Energy performance indicators for neighbourhoods applied on CONCERTO projects

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Abstract: Current practice of energy efficient neighbourhoods shows that building energy performance ratings are commonly used to characterise the energy performance of the neighbourhood itself. The main inconvenient of this practice is that this indicator usually does not consider the energy efficiency of the neighbourhood energy infrastructure and does not allow for comparisons between neighbourhoods with different characteristics (urban form etc.). In the context of the new neighbourhood developments in CONCERTO, a set of more suitable indicators was developed. The paper presents the calculation methodology for these indicators and their application to chosen CONCERTO neighbourhoods. Given the relative small number of neighbourhoods considered, it is not yet possible to propose benchmarks for energy efficient communities in different European countries. The next step in this direction would be to apply this assessment framework to a statistically relevant number of neighbourhoods in Europe.

Keywords: *Energy performance indicators, neighbourhoods, CONCERTO*

Nomenclature

RES *Renewable Energy Sources* ....
TEC *Thermal energy carrier* ....
B *Number of buildings in a neighbourhood*.. -
A_b *Gross floor area of building b* .... m²
EPR *Energy performance rating* .... kWh/m².a
F *Number of facilities in a neighbourhood*... -
E_f *Energy use of facility f* .... kWh/a
FE *Specific final energy demand* ...$kWh_{FE}/m^2.a$
PE *Specific primary energy demand* $kWh_{PE}/m^2.a$
DE_{el} *Electrical energy delivered* .... kWh_{FE}/a
DE_{tec} *Thermal energy delivered*............. kWh_{FE}/a
GE *Generated electricity from RES*........ kWh/a

1. Introduction

Whereas the use of energy performance indicators is rather diffused for buildings and overall indicators as total CO_2 emissions are frequently used at city level, few dedicated indicators are currently used at neighbourhood scale. Usually a description of the energy performance standards of the buildings located in the neighbourhoods is used to characterise the neighbourhoods' energy performance [1]. This approach reaches its limits when it comes to comparing neighbourhoods having different urban forms and consisting of different building types with different building energy performance standards. As urban development is usually interpreted in terms of neighbourhood developments, using simplified aggregated indicators expressed at neighbourhood scale would help urban planners to assess the energy performance of different master plan configurations and in particular to assess the impact of urban form on the neighbourhood's energy performance [2].

Following the needs to propose benchmarks of energy efficient neighbourhoods based on the experience of the European CONCERTO initiative [3], indicators had to be developed and calculated for all neighbourhood projects assessed. In the CONCERTO initiative, one of the requirements was to select geographical areas "within which all of the dynamic interactions and relevant energy flows between centralised and decentralised energy supplies and demands [could] be identified for measurement and assessment purposes" [4]. This could lead to a satisfactory amount of data for calculating energy performance indicators at neighbourhood scale.

After a presentation of the proposed indicators and their relevance, the indicators are calculated for all new neighbourhood development projects of the CONCERTO initiative. Based on these results and a statistically relevant amount of data available, benchmarks for energy efficient neighbourhoods can be proposed in future.

2. Methodology: proposed set of indicators

2.1. Requirements for indicators

2.1.1. Considering energy performance of buildings

At first place an energy performance indicator for a neighbourhood should refer to the energy performance level of the buildings located in the neighbourhood. There are two possibilities to implement this requirement.

On the one hand, the distribution of the energy performance ratings (EPR) of the entire building stock of the neighbourhood can be graphically represented, using a typical distribution curve as shown by Fig. 1. The EPR can refer to energy needs or energy use, expressed for heating, cooling (space heating and domestic hot water) and electricity, and can be obtained from monitoring data or energy performance calculation. A set of diagrams based on Fig. 1. provides therefore a detailed picture of the energy performance of a building stock in a neighbourhood. The effect of the urban environment on the building energy performance can be considered if this factor is taken into account in the building energy performance calculation.

