Defining and Operationalising the Concept of an Energy Positive Neighbourhood

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ABSTRACT

University campuses, residential neighbourhoods and other urban areas have different needs for energy solutions. The formulation and comparison of these solutions demands well-defined concepts and robust decision support tools. This paper proposes the following definition: "*Energy positive neighbourhoods are those in which the annual energy demand is lower than annual energy supply from local renewable energy sources. Short-term imbalances … are corrected with national energy supplies. The aim is to provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible.*" Key performance indicators are proposed along with an 'energy positivity label'. A decision support tool for the long term planning of neighbourhood energy solutions is described which is currently being used to evaluate a university campus in France and a residential neighbourhood in Finland. The research presented extends the limits of current approaches to energy analyses from individual buildings to neighbourhood level.

KEYWORDS

Energy positive neighbourhood, key performance indicators, energy positivity label, urban planning decision support tool, university campus, residential neighbourhood.

INTRODUCTION

University campuses, residential neighbourhoods and other types of urban areas have different needs for energy solutions. The formulation and comparison of the potential sustainable energy solutions for these different types of neighbourhoods demands well-defined concepts, metrics and robust decision support tools.

The research presented in this paper was carried out as part of a project called "IDEAS - Intelligent NeighbourhooD Energy Allocation and Supervision", which is funded under the European Commission's FP7 framework initiative. This project is a response to a call for research into the development of ICTs for Energy Positive Neighbourhoods (EPNs) and is part of a cluster of current smart city projects[1]. The main aim of the IDEAS project is to develop and validate the technologies and business models required for the cost effective and incremental implementation of EPNs.

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[1] The IDEAS sister project and other EU projects working in this area include the following: URB-Grade, EPIC-HUB, EEPOS, ODYSSEUS, ORIGIN, SMARTKYE, E+, COOPERATE and NRG4Cast. See the projects on a map at: http://www.ideasproject.eu/wordpress/fp7-ict-for-energy-positive-neighbourhoods-projects-map/

The approach taken in the IDEAS project and its sister projects is in line with recent research which explores the notion of net-positive energy by viewing the role of a building in adding value to its context and systems of which it is part [1]. This moves beyond the notion that individual buildings are the most effective unit to make significant energy gains [2]. In doing so it highlights the importance of extending the system's limits of energy analysis, the need for new metrics and methods to evaluate success, and advocates a shift in the framing of energy issues from a one-year timeframe to life cycle approaches [1].

The IDEAS project and its sister projects are indicative of the notion that within Europe the concept of net energy positive design beyond the building scale is coalescing around the concept of an EPN. However, despite the widespread use of the term EPN it is not clearly defined in earlier work. Its meaning is often vaguely expressed or taken as a given. If the concept of an EPN is to offer a meaningful contribution to achieving net energy positive design and development in the built environment it must be clearly defined, operationalised and easily communicated to the relevant academic, government and community stakeholders.

In this paper a definition of an EPN is proposed. To operationalise this proposed definition a set of Key Performance Indicators (KPIs) is presented. These are designed to enable the assessment of how well a neighbourhood is fulfilling the definition of EPN, i.e. the 'energy positivity level' of the neighbourhood. Furthermore, for the concept of an EPN to be accepted and provide an impetus towards net energy positive design in the built environment it is necessary to have a method of clearly communicating the 'energy positivity level' of a neighbourhood. To enable this, an 'energy positivity label' is proposed to provide a clear and easily understood approach to visualising the energy performance of a neighbourhood.

To facilitate the comparison of potential sustainable energy solutions related to different city planning options or renovation scenarios, a decision support tool (called AtLas) for the long-term planning of neighbourhood energy solutions was also developed as part of the IDEAS project [3, 4]. The development of the tool combined the key requirements of the intended users [5] and the findings from a review concerning the benefits and shortcomings of the existing tools (based on in-house knowledge at VTT, an in-depth analysis of existing tools by the French partners in the project and earlier analyses [e.g. 6, 7]). The issues addressed include the complexity of the existing tools, the detailed energy and building related knowledge required as data input, a lack of site level tools, the transparency of the processes and the lack of time and economic perspectives of the existing tools.

