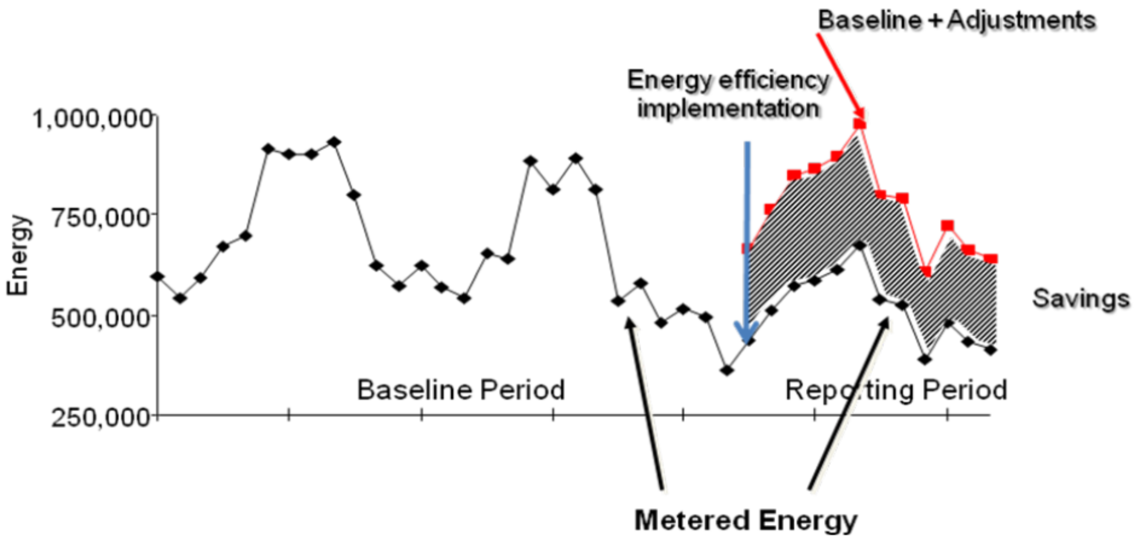
EEPOS - Energy management and decision support systems for energy positive neighbourhoods

Co-funded by the European Commission within the 7th Framework Programme.
Grant Agreement no: 600050.
2012-10-01…2015-09-30 (36 months).

Validation methodology



Authors:	Florian Judex, Blaise Kelly	AIT
	Kalevi Piira, Pekka Tuomaala	VTT
	Dan Hildebrandt	ENO
	Emil Lezak	Solintel
	Diego Gastañares	ARAIA
	Tapio Hirvonen	YIT

Table of contents

1. PUBLISHABLE EXECUTIVE SUMMARY

To be able to validate the EEPOS systems, the improvements in energy efficiency and overall energy consumption of the demonstration sites has to be assessed. All indicators for efficiency and consumption are also of interest for users of the EEPOS system. The definitions and calculations to be used for monitoring and evaluation will become part of the EEPOS system itself, and will not just be used at the end of the project for evaluation.

The central methodology is the IPMVP protocol, with its “plan, do, check, act” approach, which gives guidelines on how to proceed, but as it is a generalized approach for any industrial application, there are no rules on which values are to be used to check improvement, and how these values should be calculated to establish improvements to the baseline – since this is not defined.

For most of the energy systems relevant for production and consumption related to buildings, common standards, current practices or results from previous projects are available. The EEPOS project will be monitored and validated using the following norms and methodologies:

- For monitoring building energy systems, the scheme was created with the IEA Task 38. It covers the majority of building HVAC systems but was originally aimed solely at solar heating and cooling installations, since these generally have the more complex configurations, with several heating and cooling sources and sinks.
- The evaluation of the individual components, along with the overall system, is covered by the EN15316 ”Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies”, a European standard that covers all heating systems. Furthermore, its approaches can be easily extended to cooling systems, for which there is no comparable norms or standards at the moment. An overview of the relevant parts can be found on page at page 48 of the EN 15232.
- To calculate the reaction on demand response, the methodology developed within the European Project ”EcoGridEU” is used. This was a large scale demonstration project investigating the feasibility of market driven demand response.
- For the building itself, the methodology and calculations from the “3e-houses” project will be used.

These four sources enable the complete evaluation of the buildings and systems envisioned to be controlled by the EEPOS system. While the ability to perform demand response operation is a direct indicator how well RES can be integrated into the neighbourhood, the performance indicators will confirm that the integration was enabled without major drawbacks for efficiency or comfort.

Finally, the use of previously defined standards enables an unbiased evaluation of the project, and ensures fair comparisons to be made with similar projects using the same norms and standards.

2. INTRODUCTION

2.1 Purpose and target group

This deliverable sums up the methodologies and calculation methods identified as relevant for the evaluation of the EEPOS project. The aim was to screen existing material to identify consistent solutions that are, ideally, already part of the European standardization system. Implementing new methodologies was specifically avoided. Using these methodologies, the impact of the EEPOS software on the performance of systems and the consumption behaviour can be quantified, based on the measurements in the real demonstrator and the simulation results of the virtual demonstrators.

Aside from the EEPOS consortium itself, the target group are the consortia of other projects with similar tasks involving evaluation improvements in buildings and/or neighbourhoods. As the validation of the EEPOS system covers nearly all energy related processed in neighbourhoods, using the guidelines from this document will cover most of their needs for evaluation methodologies, and ensure comparability of the results.