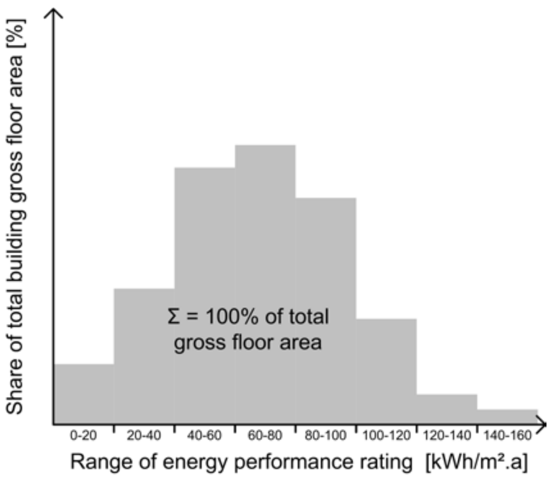


Fig. 1. Example of the distribution of energy performance ratings of the entire building stock in a neighbourhood

On the other hand, the weighted average of the EPR of each building in the neighbourhood can be calculated. This has the advantage to summarise the energy performance of many buildings and facilities (public lighting etc.) in one indicator, thus easing comparisons between projects. The EPR for a neighbourhood based on the energy use of buildings and facilities would be expressed by applying Eq. (1). Like for Fig. 1, the EPR can be calculated for heating, electricity, and possibly cooling energy use.

$$EPR = \frac{\sum_{b=1}^{B} A_b \times EPR_b + \sum_{f=1}^{F} E_f}{\sum_{b=1}^{B} A_b} \quad (1)$$

Another advantage of using an overall indicator consists in being able to integrate the energy use of facilities, i.e. applications which are not assigned to buildings but are to be included in the energy performance assessment of a neighbourhood (e.g. public lighting). Expressing them as ratio to the total gross floor area of buildings in the neighbourhoods is a way to relate the public facilities to the buildings (and people) they serve.

2.1.2. Considering the efficiency of energy supply in the neighbourhood, in particular the use of onsite RES

A second requirement for a neighbourhood energy performance indicator would be that is has to consider the efficiency of the energy supply infrastructure. In a low-density neighbourhood supplied by a district energy system, the relative thermal distribution losses are higher than in a high density neighbourhood where network piping length is reduced due to high settlement compactness. This influences also the electricity demand of pumps and therefore has to be considered in the indicator.

In addition to this, the contribution of onsite renewable energy technologies has to be considered as well because it influences the theoretical neighbourhoods' dependency from energy flows from outside the system boundaries.

The most suitable approach for including these requirements is to use an efficiency indicator of the overall energy transformation chain, considering extraction, conversion, storage and distribution to the final end-user. The primary energy factor for an energy system, defined in the sense of [5] seems to be the most appropriate factor. It can be determined also for district energy systems [6] and therefore can be used at the scale of a neighbourhood.

2.1.3. Considering the geographical extension of the neighbourhood and the settlement density

Last but not least, it is important to quantify the energy intensity in relation to the settlement density and to point out the links between land and energy use. For a given area, one of the main requirements for urban master plans consists in specifying the targeted plot ratio, defined as the "ratio of total gross floor area of a development to its site area" [7]. Comparing the EPR of different master plans proposed for a given plot ratio is a way to quantify the land-use efficiency in energy terms.

2.2. Proposed indicators

Based on these considerations, it is clear that a combined set of indicators needs to be used to express the energy performance of a neighbourhood:

- using only building EPR based on final energy use would not take into account the renewable energy sources available onsite and the efficiency of the energy supply infrastructure

- using only EPR based on primary energy use would not make building energy efficiency visible, since a low primary energy use due to high contribution of renewable energy sources would possibly hide a low building energy efficiency

It is therefore proposed to graphically represent couples of indicators in order to consider all relevant parameters and obtain an appropriate assessment of the energy performance of a neighbourhood considering the dimensions previously mentioned.

2.2.1. Combined representation of specific average final and primary energy use

Following the general principles already presented in [8], the combined representation of specific average final and primary energy use requires the calculation of specific final and primary energy use ratings at neighbourhood scale.

Applying Eq. (1) in a way to consider all energy flows delivered to the buildings (electrical and thermal energy flows) leads to Eq. (2). In this case the EPR of the neighbourhood is expressed as specific final energy demand.

$$FE = \frac{\sum_{b=1}^{B}\left(DE_{b,el} + DE_{b,tec}\right) + \sum_{f=1}^{F} E_f}{\sum_{b=1}^{B} A_b} \qquad (2)$$

The primary energy demand of a neighbourhood is then calculated by weighting the delivered energy flows by the primary energy factors of the related energy carrier, as shown by Eq. (3). All thermal energy carriers are to be considered here: renewable energy carriers, district heating, heat from small-scale combined heat and power plants and non-renewable energy carriers. The electricity yield from onsite renewable energy technologies in monovalent processes is substracted from the total after multiplication by the primary energy factor for electricity.

