energy modeling we are using City Energy Analyst (CEA), a free and open-source district and city scale modeling tool [16]. The tool performs detailed hourly simulations of the interaction between buildings, users, and their surroundings to produce energy demand forecasts, and other features. Following a detailed evaluation of various energy modeling tools, CEA can be considered as a middle point between accuracy and detail [13]. To investigate its accuracy we performed a validation study on a single building, before applying it to the PED case study at district level presented in section 3.

A university building was selected for the validation study. The measured energy performance from 2019 was selected to establish a reference case for comparison with CEA. Two simulation scenarios were created, 1) a default scenario and, 2) a user-defined scenario. The default scenario was created using basic input data on building typology and architectural shape and the default databases of CEA were used to generate building energy demand profiles. In the user-defined scenario, the input values were brought as close as possible to the reference building.

A Z-test hypothesis was used to assess the comparability of the simulation scenarios against the measured data. The results of the analysis found that electricity demand for both simulation scenarios was comparable, within 20%, with the measured building data. The simulated values for heating and domestic hot water (DHW) demand were significantly lower than the measured values. Further analysis showed differences in operation hours that need further investigation for validation. CEA simulation values for heating and DHW were however comparable within ~10% with Dutch building performance standards for a typical office-type building <5000m^2 [17].

3. PED Case Study, Amsterdam

In the following district case study, we investigate the application of standardised input data from an EPC using CEA and compare the energy performance outputs with BEST and ISO52000.

3.1 Description of PED case

ATELIER is an EU-funded Smart City project aiming to create and replicate PEDs in the Lighthouse Cities of Bilbao and Amsterdam, and six Fellow Cities across Europe [15]. The Amsterdam PED is located in the former industrial harbor neighborhood of Buiksloterham. The PED is currently in the implementation phase and will be operational in 2023. Republica is the largest development (~16,000m^2) in the Amsterdam PED accounting for approximately 60% of the total energy demand. Republica is comprised of six mixed-use buildings including residential, office, hotel, restaurant, and sports functions [15].

3.2 Application of the three methodologies

The three methodologies were applied in the following manner:

1) BEST + SCIS: The assessment of PED energy performance was undertaken during the EU proposal stage in 2018, prior to detailed design and engineering calculations. Preliminary calculations were

based on theoretical values according to Dutch building standards and typical technical component efficiencies and were presented in the BEST.

2) ISO52000 / MAKING-CITY: The information and data contained in the BEST of Republica serves as an input for the ISO52000 / MAKING-CITY PED calculation methodology to facilitate comparison against the other two approaches.

3) Open simulation tool CEA + EPC: Technical inputs from the 2019 Republica EPC, is used to build an energy simulation model using CEA. Primary inputs for CEA include information about the geometry and location of the buildings, information about the year of construction and use types and information about the weather conditions at the location. Secondary inputs include information on building architecture, internal loads, indoor comfort, supply systems, air-conditioning systems, and occupancy schedules. The default databases of CEA were customised to account for mixed-use buildings with multiple energy supply systems.

Comparison of the methods is on the level of energy demands included and the provided energy balance. In earlier research, the methods were compared on applicability to a wide range of mixed usages, district level, detail, accuracy, energy technologies and possible data inputs [13].

3.3 Results and discussion

The results in Figure 3 present the calculation of annual energy need and energy use, for the Republica buildings of the ATELIER PED, comparing the three PED calculation methodologies as described in Section 2. The primary energy balance is presented in Figure 4.