2.2 Relations to other activities

The methodologies and calculations described or referenced in this document will be implemented within the EEPOS system as a part of T3.3 (Performance monitoring and operations planning tools), and will therefore also influence T3.2 (Energy Brokering Tool) and T3.4 (End-user collaboration tool). These tasks will have to rely on the results of the performance monitoring in order to progress. Furthermore, the overall success of the EEPOS project will in part determined by the operating figures provided by the methods described in here.

3. EVALUATION METHODS AND CRITERIA

3.1 State of the art and relation to other projects

3.1.1 MCHP

The goal of sustainability in the building sector requires a tremendous effort to reduce energy demand, boost energy efficiency and increase the share of renewable energy sources. On the demand side, the improvement of the building envelope’s insulation, air tightness and fenestration are accepted measures. On the supply side, micro-cogeneration, also termed Micro Combined Heat and Power (MCHP) or residential cogeneration, is an emerging technology associated with the potential to reduce primary energy consumption and associated greenhouse gas emissions through the concurrent production of electrical and thermal energy from a single fuel source. The distributed generation nature of the technology also has the potential to reduce losses due to electrical transmission and distribution inefficiencies and to alleviate utility peak demand problems. However, the technology competes with other supply options such as innovative central electricity generation and heat pump technologies and – for renewable energy – solar thermal and photovoltaic systems along with biomass heating systems.

A number of studies deal with building-integrated cogeneration systems and their environmental and economic performance in comparison with other supply options. There are also a wide range of techniques for modeling and assessing the performance of MCHP technologies (Onovwiona et al), based on a variety of basic modeling aims; from economic assessments (Alanne et al) through to studies of the impact on national electricity distribution networks (Hawkes and Leach 2008). Modeling methods range from simple calculations using aggregate energy demand (several computer design tools are commercially available), through to multiple-objective optimisation approaches (Palazzi et al). Even when focusing on energy and emissions evaluations of individual building-integrated MCHP systems, there are a wide range of levels in modeling detail and temporal resolution. The analysis of thermal energy utilization in buildings is complicated by strong coupling between the cogeneration unit and other Heating, Ventilation and Air Conditioning (HVAC) components, and the building’s thermal and electrical demands. These system integration issues lead to the need for whole building simulation programs to facilitate the analysis of residential cogeneration.

A number of studies have investigated cogeneration systems integrated in individual buildings using whole-building and system simulation tools which analyse their environmental performance and evaluate this using other supply options. The building types and grid electricity generation mix are typical of national, regional or municipal character, and the results of performance assessment studies may vary accordingly. In the following section, some typical studies are referenced, with the primary focus on Central European countries. In the Belgian context, (Voorspools and D’haeseleer) studied MCHP and mini CHP as well as the dynamic interaction between the cogeneration and central power systems. Different types of MCHP were also studied by (DePaepe et al.). For Germany, Bruckner et al. already demonstrated that cogeneration offers considerable scope for energy savings on a municipal level. (Lindenberger et al.) explains how a gas Internal Combustion Engine (ICE) micro-cogeneration units can be used to achieve cost and 20% (non-renewable primary) energy savings when compared with a gas-fired condensing boiler and German National Grid electricity mix. The role and potential of fuel cell MCHP was summarised in great detail in other studies (Krewitt et al.). The situation in Italy was studied e.g. by (Dentice d’Accadia et al.) and (Possidente et al.), with (Sibilio et al.) extending their studies to also include residential trigeneration applications. For SE and fuel cell MCHP systems in UK SFH, (Peacock and Newborough, 2006) predicted 9% and 16% CO_2 emissions reductions compared to using a condensing boiler and grid electricity, and even greater savings for higher power output systems of high efficiency, with greater portions of generated electricity being exported (Peacock and Newborough, 2008). In several papers, (Hawkes et al. 2005) examined the techno-economic aspects of MCHP and the related least-cost optimization strategies, (Hawkes and Leach, 2007), and also investigated the influence of temporal precision on the performance results (Hawkes and Leach, 2005). A comparative CO_2 savings assessment of FC, SE and ICE MCHP and heat pumps for the UK domestic sector was made by (Cockroft and Kelly).

Analyses of the combination of residential cogeneration systems with solar thermal systems confirmed that an overall increase in the contribution of renewable energy to meet energy demands was possible, but also identified conflicts between the heat produced in the residential cogeneration and with that from the solar thermal system. Heat buffer storages may significantly enhance energy efficiency in MCHP systems.

Demand profiles for Domestic Hot Water (DHW) and electricity for appliances and lighting are based on measurements, aggregated on the basis of probabilistic distributions for occupancy and for the individual components, or generated using stochastic methods. The different control strategies and modes were shown to have significant effects on energy and environmental system performance. In many cases, the modes following heat generation exhibited the best efficiency for energy, and electricity-following control modes for cost, but in many cases combined control modes were shown to be the most effective (Hawkes et al 2007). The efficiencies of an MCHP system under real operating conditions can be considerably lower than those of an MCHP device operating alone when running at full load. Start-up and shut-down cycles and thermal losses from heat storage were associated to such performance reductions for an SE device in a Canadian study (Ribberink et al). MCHP modeling and simulations also form the basis for performance optimisations. To define sets of optimal configurations, sensitivity analysis (Wallmark and Alfors) or multiple-objective (energy-economic or energy-environmental) optimization techniques were applied. These also combined process flow models with process integration methods and multiple-objective optimisation. A more comprehensive overview of available studies and projects that cover the performance assessment of residential cogeneration systems in terms of environmental criteria, mainly primary energy demand and greenhouse gas emissions, was given (Dorer).