At the time of writing this paper, the AtLas tool is being used to evaluate potential future scenarios for the two demonstration sites of IDEAS project: a university campus in Bordeaux, France and a residential neighbourhood in Porvoo, Finland. The Finnish residential area was selected as a demonstration site as it is representative of European building stock, which consists mainly of residential buildings (75 % of the total gross floor area [8]). Typically commercial or public service buildings are constructed in the same area with residential buildings, as in the Finnish demonstration site. As is also common practice in Northern and Eastern Europe the buildings at the Finnish site are heated by CHP plant [9]. The second demonstration site at a French university was selected because educational buildings represent 17 % of the non-residential building stock in Europe [8]. This demonstration site is also similar to hospitals (7 % of the European building stock) which are often constructed as groups of buildings in close proximity, although the energy use patterns may differ remarkably [8]. The tool and the demonstration sites are described in sections 5 and 6 of this paper.

1. DEFINITION OF ENERGY POSITIVE NEIGHBOURHOODS

"*Net-positive approaches…. emphasize how buildings work collectively within networks. A key issue, therefore, is how new buildings fit into and work with the existing building stock*" [2]. As such the concept of net-positive energy demands that the role of buildings is reconceptualised to see them as adding value to the context and systems of which they are a part [1]. This in turn demands that debate is moved from defining energy positive buildings to defining energy positive building contexts and their energy infrastructures. In line with this approach the following definition of an EPN was developed at the outset of the IDEAS project [9]:

> "***Energy positive neighbourhoods*** *are those in which the annual energy demand is lower than annual energy supply from local renewable energy sources. Short-term imbalances in energy supply and demand are corrected with national energy supplies. The aim is to provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible.*
>
> *Balancing the energy supply from local renewable sources with the energy demand of a neighbourhood will involve maximising energy efficiency and minimising peak power demand while maximising local renewable energy supply and resolving energy storage issues. To avoid sub–optimisation it is key that the wider context is considered in the design and operation of energy positive neighbourhoods throughout its entire life cycle.*
>
> *Energy demand of a neighbourhood includes the energy demand of buildings and other urban infrastructures, such as waste and water management, parks, open spaces and public lighting, as well as the energy demand from transport*[2]*. Renewable energy includes solar, wind and hydro power, as well as other forms of solar energy, biofuels and heat pumps (ground, rock or water), with the supply facilities placed where it is most efficient and sustainable. The transport distance of biofuels must be limited to 100 km.*"

A report from a Thematic Working Group on ICT for energy efficiency concluded:" *Energy-positive buildings and neighbourhoods are those that generate more power than their needs. They include the management of local energy sources (mainly renewable, e.g. solar, fuel cells, micro-turbines) and the connection to the power grid in order to sell energy if there is excess or, conversely, to buy energy when their own is not sufficient*" [10]. In COOPERaTE project[3], which is running concurrent with the IDEAS project, an EPN is defined as *"a neighborhood which can maximize usage of local and renewable energy resources whilst positively contributing to the optimization and security of the wider electricity grid*". [11]

Both the above definitions are compatible with the definition of an EPN developed in the IDEAS project. However the notion that local energy demand is met by locally produced renewable energy, which is central to the IDEAS definition, is lost in the COOPERaTE definition and both the above definitions of EPNs lack the level of clarity in the more extensive IDEAS definition of an EPN. However their core ideas could be incorporated into the definition of an EPN by adding the following: "Their (EPNs') energy infrastructures are connected to and contribute to the optimisation and security of the wider heat and electricity networks." The implications of this change to the definition of an EPN are further discussed in section 7.

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[2] The energy use of waste and water management and transport are included, even though they are out of scope of the IDEAS project. This is important as the definition for EPNs developed is intended to be applicable to wider research in the field rather than being specific to the IDEAS project.