$$PE = \frac{\sum_{b=1}^{B}\left(DE_{b,el} \times PEF_{el} + \sum_{tec=1}^{TEC_b} DE_{b,tec} \times PEF_{tec}\right) + \left(\sum_{f=1}^{F} E_f - GE\right) \times PEF_{el}}{\sum_{b=1}^{B} GFA_b} \qquad (3)$$

In case of small-scale combined heat and power plants located in the neighbourhood, the primary energy benefits from electricity generation are assigned to the heat based on Eq. (4).

$$PEF_{Heat,CHP} = \frac{Q \times PEF_{gas} - W \times PEF_{el}}{H} \qquad (4)$$

where Q is the calorific value of natural gas multiplied by the amount of gas yearly used in the CHP, W the yearly amount of electricity generated by the CHP and H the yearly amount of heat generated by the CHP and used in the building.

The set of indicators consists in representing the energy performance of the neighbourhood placing FE (Eq. (2)) on the x-axis and PE (Eq. (3)) on the y-axis.

2.2.2. Combined representation of specific average final energy use and plot ratio

The combined representation of specific average final energy use and plot ratio does not require a particular additional effort in data collection, but a special care in calculating the plot ratio and in particular the site area. The same conventions should be used in all projects assessed, mainly regarding the non-built spaces (roads, parks…).

When this is done, the set of indicators consists in representing the energy performance of the neighbourhood placing the plot ratio on the x-axis and *FE* (Eq. (2)) on the y-axis.

2.2.3. Normalised indicators

Assuming that a statistically relevant number of communities would be available for benchmarking, final and primary energy performance ratings could be normalised referring to the benchmark, mainly depending on building type and climate conditions. In this context, a neighbourhood energy performance index can be calculated based on Eq. (5).

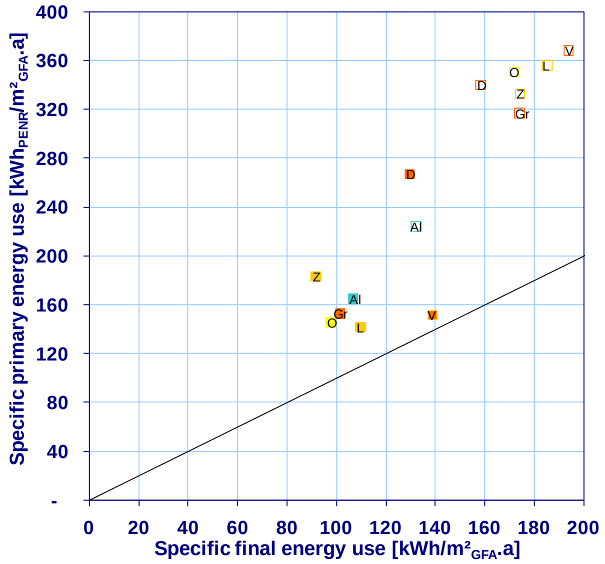
$$EPI = \frac{\sum_{b=1}^{B} \frac{Q_b}{Q_b'} \cdot A_b}{\sum_{b=1}^{B} A_b} \qquad (5)$$

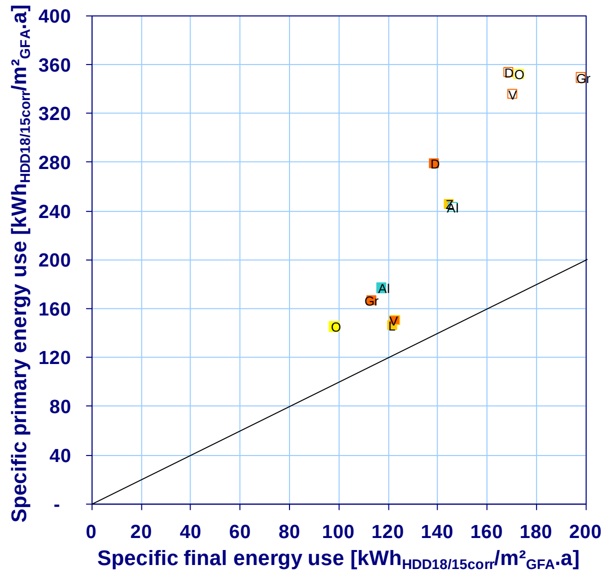
where *EPI* is the energy performance index of the neighbourhood, Q_b the specific final or primary energy demand of the building b, Q_b' the benchmark for energy performance rating, depending on building type and climate conditions and A_b the gross floor area of building b.