3.1.2 District heating and cooling

District heating and cooling – referred to as district energy (DE) - involves multi-building heating and cooling, in which heating and/or cooling is distributed by circulating either hot water or low-pressure steam through underground piping. Compared to electrical power, much higher transmission losses are involved and confirms previous expectations on the limited feasibility of DE systems over longer distances. It is therefore the only system where considerable work was already undertaken for neighborhood energy system, and is hereby discussed separately.

District networks can incorporate an underground system of piping from one or more central sources to industrial, commercial and residential users. The heat delivered to buildings can also be used for air conditioning by adding heat pumps or absorption chillers. DE can provide efficiency, environmental and economic benefits to communities and energy consumers. DE systems usually exhibit lower environmental impacts compared to conventional systems. DE applications in industrial processes lead to increased resource energy efficiency.

The energy source for district heating systems can be fossil fuel, other energy sources, or mixed systems combining two or more energy sources, like natural gas, wood waste, municipal solid waste and industrial waste heat. Many are economically feasible. Heat supplies for DE may also include combined heat and power (CHP), Waste-to-Energy (WtE), biomass and geothermal energy plants (it should be noted that a WtE plant can be a CHP plant as well). This flexibility is one advantage of DE systems. The thermal energy needed by the district grid is often supplied by one dedicated plant, while industrial waste energy is an attractive alternative or supplement because it permits depreciation and maintenance costs for a power plant to be divided. Fossil fuels used to be the primary energy source for the heat, but hybrid systems combining renewable or alternative energy technologies like solar collectors, heat pumps, poly-generation, seasonal heat storage and biomass systems are currently becoming established as the main energy source.

District energy systems are categorised based on different aspects. One grouping is classifies the heat transport fluid, i.e. low-pressure steam, hot water or hot air. Another classification is based on the thermal energy transported: heating, cooling, or cooling and heating. A further categorisation of district heating systems can be based on the heat resource: using a separate source of energy for heat or using recycled energy/heat. The most practical example of the latter type of source is the CHP plant. In this situation cogenerated heat produced from generating electricity can then be utilised for heating nearby buildings.

District heating can also be classified based on energy source. For example energy sources for district heating systems, can include fossil fuels, nuclear power, cogenerated heat, waste heat, and renewable thermal energy including solar thermal energy, heat from ground source heat pumps and biomass. Note that natural gas is a common energy source in present thermal networks because of its availability, price and relatively low emissions compared to other fossil fuels. Renewable technologies are expected to be increasingly used in future designs. Also note that electricity is often required by the thermal networks to drive chillers, to run ancillary equipment and sometimes for heat conversion. This electricity can be provided via the electrical grid or by renewable energy (e.g., solar photovoltaic or wind energy). In the following subsections further explanations are provided about energy resources.

For CHP systems common operational modes follow the electric load and subsequent thermal load. Depending on system design/objectives during both modes some operation points may produce more electricity than required. Since CHP are distributed generation systems, a rational approach it is to assume that any surplus electricity will be consumed by surrounding users. Therefore, energy losses due to transmission and distribution can be neglected and the surplus electricity will save primary energy at the source as if it were used by the building itself. If the CHP system operates in the mode where it follows the electric load, when the thermal energy recovered from the PGU (Power Generation Unit) is larger than the demand, the surplus recovered thermal energy needs to be dissipated using an emergency radiator. Surplus recovered thermal energy is considered in the analysis through the limits imposed by the demand, which means that only the useful thermal energy is considered as recovered energy. For CHP systems, because of the low efficiency of absorption chillers, better energy performance may be achieved if only a fraction of the cooling load is handled by the absorption chiller. The fraction to be covered by the absorption chiller would be based on the recovered thermal energy, allowing an electrical chiller to be used for the difference. However, although this may be a more rational approach, since the present analyses intend to study how the use of the boiler affects the PES (Primary Energy Saving) when the recovered heat is not enough to handle the heating or cooling load, the analysis assumes that the cooling load is handled by the absorption chiller.

This analysis is based on basic operation logic for CHP systems and is described as follows. The PGU provides electricity based on the building demand. If the building electric demand is higher than the PGU capacity, electricity is consumed from the grid. The Heat Recovery System (HRS) recovers heat from the prime mover to be used in the Heating Coil (HC) for space cooling or by the absorption chiller (CH) for space cooling. The analysis does not include the option of having space heating and cooling at the same time. If the thermal energy demand from the HC or CH is greater than the available recovered energy, the boiler (B) provides supplementary energy. In order to assess primary energy savings from the use of CHP technology, the analysis compares Primary Energy Consumption (PEC) with respect to a reference building. This reference building has a HVAC system comprised of a separate Heating System (HS) and a Vapor Compression System (VC).

3.1.3 Energy consumption

Energy savings can't be measured directly. It is always necessary to compare different situations: The situation before the implementation of the ECM (the *baseline period*), and the one after the implementation (the *reporting period*). More practical is a calculation of the energy savings with a standardised calculation methodology. This chapter bases mainly on the findings in the 3e-Houses project (Porto, et al., 2011), the SmartCoDe project (Cochrane, et al., 2012) and the eSESH project (Lohmann, Heilmann, Hacke, & Robinson, 2011) give an overview about the different types of methodology to calculate these savings.