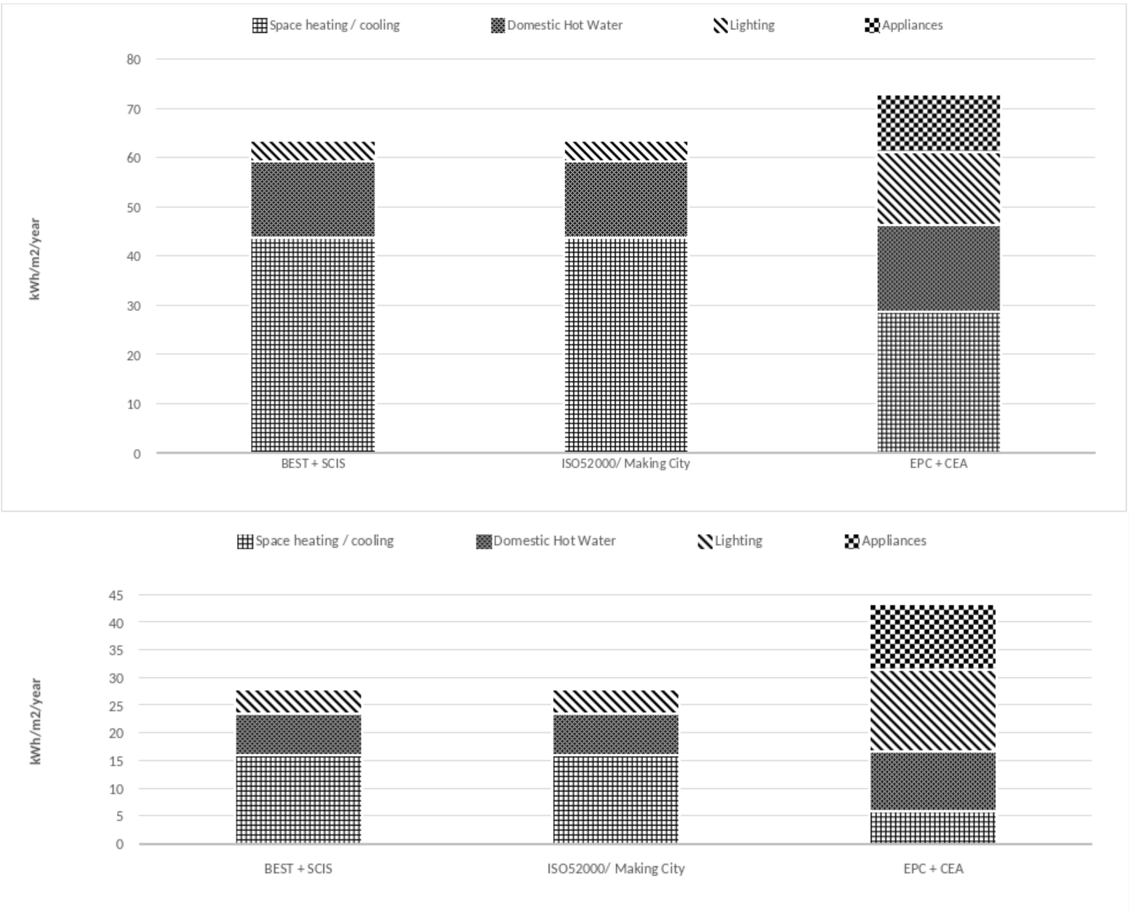

Figure 3. Comparison of PED calculation methodologies applied to the ATELIER Republica buildings in the calculation of Energy Need (top) and Energy Use (bottom).

The BEST+SCIS calculation gives an energy need of 63.7 kWh/m^2/year, energy use of 28.1 kWh/m^2/year and primary energy balance of 14.7 kWh/m^2/year. The ISO 52000/MAKING-CITY calculation gives almost the same result. The open simulation approach using the CEA model extends the system boundary to include energy from appliances, a significant contributor to total energy needs and use (~16% and ~27% respectively).

Comparison: The results highlight discrepancies in the calculation of energy needs and use for space heating/cooling and lighting. In the case of BEST and ISO52000/MAKING-CITY, the energy needs for lighting were 4.4 kWh/m^2/year which agrees with the average lighting needs for an apartment built to current building standards [17]. Whereas the EPC+CEA method produced lighting needs of 14.7 kWh/m^2/year reflecting a more accurate estimation of the lighting energy needs associated with the mixed building typologies of Republica. The EPC+CEA calculation of energy needs for heating and cooling (28.7 kWh/m^2/year) were lower than the BEST and ISO52000 comparison methods (43.9 kWh/m^2/year). The variance in the EPC+CEA model can be attributed to the input of more reliable data from the EPC as well as accounting for the building location, orientation, and building properties, such as wall-to-window ratios and influence of the building fabric.

A summary of the overall energy balance for the three calculation methods is presented in Figure 4. In all three cases it is apparent from the balance of imported and exported primary energy that the Republica buildings do not produce a surplus of primary renewable energy. This is due to the contribution of non-renewable energy imported from a district heating system and the challenge of incorporating sufficient local renewable generation within a dense mixed typology building development such as Republica. The full Atelier project with all its components does have a surplus of renewable energy according to the BEST [15].