[3] http://www.cooperate-fp7.eu/

2. KPIS FOR EVALUATING THE PERFORMANCE OF EPN

2.1. KPIs for matching the neighbourhood energy supply and demand

To operationalize the concept of an EPN and enable the assessment of how well a neighbourhood is fulfilling the definition of EPN (i.e. the energy positivity level of the neighbourhood) a set of KPIs have been developed [4][9].

Foremost among these is the overall balance between energy demand and renewable energy supply in a neighbourhood measured using an **On-site Energy Ratio (OER)**, which is the ratio between annual energy supply from local renewable sources and annual energy demand.

However, in addition to considering the overall annual energy balance it is important that the balance between supply and demand for different types of energy (i.e. heating, cooling and electricity) are taken into account along with the matching of the timing of the supply and demand of these different types of energy. The latter is necessary to avoid the challenges caused by peak demand hours particularly in relation to electricity. Therefore, the following indicators calculated for each energy type separately (x = h for heating, c for cooling, e for electricity) are suggested in addition to the OER:

- **Annual Mismatch Ratio (AMRx)**, which indicates how much energy is imported into the area for each energy type on average;
- **Maximum Hourly Surplus (MHSx)**, which is the maximum yearly value of how much the hourly local renewable supply overrides the demand during one single hour (by energy type) compared to the OER;
- **Maximum Hourly Deficit (MHDx)**, which is the maximum yearly value of how much the hourly local demand overrides the local renewable supply each hour;
- **Monthly Ratio of Peak hourly demand to Lowest hourly demand (RPLx)** indicates the magnitude of the peak power demand.

2.2 Additional indicators for EPN

The ultimate goal of an EPN is not merely to reach energy positivity. As the EPN definition states, the energy positivity contributes to providing a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible [8]. As the indicators discussed above do not measure the energy efficiency or the functionality of a neighbourhood etc. additional indicators are needed to assess these qualities. These include the following:

- **Level of energy demand**: indicated either by comparing the energy demand of buildings and other infrastructures to those of similar areas or by the energy classification of the buildings (if they are the largest contributor to the demand).
- **Environmental impact**: The most obvious indicator is the CO_2 equivalent emissions, and in some cases the amount of radioactive waste could be relevant. The baseline measurement for these can also be based on comparisons with similar areas, or on emissions avoided by using the renewable supply in the area compared to external supply.
- **The distance biofuels are transported**: this is mentioned in the definition as a qualification, and should therefore be included as an indicator.

4 As with earlier research into the development of indicators for sustainable urban development the KPIs developed within the IDEAS project are designed to address the particular research questions addressed (see for example [12]).

3. ENERGY POSITIVITY LABEL

An Energy positivity label is also suggested in the IDEAS project. It is based on the previously presented indicators for annual energy demand, annual energy supply and short term imbalances. The fundamental difference between existing labels related to sustainable construction and the proposed energy positivity label is the scale of analysis. Existing labels are largely designed to indicate the sustainable construction of individual buildings and on the whole focus on new construction [2, 13]. Whereas the 'neighborhood energy positivity label' is designed to support the incremental development of sustainable neighbourhoods or districts which include pre-existing buildings as well as new developments.

To have an impact, the energy positivity label must be simple and easily understood. The label proposed is similar in style to that used for white goods[5] with plus signs to provide an intuitive indication of energy positivity (see Figure 1). The challenge, as with all labelling schemas developed to express complex phenomena, is that many details have to be overlooked to provide a simplified presentation. To achieve the required simplicity of representation the energy positivity class shown on the label is based on one overall indicator - the yearly on-site energy ratio, OER, which does not make a distinction between different types of energy nor the timing of the energy supply and demand. However, this is in line with the core of the definition of an in an EPN as being one in which *"the annual energy demand is lower than annual energy supply from local renewable energy sources"* [9].