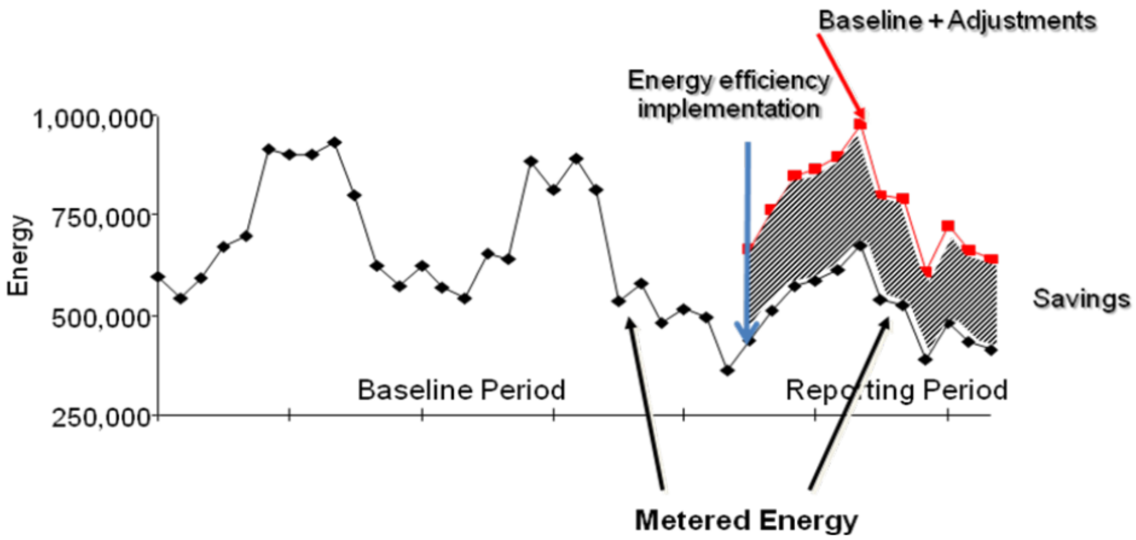


Figure 1: Definitions of Baseline, Reporting and Saving periods

In general, the energy-saving is the difference of the consumption according to the energy efficiency measures (EEM) and the consumption prior to the EEM-implantation (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Power consumption, however, is influenced by different variables like weather, usage or occupancy, which makes a direct comparison difficult since it might not be obvious if an observed difference is caused by EEM or other effects. If the differences are small in absolute values, as it is can be the case in the EEPOS demonstrators, it is necessary to eliminate these influences as much as possible. Ideally, the two periods which are to be compared should have the same conditions (e.g. be in the same time of the year with the same weather conditions). Where this cannot be achieved, suitable adjustments have to be made. The calculation of baseline and reporting period energy can originate from short-term or continuous measurements of key operating parameter(s) (sub-metering ECM affected system), consumption measurements of the whole building and calibrated simulations.

The method which has to be chosen to describe the baseline and to make the necessary adjustments should be easy to implement, deliver accurate, useful and transparent results and – quite important – has to be adaptable for this type of project.

3.2 Energy related systems in neighbourhoods

The project foresees 3 major energy types on the neighbourhood level, all of which have to be included in the EEPOS tool, namely

- thermal
- electric,

with the processes used in each one varying to different degrees. On the neighbourhood level the following energy suppliers are deemed feasible and will be supported. Although not all of them can be considered as renewables, for the sake of enabling the EEPOS platform to support a broad range of installations they also are to be included.

- Heat: Heat pumps, Geothermal Energy, CHP, Solar Thermal, Gas Boilers.
- Cooling: thermally driven cooling (adsorption, absorption, desiccant) installations, compression chillers.
- Electricity: CHP, PV, Wind Power.

Other sources, such as geothermal electricity consumption were thought not to be be of interest on a neighbourhood level, and therefore not considered, although the proposed measurement and evaluation system can be easily extended should this be required. Consumption from a higher level grid with respect to all three energy types has to be considered, as the neighbourhood will most likely not be self-contained.

The energy related systems can be split into two major groups

- suppliers and
- consumers

however these categories' are not strict. For the evaluation of the EEPOS systems, the separation will be made with respect to the major function of the system. Suppliers are systems whose main purpose is the generation of energy for the use of other units. Furthermore, they are considered to be well monitored, leading to a transparent distribution of the created energy to the consumers using a distribution network. In case this transparency is not given, these three may merge into a single unit, e.g. a larger building where the supply side energy production throughout monitored, while the consumption side is not monitored at all. For example thermal energy leaving e.g. the CHP is distributed through the building, but only split based on floor area, but not on further metering for billing purposes.

As neighbourhoods may vary considerably, the EEPOS system can only be rated by improvement of the energy efficiency compared to the performance before the implementation, or to a state where it does not influence the neighbourhood.

3.3 Energy generation

The idea of a NEMS is currently only in development for several projects and the overall energy efficiency of a neighbourhood is yet to be defined. But as the production units have to satisfy the demand of the consumers, even if both are controlled by the EEPOS system, the aim of the production units has to be to produce the energy required as efficiently as possible. This efficiency can be seen either in terms of greenhouse gasses (GHG) or other indicators with respect to environmental impact, or to financial costs or gains.

3.3.1 Monitoring of HVAC systems and electrical producers

The energy related systems can be quite well divided into two types: The HVAC related systems, which also include district heating plants, and the purely electric producers which will on the neighbourhood level can be reduced to wind power and PV. Heating and cooling systems.

3.3.1.1 Monitoring of electrical power producers

In the case of pure electrical power producers (PV and wind power), the produced power will be monitored.