3. Results

The methodology presented here was applied to the CONCERTO communities which included new neighbourhood developments or neighbourhood renovation as demonstration projects. In the following, the results are presented for the new neighbourhood development projects and are only related to buildings. Other facilities (e.g. public lighting) located in the neighbourhoods are not included since they were not considered in CONCERTO.

3.1. Specific average final and primary energy use





Legend

Reference situation: without CONCERTO

Situation with CONCERTO

Each square represents the performance of a neighbourhood, calculated as a **weighted average** of all buildings of the neighbourhood.

Conventions used for calculations:

- Energy use for **heating, cooling and all electrical appliances** is considered.

- If electricity use for appliances is not available, **average figures** are taken from projects providing data.

- All energy performance ratings are expressed as ratio to the **Gross Floor Area** (gross floor area of heated spaces).

- Only the **non-renewable part** of primary energy is considered.

- Common **EU-wide primary energy factors (PEF)** are used for **gas (1,36) and electricity (3,14)**.

- PEF are **calculated** for each district heating network, if **energy balance is known**.

- **A default value (0,8)** is used as PEF for district heating networks **if energy balance is not known**.

List of neighbourhoods considered:

- **Al: Almere**
  Neighbourhood „Noorderplassen West“
  Neighbourhood „Columbuskwvartier“
- **D: Delft**
  Neighbourhood „Harnaschpolder“
- **Gr: Grenoble**
  Neighbourhood „De Bonne“
- **L: Lyon**
  Neighbourhood „Confluence Lots A, B, C“
- **O: Ostfildern**
  Neighbourhood „Scharnhauser Park“
- **V: Växjö**
  Neighbourhood „Biskopshagen“
- **Z: Zaragoza**
  Neighbourhood „Valdespartera“

Fig. 2. Specific final and primary energy use of new neighbourhood developments in CONCERTO (top: without heating degree days correction / bottom: with heating degree days correction).

Specific final and primary energy use figures for the new neighbourhood developments in CONCERTO are presented in Fig. 2. The bottom graph considers a correction of all heating energy use figures by normalizing them to the average heating degree days in Europe.

The best neighbourhood energy performance levels are reached when both the primary energy use and the final energy use reach low values, i.e. the points are located on the bottom-left part of the graph. The neighbourhoods of Scharnhauser Park (Ostfildern (D)) and Confluence (Lyon (F)) reach high levels of performance in this comparison, mainly because they combine energy efficient building standards (ambitious compared to 2005 levels) with a high share of heat generated from biomass (district heating in Scharnhauser Park and individual boilers in Confluence). The De Bonne neighbourhood in Grenoble (F) reaches comparable energy performance standards and the use of small-scale gas CHP plants allows for a high primary energy performance.

3.2. Combined representation of specific average final energy use and plot ratio

As shown by Table 1, there is a high variety of urban settlement typologies in the chosen CONCERTO neighbourhood projects, ranging from low-rise terraced house (Almere, neighbourhoods Columbuskwartier and Noorderplassen West) to rather dense urban forms with multi-storey building blocks (Lyon, neighbourhood Confluence (Lots A, B, C)).

Table 1. Settlement typologies in the chosen CONCERTO neighbourhoods

			
Almere	Zaragoza	Grenoble	Lyon

Following the plot ratio definition of [7] and considering the entire land area of the developments (i.e. including all internal roads, parks etc.), Fig. 3 shows the various plot ratios obtained for the neighbourhood developments of Table 1 and the average specific final energy use of these neighbourhoods (without considering any heating degree days correction).