In energy labelling it is also common practice to present figures to further detail the energy efficiency class image. For example in the case of labelling for light bulbs the energy consumption for 1000 hours is indicated in numbers, as well as the lumen value, power demand and estimated service life [14]. This method is also applied for the energy positivity label, so that the mismatch indicators (AMRx, MHSx, MHDx and RPLx) are presented to further qualify the information about the overall energy class (see Figure 1).

No definitive scale is available at this stage of the project as it is the first time these indicators are proposed. The creation of threshold values these different classes of EPNs is also part of the ongoing work in the IDEAS project (see section 7).

[5] Household electrical goods that are traditionally white in colour such as refrigerators and washing machines.

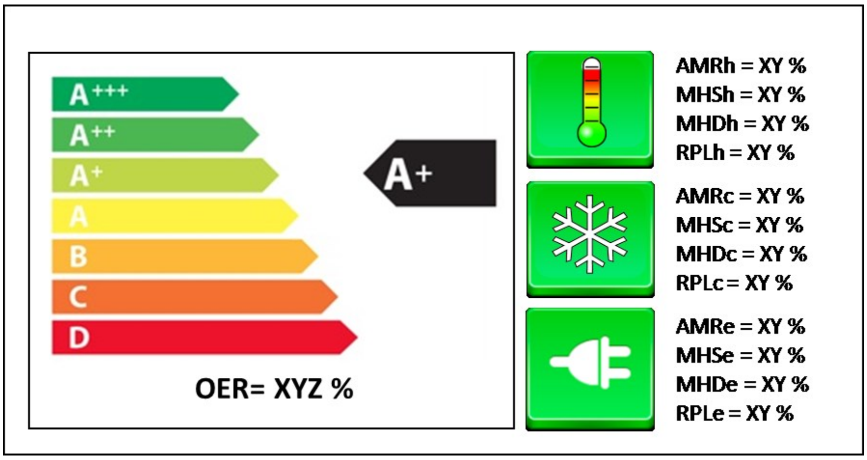

Figure 1. Draft of energy positivity label for IDEAS. For this neighbourhood, the OER must be > 100%, because it is an energy positive neighbourhood (A+).

4. CALCULATING OF THE KEY PERFORMANCE INDICATORS

The mathematical formulation for OER and AMR are presented below. Due to space constraints only the concept is presented in the case of the other mismatch indicators. Also the more traditional indicators discussed in section 2.2 are not discussed due to space constraints. However detailed descriptions of all the indicators discussed and the mathematical formulas underpinning them are provided in the reports arising from the IDEAS project [9].

4.1 On-site Energy Ratio

The concept of an on-site energy ratio (OER) is based on the idea of an on-site energy fraction (OEF) [15]. The OEF is developed for the evaluation of nearly zero-energy buildings, and it indicates the proportion of demand covered by on-site energy supply, while OER indicates the ratio between on-site supply and demand, which is more relevant in case of energy positive neighbourhoods.

According to the definition of an EPN, the annual energy demand must be lower than energy supply from local renewable energy sources for the neighbourhood to be regarded as energy positive. So we need to compare the local renewable supply to the demand over one year. This is expressed by the OER:

$$OER = \frac{\int_{t_1}^{t_2} G(t)dt}{\int_{t_1}^{t_2} L(t)dt} \tag{1}$$

Wh ere dt = 1 year, G(t) is the on-site energy generation power and L(t) is the load power of all energy all energy types (heating, cooling, electricity) combined. Simplified expression can be articulated as follows:

OER = Annual local supply in kWh/Annual demand in kWh (2)

According to the definition used in IDEAS, a neighbourhood is energy positive when it has OER > 1. For net zero energy neighbourhoods OER is 1, meaning that 100% of the energy demand is covered by local renewable energy supply. For other neighbourhoods it is < 1. In the energy positivity label, OER is presented in percentages, which is easier for the public at large to understand.

In the IDEAS project's definition of EPN, all energy types are treated as equal, so OER > 1 is the only condition that needs to be fulfilled for the neighbourhood to qualify as energy positive. However, in practice it is important to take into account different energy types separately, as well as the timing of the demand and supply. This is achieved by calculating the energy mismatch indicators separately for each energy type. The OER does not consider e.g. primary energy factors.