3.3.1.2 Monitoring of HVAC systems

For HVAC systems, the monitoring procedure established in the IEA Task 38 will be used. As can be seen in Figure 2, the system presented here can be used for all types of HVAC systems, as the monitoring procedure is aimed at being universally usable. This is because, although it was first devised for solar cooling installations, this type of installation almost always uses conventional back up sources, which in case of conventional installation are present, while the part relating to solar heating are not. For example, in a simple system, consisting of a gas boiler for DHW and space heating, only E3, E4, E5 are relevant.

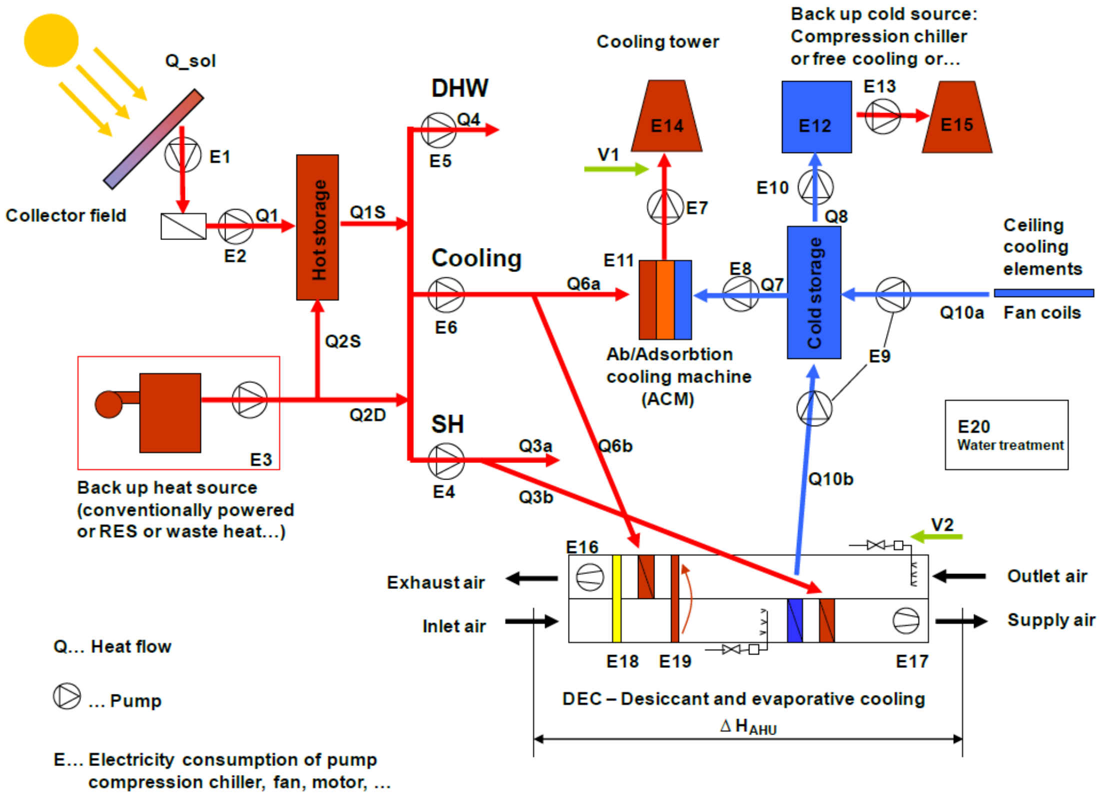


Figure 2: Monitoring schemes from the IEA Task 38

The actual data available from the demonstrators can be found in **Fehler! Verweisquelle konnte nicht gefunden werden.**,**Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**.

3.3.2 Performance Indicators

To provide insights if and how the EEPOS system improved the performance of the neighbourhood, already established performance indicators will be used.

3.3.2.1 Energy efficiency

The basic performance indicator for the building energy systems related to processes will be calculated according to the energy efficiency defined in EN 15316-1, While EN 15316 is only written for space heating and domestic hot water production, cooling and electricity production can be covered as well. As the core of all the energy efficiencies described in this standards is the formula

$$efficiency = \frac{energy\ output}{energy\ input + auxiliary\ energy},$$

definitions from EN 15316-1 and 15316-4 with respect to system boundaries (e.g. for calculation of the auxiliary energy) can be used accordingly. This also holds for larger scale production, e.g. a district heating plant utilizing combined heat and power, as the overall energy efficiency remains the same, independent of the size. This efficiency definition already covers the use of appropriate conversion factors e.g. to primary energy. The relevant conversion factors for the demonstrator are to be found in **Fehler! Verweisquelle konnte nicht gefunden werden.** to **Fehler! Verweisquelle konnte nicht gefunden werden.**. This factor is always dimensionless, and can be computed for any given span of time. It therefore satisfies the need of the EEPOS project for comparing the performance with or without the system. A good overview of the different calculation needed for all function is to be found at page 48 of the EN 15232 - Energy performance of buildings – Impact of Building Automation, Controls and Building Management -deals with the rating of building automation systems with respect to functionality and energy consumption.

3.3.2.2 Demand response

The shift or shed of electrical or thermal load in time will be calculated according to the method developed in the EcoGrid EU[1] project. It should be noted at this point, that the increase of on-site consumption of energy generated by local renewable energy sources can be interpreted as a load shift, and can therefore also be covered by this approach.