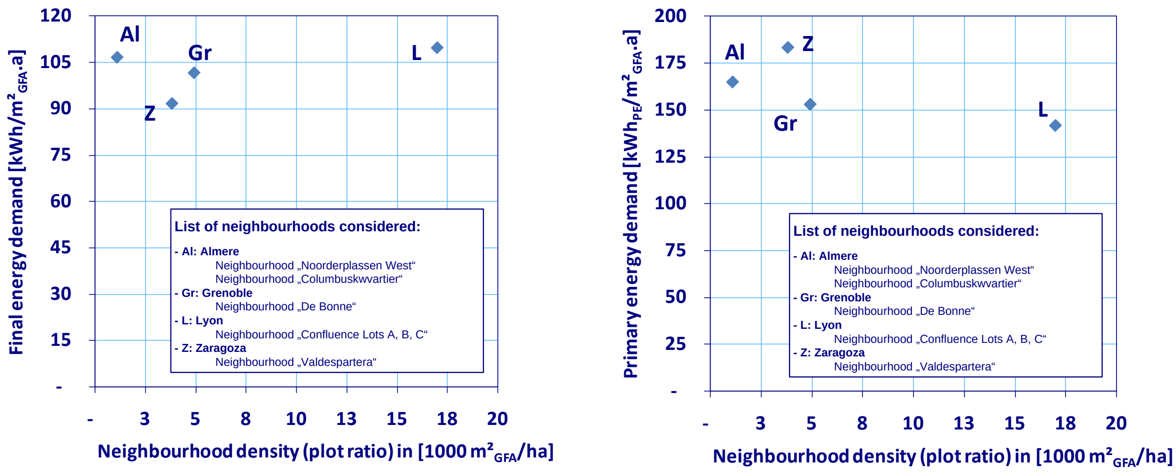


Fig. 3. Specific final energy demand and plot ratio.

Fig. 3 clearly shows that in the Confluence (Lots A, B, C) neighbourhood in Lyon, a high plot ratio is associated to ambitious energy performance standards, whereas the other neighbourhoods are not so densely built, even having similar performance levels. Considering final energy and on the basis of these examples, one could say that this level of energy performance can be reached independently of the plot ratio chosen. However, it would be interesting at this point to compare the energy performance of other neighbourhoods having the same plot ratio as Confluence, in order to compare the effect of different master plans proposed at a given plot ratio.

4. Conclusion and outlook

An attempt to establish benchmarks for energy efficient neighbourhoods was presented in this paper, mainly based on the definition of new sets of indicators and their application to some of the CONCERTO communities.

The proposed sets of indicators allow for considering the most relevant dimensions when it comes to energy use in the built environment of neighbourhoods, which are the final and primary energy use calculated on the basis of unified conventions for balancing energy flows, and the plot density as indicator of land-use intensity.

In the case of CONCERTO, the neighbourhoods combining ambitious energy performance standards in buildings with a high share of biomass in heat generation or combined heat and power reach the highest levels of neighbourhood energy performance. The high range of plot ratios in the neighbourhoods assessed show the different ways of dealing with land-use in CONCERTO.

Nevertheless, given the relatively low number of neighbourhoods assessed, the statistical relevance of the assessment results is rather limited. It will be necessary in future to apply this methodology to a high number of neighbourhoods, considering in particular a range of settlement typologies, different climate zones and sets of technologies.

In future, the energy demand for the overall public infrastructure (public lighting, street cleaning, gardening etc.) should be included in the indicators, as mentioned in Eq. (1).

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References

[1] A. Koch et al., Description of the state-of-the-art of energy efficient projects on the scale of neighbourhoods, Subtask A report of IEA ECBCS Annex 51: Energy Efficient Communities - Case Studies and Strategic Guidance for Urban Decision makers, 2011

[2] K. Steemers, Energy and the city: density, buildings and transport, Energy and Buildings 35, 2003, pp. 3-14

[3] O. Pol, D. Österreicher, Evaluation methodology to assess the theoretical energy impact and the actual energy performance for the 27 communities of the European CONCERTO initiative, proceedings of the eceee summer study 2007

[4] FP6 work programme, European Commission, 2003

[5] EN 15603:2008, Energy performance of buildings – Overall energy use and definition of energy ratings, European Committee for Standardization, January 2008

[6] EN 15316-4-5:2007, Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies, Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems, European Committee for Standardization, July 2007

[7] V. Cheng, Understanding density and high density, in Designing high-density cities for social & environmental sustainability, Edited by Edward Ng, ISBN 978-1-84407-460-0, 2010, pp. 3-19

[8] O. Pol, S. Shoshtari, A simplified method to assess the quality of integration between activities targeted to increase energy efficiency and use of renewable energy sources in urban areas: example of the CONCERTO initiative, CISBAT 2009, Lausanne