4.2 Annual mismatch ratio

Annual Mismatch Ratio (AMR) indicates on average how much energy is imported into the area for each energy type. Annual mismatch ratio is the average of the mismatch percentage for each hour of the year, i.e. the difference between local renewable energy supply and demand compared to the demand. It is relevant only for those hours, when the local renewable supply does not fully meet the local demand. If there is on-site energy stored for certain hour, and used in the area, then it does not need to be imported. Therefore the on-site supply can include the stored energy, if it is available. Hourly information is regarded as reasonable resolution for the mismatch.

The Annual Mismatch Ratio for each energy type, AMRx (x = h for heat, c for cool, e for electricity) is calculated by taking an average of the hourly mismatch ratios:

$$AMRx = \frac{\sum_{t=1}^{8760} HMRx\,(t)}{8760} \tag{3}$$

The hourly mismatch ratios are calculated for each hour of the year depending on the storage status and the generation vs. load situation as follows:

When the local renewable energy supply meets or exceeds the demand, the value for the hourly mismatch ratio HMRx(t), is 0. If the local storage is not full (and providing that the storage capacity fully meets the surplus generation), or if the stored energy with the local supply fully covers the need, then for these hours the storage rate S(t) gets values different from 0, (positive value when loading the storage, negative value when discharging).

If $\int_{t_1}^{t_2} G_x(t)dt < \int_{t_1}^{t_2} L_x(t)dt$ and the local storage is empty, then

$$HMRx(t) = \frac{\int_{t_1}^{t_2}[L_x(t) - G_x(t)]dt}{\int_{t_1}^{t_2} L_x(t)\,dt} \tag{4}$$

$G_x(t)$ is the on-site energy generation rate of the energy type, $L_x(t)$ is the load for that type and $S_x(t)$ is the rate of storage loading or discharge, dt = 1 hour. To be able to calculate HMRx for certain time step, the state of the storage at end of the previous time step needs to be known. A loss factor also needs to be known for the storage.

AMRx gets values between 0 and 1: it is 0 when local supply supported with the storage for a certain energy type meets the demand for a certain hour, and 1 when all energy needs to be imported to the area. The smaller AMRx, the nearer local renewable energy supply is to meeting the demand at the right time.

4.3 Other mismatch indicators

Maximum Hourly Surplus (MHSx) indicates the maximum hourly ratio of difference between on-site generation and load to load for each energy type. It is obtained by calculating the ratio for each hour of the year, for those hours when there is demand in the area, and taking the maximum of these values. The volume of MHSx compared to OER will finally indicate the ability of the neighbourhood to balance the demand and supply on short term: if the MHS is high, but OER is low, then the renewable supply of the neighbourhood is not optimally timed. On the other hand, if OER is high, then MHS will necessarily be high, since the neighbourhood is overall supplying more than its own demand. This comparison will be part of the process of developing the energy positivity label and the thresholds for it.

Maximum Hourly Deficit (MHDx), indicates the maximum ratio of the difference between load and on-site generation (including energy retrieved from local storage to cover the load) to load for each energy type. It is calculated taking the biggest value of those ratios calculated for each hour of the year, for those hours when local renewable supply is smaller than the demand.

The monthly Ratio of Peak hourly demand to Lowest hourly demand (RPLx) is the ratio between the highest and lowest value for hourly demand over the month (by energy type).
The largest value of these 12 monthly values will be the one considered for the energy positivity label. In a good energy positivity level, this will be as low as possible.

5. DECISION SUPPORT TOOL FOR URBAN PLANNING

A decision support tool called AtLas, designed to inform the long-term planning of neighbourhood energy solutions towards energy positivity was developed as part of the IDEAS project [4].

The simplicity of use, ability to function with limited input data, and perform calculations over different time periods are key to meeting the envisaged users' requirements for the AtLas tool, as expressed by them during the requirements capture [5]. The specifications of the tool were also informed by a review of benefits and shortcomings of existing tools used by city planners and facilities managers to support their decision making and by showing initial pilot versions of the Atlas tool to intended users [3].