We can assume that we will have time (*t*) dependent data from days where the EEPOS system has not influence the consumption of power (*p)*, which can be either thermal or electric. Also, additional data for wind (w), solar radiation (I) and temperature (T) is available. Formally, the data can be described as the mathematical set

$$\left\{p, T, I, w, t \middle| p[kW] \in R, T[°C] \in R, I\left[\frac{\mathrm{W}}{\mathrm{m}^2}\right] \in \mathrm{R+}, \mathrm{w}\left[\frac{\mathrm{m}}{\mathrm{s}}\right] \in \mathrm{R+}, \mathrm{t}[s] \in \mathrm{R+}\right\}. \tag{1}$$

First, it will be established if the correlation of temperature, wind and solar radiation to power is important enough to be taken into account for further calculations, or if temperature alone will be enough. This will be done using undisturbed data and a linear statistical model of the form

$$p \cong a_0 + a_1 T + a_2 w + a_3 I \tag{2}$$

where a_1, a_2 and a_3 are constants. The ratio between a_1, a_2 and a_3 can be interpreted as a measure which of the three factors is influencing the power consumption the most. This should be done using normalized data for all three parameters. Depending on the type of generation and usage, F-tests can be used to determine if all of the variables actually have a statistically significant influence on the power consumption.

To calculate the actual influence EEPOS system on the consumption, a comparison between days with and without influence is necessary. As the probability of having days with exactly the same climate conditions is extremely low, a method to decide which days to compare is used. For each day we also have the dataset of environmental values in five minute intervals,

[1] FP7, *EcoGrid EU – A Prototype for European Smart Grids. EU Seventh Framework Programme Deliverable 6.2* (Brussels: European Commision, n.d.).

$$\left\{d_j = \{T_{i,j}, w_{i,j}\} \mid T_i[°C] \in R, w_i\left[\frac{m}{s}\right] \in R+, I_i\left[\frac{\mathrm{W}}{\mathrm{m}^2}\right] \in \mathrm{R}+, i = 1 \cdots 288\right\}. \quad (3)$$

Together with the results from (1), the distance d_j between two days can be defined by the weighted distance of temperature and wind

$$\overline{d_k d_l} = a_1 \sum_{i=1}^{288} \left(T_{k,i} - T_{l,i}\right)^2 + a_2 \sum_{i=1}^{288} \left(w_{k,i} - w_{l,i}\right)^2 + a_3 \sum_{i=1}^{288} \left(I_{k,i} - I_{l,i}\right)^2. \quad (4)$$

Using this method, it is possible to choose an arbitrary number of days which can be considered to be the most similar ones to a given day by calculating the distance to each other day in the dataset. Averaging the power consumption data from those days most similar, and comparing this to the power consumption when a change in behaviour is requested by the EEPOS system, the change in behaviour can be quantified.

3.3.3 Evaluation period

The IPMVP (EVO) and ISO 50001 standards provide guidelines for the continuous improvement of energy management projects with the "plan, install, maintain" and "plan, do, check, act" methodologies respectively. However there is currently little guidance on establishing baseline data for projects.

Very often it is assumed between one and two years' worth of monitoring data are required to establish such a baseline (EPA)(Worley)(ICT PSP). In recent years this has been questioned and other methods used to reduce time spent simply monitoring the baseline. One example that has been used in the EcoGrid EU and Sounds for Energy Control of Buildings (S4ECoB) (Braun eta al) projects.

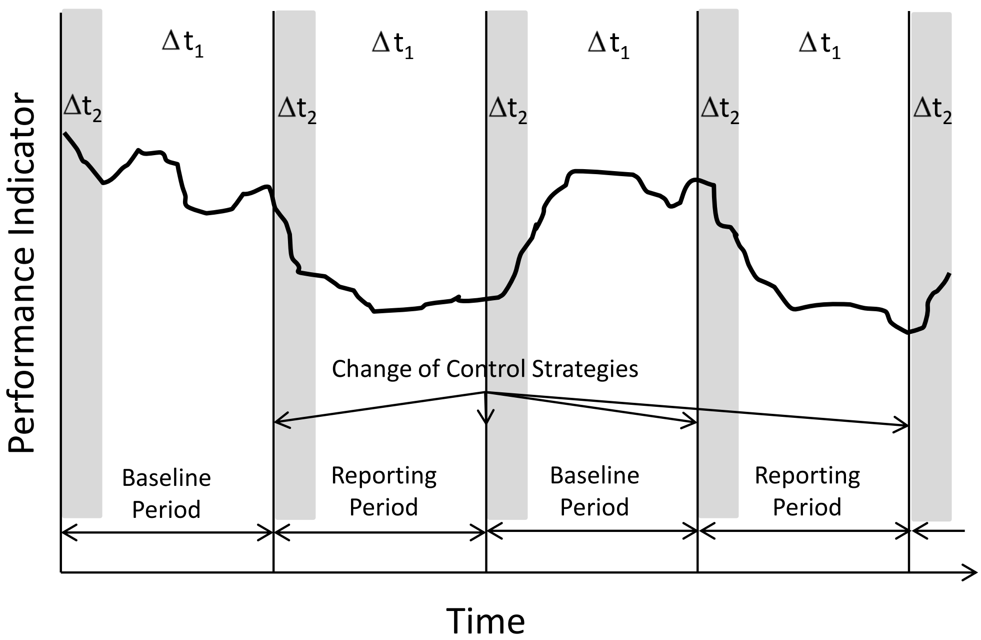


Figure 3 Example for the evaluation with interlacing periods for an arbitrary perfomance indicator

During the monitoring phase the control strategies will be alternated with the old ones. The baseline for the project is established when the old strategies is used and data on how the new system/strategy is performing is recorded when those are run. This is especially useful for demand response applications, where short time reactions are crucial. Therefore to make them more comparable they will be run alternately within a short space of time such as e.g. three days apart. Figure 3 shows an example for this approach. Because the system is controlling a complex building climate a transition period is included at the changeover of each strategy to allow the building conditions to adjust without skewing the data. During this time data will not be recorded.