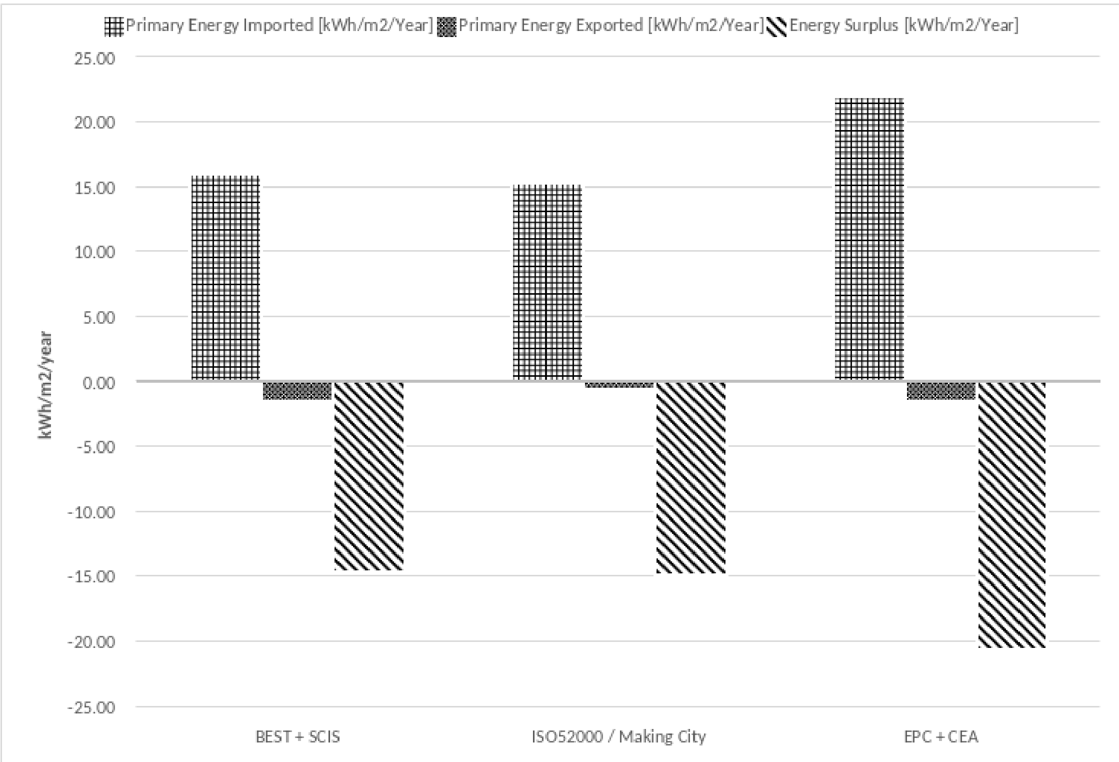

Figure 4. Comparison of PED calculation methodologies for ATELIER Republica buildings detailing primary energy imported, exported and the overall balance, so the energy surplus.

The outcome of the primary energy balance calculation using the CEA method highlights that the challenge to achieve a positive energy balance is made greater when we extend the boundary to include energy from appliances. In turn, this can also provide opportunities to identify sources of flexibility in the system from load shifting relating to user-demand sources.

4. PED Assessment – translation to planning and policy

The analysts and academics that develop and apply the PED assessment methodologies, models and tools are not the main promoters of PED upscaling and replication in the city. These are the project developers, city planners, communities, municipalities, and policy makers. These actors need to understand what energy system modelling tells them and be able to use the results for informed decision making. This is still a major gap. The ATELIER project, as well as the other SCC projects focus on PED needs to address these gaps, as the actors need to make critical decisions on the roll-out of PEDs in the coming years. Increasing transparency about data and assumptions, using open energy models, and collaborating on data and modelling with revenant stakeholders is necessary, as well as improving the links between technical modelling and practical implementation [18]. The current practice using the BEST tables does not meet these requirements.

5. Conclusion and future work

This paper has sought to address the challenges in assessing the energy performance and greenhouse gas mitigation impacts of Positive Energy Districts. These challenges can be expressed in terms of gaps:

- The gap between the need for a clear PED definition and boundaries to allow consistent reporting and benchmarking of PED performance and the required flexibility in considering the regional and urban context when addressing upscaling and replication. This implies that PED energy accounting tools should be flexible in terms of scope and boundaries and that these should be explicitly considered in drawing conclusions on the energy performance of PEDs.
- The gap between the need to optimize the energy system at a district level, while objectives and targets for districts can best be set starting with a regional or city-level strategy. This implies that PED performance assessment is best done in combination with a wider higher level energy system assessment.
- The gap between the current practice in limiting the scope to building-connected energy demand in PED energy performance, while the urban transition towards electrification requires an integrated assessment of the energy system, including other major demands, such as e-mobility charging. PED-calculation methodologies need to be further developed to incorporate citizen-led energy uses such as appliances and e-mobility and local energy sources. We showed that an open tool as CEA, that can analyse at district level can provide a step in this direction with including appliances. However e-mobility and energy storage and smart energy management systems still need to be investigated and integrated in an integral methodology.

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