The AtLas tool simulates the long-term impacts of the energy consumption and production of buildings and districts. It enables the assessment of multiple possible options for interventions in urban planning and energy supply and distribution. The calculations underpinning the tool combine, in a computationally efficient way, detailed hourly data of the energy demand and supply with long-term planning that usually spans several decades. If no hourly energy data is available the tool also incorporates simplified methods of calculation. For example simplified energy demand specifications are available based on the energy class of buildings[6].

The AtLas tool is implemented using Excel. It contains: a 'Buildings' spreadsheet for defining a neighbourhood and its buildings; a 'People' spreadsheet for detailing the population of the area; a 'Planning' spreadsheet for detailing the simulated interventions and their comparison; an 'Indicators' spreadsheet to display the energy positivity level; and a 'Results' spreadsheet which displays the results calculated by the tool as tables. The AtLas ribbon with the navigation icons

[6] A new method for estimating the heat, hot water and electricity consumption from the selected building energy class was developed for the use of the AtLas tool, to improve the simplicity of use.

contains links to basic modules (the spreadsheets), simulation control and the language options (see Figure 2). The tool is available in English, French and Finnish. Detailed user guides are available in Finnish and French, the languages of the intended users at the demo sites [4].

Due to the large number of possible input variables, the Excel spreadsheets are formatted to guide the user to understand the meaning of the input data and its possible impacts on the simulation results. The data input, such as the name or size of the area, required for the spreadsheets is either inserted by the user or it is provided by selecting from drop down menus. These are populated by the information stored in the Advanced sheet (e.g. the building types or the energy production options) (see Figure 2). The data input for the Advanced sheet requires expert knowledge but normally needs to be input to the tool once for each country and updated only when shares of energy types, CO_2 emissions, costs or building codes change. If available, site specific data can also be input into the Advanced spreadsheet (e.g. energy sources).

The Planning sheet is a key element of the user interface. On the Planning sheet, the user chooses the actions (= the combination of changes to the district and the buildings) that are to be taken on the area, from the drop-down menus, and inserts the new values that are realised after the action is completed. Also the values for the start date of the plan and its duration, as well as the action start and duration and related costs are inserted by the user. The original values are retrieved from the Building sheet.