As an example the strategy for the Ecogrid project is shown in Table 1, where the first day is equal to a baseline period, while the experiments are the reporting period. As this is concerned with the supply of electricity no transition period is required.

Timing	Test case	Parameters
Start: 1 January 00:00 End: 2 January 00:00	Baseline	Price: REF
Start: 2 January 00:00 End: 2 January 06:00	Expected step	Reference price: REF Step price: REF - 100 EUR/MWh Step start: 2 January 00:00 Step end: 2 January 02:00
Start: 2 January 06:00 End: 2 January 12:00	Expected step	Reference price: REF Step price: REF + 100 EUR/MWh Step start: 2 January 06:00 Step end: 2 January 08:00
Start: 2 January 12:00 End: 2 January 18:00	Unexpected step	Reference price: REF Step price: REF - 100 EUR/MWh Step start: 2 January 12:00 Step end: 2 January 14:00
Start: 2 January 18:00 End: 3 January 00:00	Unexpected step	Reference price: REF Step price: REF + 100 EUR/MWh Step start: 2 January 18:00 Step end: 2 January 20:00
Repeat every 16 days		

Table 1- Methodology for baseline and reporting period sequence in Ecogrid[2]

The advantages of these methodologies are:

1. The data monitoring systems have all been fully installed and the gathered parameters are similar.
2. It thought not necessary to normalise the data with weather since the two strategies are being run much closer together. Analysis of weather data over an eleven year period from Pittsburgh airport in Pennsylvania[3] reveals that the temperature on a given day is nearly three times more likely to be similar to that of the previous or next day than the same day on any other year in the measured period.
3. Projects where little data is available on the previous system do not have to wait for baseline data to be recorded.

[2] FP7, *EcoGrid EU – A Prototype for European Smart Grids. EU Seventh Framework Programme Deliverable 6.2*.

[3] NOAA, “Hourly Climate Data Page,” June 10, 2013, http://www.erh.noaa.gov/pbz/hourlyclimate.htm.

3.4 Energy consumption

In case of the main consumer which the EEPOS system should be able to handle – building and their users – measurements as discussed for the producers do get very difficult. Most of the time plug loads, auxiliary energy for heating etc. are only subsumed as a single energy consumption value. The same may hold in case of heat energy if the DHW and heating are not accounted for separately. To deal with this problem, which includes the behavior of the tenants or user, different methodologies have to be used, as these unknown loads introducing a base load not much aligned with outdoor conditions to system.

The basis for this class of systems is the methodology for Energy Efficiency Measurement (EEM) developed in the 3-e HOUSES project (Porto, et al., 2011), based on Energy Savings, avoided CO_2 emissions and load curve shifting (demand response) measurements. This enables the EEPOS project to meet one of the objectives of the project, namely the calculation of the energy saving results achieved in the Finnish and German demonstrators.

In order to know and evaluate the energy consumptions prior to the implementation of the Energy Conserving Measure (ECM) solution, it is necessary to develop energy audits and a measurement campaign. The necessary information was:

- equipment in the facility
- state and operation profile of the equipment
- operation detail to calculate the distribution of the energy consumption
- behaviour of the energy consumption in the facility.

In order to calculate the energy savings, it is necessary to know the baseline consumptions, the consumption after the ECM solution implementation and the necessary adjustments to do.

After an introduction to the methodology we describe its usage in the EEPOS project and the concrete application to the demonstrator sites.

3.4.1 Quantities to formulate ratios to the baseline – Key Performance Indicators

Generally, there are different ratios which can be measured and monitored to calculate energy savings (technical, environmental, economical) but there are also ratios which can be only rated in a specific way (social) or only indicators to relate to these ratios can be measured. The following list shows existing ratios in relation to energy efficiency:

- technical ratios are important to calculate the energy savings and therefore measure the energy efficiency. With technical ratios it is possible to visualise the results in diagrams to analyse them and show inconsistency clearly. Examples are “heating consumptions per person (kWh/person)”, “lighting consumption per square meter (kWh/m²)” or “cooking consumption per person (kWh/person)”.
- environmental ratios: The level of this ratio is depending on the previous known technical ratios; the higher the energy savings are, the lower are the emissions caused by the energy generation. Examples are “HVAC, lighting: CO2 emissions per m2” or “cooking, pumping: CO2 emissions per person”.
- social ratios: An important ratio is the “comfort” which is directly influenced by the general condition of the building and the installed technical systems. A very important factor to regulate the comfort is the behaviour of the tenant. With the knowledge of the use of the technical systems the tenant can influence the comfort level directly. Ratios to measure the comfort are room temperatures and relative humidity in the dwellings.
- economical ratios: These ratios are directly related to the energy consumption and their costs. Economical ratios shall be provided e.g. in a web interface to have a direct

overview of the costs and savings generated by the measured energy consumptions. Examples are “€/person or €/m2: total consumption / key factor” or “cent/saved kWh: costs per saved kWh of end energy on the level of a building or dwelling”.