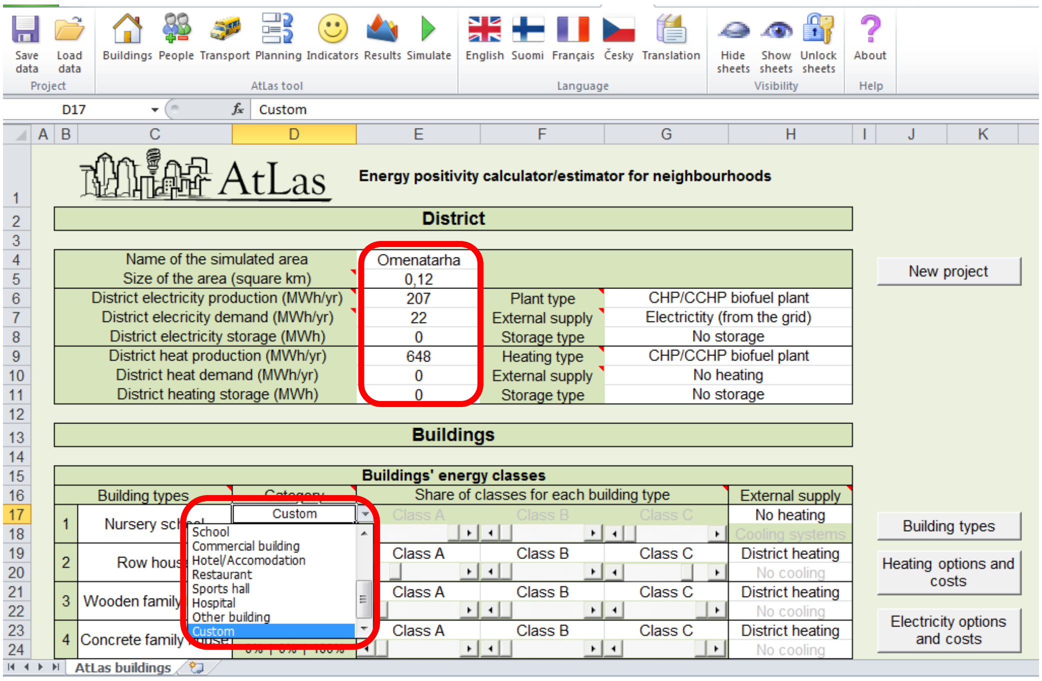

Figure 2. On the Buildings spreadsheet the user inserts information about the area in the white cells by hand or chooses the options from drop-down menus.

The tool is designed to be very flexible. It facilitates the comparison of scenarios related to one building or a group of buildings in an area, with building integrated or centrally located energy production and storages in the area. Different scenarios can be simulated such as change of district consumption and production (e.g. new wind farm), change of buildings floor area (e.g. new construction or demolition), change of buildings energy efficiency level (e.g. renovation) or change of buildings energy production (e.g. new solar panels on the roof), to mention but a few.

AtLas tool presents the outputs in formats that will help the user to present the relevant information to other decision makers and stakeholders. The outputs can be presented as energy positivity indicators and as particular impacts in the form of purchased energy and costs including investments required and CO_2 emissions, normalized to different bases (e.g. floor area, population or area of the district). The values can also be presented separately by each energy type or in total, and as time-related or cumulative values. This makes the software very versatile so it can support the decisions of facility managers, city planners or the planning of energy distribution networks.

6. IDEAS DEMONSTRATION SITES IN FINLAND AND FRANCE

The Finnish demonstration site of IDEAS, in Omenatarha area, is part of the Skaftkärr area in Porvoo [8]. The Skaftkärr development project aims to create an energy efficient, safe, personal and cosy area that offers different living alternatives. Omenatarha is one of the first areas to be built in Skaftkärr, and it comprises 12 hectares. It will have 500 inhabitants and a nursery school for 120 children from surrounding areas. Porvoo Energy, a partner in IDEAS project, will be the energy provider in the area, providing both electricity and district heating produced by a local combined heat and power (CHP) plant (running mainly on bio-mass). Porvoo Energy also has plans for a solar collector field to provide heat to the Skaftkärr area. The principal stakeholders in the Finnish demonstration site are the residents, the nursery school children and staff, the energy provider, the city officials and the development coordinator (Posintra Oy) and the construction companies working in the area.

The French demonstration site of IDEAS is part of a university campus in Bordeaux, which houses the University Institute of Technology [9]. The institute provides teaching and office facilities for some 2000 students and 500 staff members in 22 buildings. The total area of the site is 80 000 m^2 with around 40 000 m^2 of buildings. The buildings within the demonstration site are predominantly used for teaching and office administration. Most of the heating for the buildings in the demonstration site is provided by a local gas boiler connected to a heat loop, which is locally managed by the site energy management/maintenance team. A few photovoltaic (PV) panels are installed for teaching purposes but they are not connected to the grid. The local stakeholders in the demonstration site include the Chief Executive Director (general manager of the site), teaching staff, the technical services team, and students.

Neither of the demonstration areas currently reaches energy positivity (OER > 1). The Finnish site is quite near to energy positivity, as already 98% of the energy demand is produced from renewable sources in the area. It still only reaches level B on the suggested scale for energy positivity. To reach energy neutrality (A level), it would be necessary to produce 8 MWh of more renewable energy annually. This means e.g. 53 m^2 solar panels or 25 m^2 solar collectors. The French site currently represents C-level on the energy positivity scale. Currently there is no local renewable energy production on the area, except the few PV panels. To reach energy neutrality (A level), and cover the current energy demand, it would be necessary to produce 4700 MWh of more renewable energy annually. This means e.g. a bio based CHP (producing all the heat and 70 % of electricity) and 3 000 m^2 of solar panels. Local energy storages could be introduced to both sites to better match the timing of production and demand.

7. FUTURE WORK

Threshold values for the EPN indicators constituting the energy positivity label are yet to be addressed. They might be different for different countries, e.g. for a southern country, if the local demand is predominantly as a result of electricity driven cooling and domestic hot water, it might be easiest to meet the low AMR values by increasing local solar energy supply. For the energy positivity label, it is suggested to use a scale with letters from A to D, and indicate energy positivity with a plus sign (A+, A++ or A+++ for very high levels of energy positivity). Currently it is proposed that an energy positive neighbourhood would receive label A+, and a zero energy neighbourhood would reach class A. A neighbourhood with standard houses and only modest renewable production would represent class D.

The target values for AMR and MHS are also yet to be addressed. This is in part because whether a surplus of energy production is a good or bad depends on the timing of the production of the surplus energy and/or the ability to store the surplus energy produced locally. For example if national electricity demand is high and the energy production at an EPN is more energy than is required by local energy demand then this is good because it can be sold to the national network. However, if surplus electricity production occurs at a time of the day when there is a low national energy demand and the energy cannot be stored locally until there is a national or local demand for it, then you have a problem, because this could contribute to overload problems on the national distribution and transmission networks. National energy demand also affects the economics of the EPN [16]. "*When national electricity demand is low, supply comes from relatively inexpensive base load generation. When demand is high and base load generation is exhausted, supply comes from relatively expensive peaking generators. This creates rapidly fluctuating energy costs throughout the day in all EU energy markets"* [16].

Based on the definition of the IDEAS project developed at the outset of the project, during the development of the indicators for EPNs presented in this paper the authors have considered the possibilities for EPNs in the near future. These will probably be nearly zero-energy neighbourhoods with relatively modest surplus energy production. Further into the future as the cost of energy storage reduces it should become financially viable to produce significantly more energy within an EPN than required to meet local energy demand, as the surplus energy could be stored and sold when national energy demand is high and the price for the energy is at its peak. This further future scenario will entail a re-evaluation of the indicators presented in this paper and fits more closely with the idea discussed in chapter 1 for further development of the definition, namely that: **Energy positive neighbourhoods** are those in which the annual energy demand is lower than annual energy supply from local renewable energy sources. Their energy infrastructures are connected to and contribute to the optimisation and security of the wider heat and electricity networks. The aim is to provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible.

8. CONCLUSIONS

Different actors, such as the city officials, area planners, energy producers, energy distributors and facilities managers, need information about the costs and environmental effects of different energy solutions in the short, medium and longer term. The Atlas tool presented in this paper offers this functionality, enabling assessments of different energy solutions based on limited data or a deeper analysis of specific cases, when detailed information is available.

"*In contrast to the considerable effort that has been directed at the formulation of a definition of 'net-zero', the notion of net-positive has yet to receive the same level of broad engagement, exploration and scrutiny by the research community*" [2]. It must also be noted that the limited efforts focusing on net-positive energy approaches are focused at the building level, which does not account for the notion central to net-positive energy that buildings are part of an urban system and need to be analysed as such [2]. This paper presents the first attempt to explicitly define the concept of an EPN, develop metrics and tools to measure the progress of an area towards becoming an EPN and an energy positivity label to help visualise that progress. In doing so it extends the systems limits of current approaches to energy analysis for urban sustainability.

9. ACKNOWLEDGMENTS

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NOMENCLATURE

EPN	Energy Positive Neighbourhood
KPI	Key Performance Indicator
OER	On-site Energy Ratio
AMR	Annual Mismatch Ratio
MHS	Maximum Hourly Surplus (MHSx)
MHD	Maximum Hourly Deficit
RPL	Monthly Ratio of Peak hourly demand to Lowest hourly demand
OEF	On-site Energy Fraction
HMR	Hourly Mismatch Ratio

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