3.4.2 Options to determine the baseline and the energy savings of the involved households

Baseline and energy savings can be determined either by measurements or calibrated simulations. Again, the IPMVP gives different options to measure the achieved savings after the introduction of an energy management solution. Depending on the use case, the energy efficiency savings potential and the measurement capabilities different options are available. In the case of EEPOS validation, measurements are primarily for monitoring and therefore performed with high time resolution. Thus, we were able to identify the Key Parameters *energy consumption* and *operating hours* by simply analysing the consumption data.

In each method, adjustments have to be used. We make a distinction between routine and non-routine adjustments.

- Routine adjustments are used for changes in selected independent variables that can be expected to happen throughout the baseline period. These adjustments are often seasonal or cyclical (weather or occupancy variations). Therefore heating degree days (HDD) or cooling degree days (CDD) are used for these reasons as the climatic changes are the main reason of variability in the residential consumption profiles.
- Non-Routine adjustments are adjustments for changes in parameters which cannot be predicted and for which a significant impact on energy use/demand is expected. Non-routine adjustments should be based on known and agreed changes to the facility, for example changes in the amount of space being heated or air conditioned, respectively, or changes in the amount or use of equipment.

Depending on the adjustments, we evaluated four options: measurements of the consumptions of the whole system using utility meters (A), specific measurements of Key Parameters of ECM-affected systems (B), calibrated simulations based on the EPBD assessment of the building (C) and the Demand Response methodology (D).

In **Option A, the measurement of consumption of the whole facility**, the savings are determined by measuring energy use (utility meter) at the whole facility or sub-facility level. Continuous measurements of the entire facility’s energy use are taken throughout the reporting period. One or more ECMs might be included. Routine adjustments have to be used as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments have to be used as required.
A multifaceted energy management program affects many systems in a facility. For the energy savings calculation it is necessary to measure the energy use with the electric utility meters for a twelve month baseline period and throughout the reporting period. It is possible to explain the residential consumption with the following formula:

$$\text{Electricity consumption} = \text{constant} + X * \text{number people} + Y * \text{HDD} + Z * \text{CDD} \quad (5)$$

$$\text{Saving} = \text{Baseline Energy} - \text{Reporting Period Energy} \pm \text{Adjustments} \quad (6)$$

Where X, Y and Z are the people-, heating- and cooling-dependent parts of the electricity consumption, respectively.

Example: Energy consumption of a university building. Figure 3 shows a screenshot of the ongoing commissioning system of the University of Stuttgart with commissioning comments from the energy manager. It can easily be seen that is a helpful tool which animates energy managers to interpret the consumption on an actual basis.

Figure 3 : Screenshot of the commissioning system of the University of Stuttgart with ongoing commissioning comments from the energy manager

This option is applicable for energy savings > 10%* due to measuring the whole facility.For the EEPOS project, a feasible alternative to calculate energy savings with option C would be to assess energy savings by applying the “CONTROL GROUPS” method. This alternative is used when individual/dwelling consumptions before implementation of EEM are unknown. In this case is possible to use two groups of tenants: one where the EEMs are implanted and another very similar where consumptions are measured without any EMM implementation. The savings achieved by the EEMs are calculated comparing consumptions of both groups.

As shown in the diagram, we would follow this methodology:

1. Select a group of facilities
2. Divide it into 2 groups: TREATMENT group and CONTROL group
3. Establish couples of analogues cases from both groups.
4. Assess energy consumption in each group before the EEM is implemented in the treatment group
5. Implement EEM in the treatment group
6. Measure defined variables during the reporting period,
7. Calculate energy savings

Note: The approach of a control group calculation is only feasible, if the number of users is very high, to minimize the peak effect of very high or very low consumption.

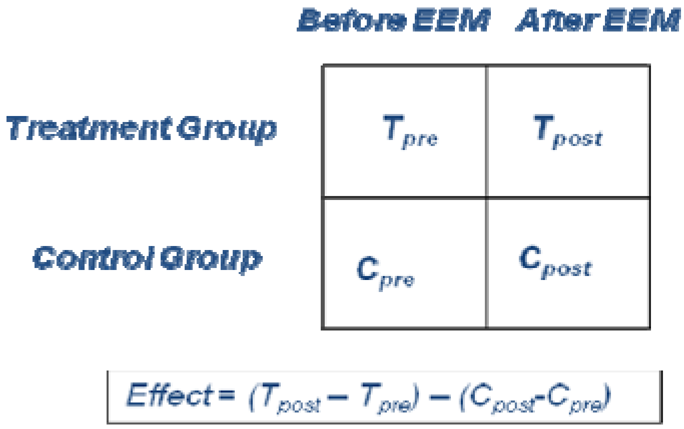


Figure 4. Calculation of energy savings with a control group

In **Option B, the Measurement of Key Parameters of ECM-affected systems** the savings are determined by field measurement of certain crucial performance parameter(s) which define the energy use of the system(s) affected by ECM. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period. Routine and non-routine adjustments are calculated as required.

The energy savings calculation is done for each ECM:
Saving = Baseline Period – Reporting Period ± Adjustments
Example: A lighting retrofit where power draw is the key performance parameter that is measured periodically. Operating hours of the lights based on building schedules and occupant behaviour.

Before: Power = 60 W operation hours: 10 h/week
After EEM: Power = 15 W operation hours: 10 h/week
Savings: (60–15)*10=450Wh/week
Saving year: 450Wh/week*52weeks/year=23.4 kWh/year

This option is mainly used to determine energy savings for new behaviour or/and new equipment (including submetering).

In **Option C, the Calibrated Simulation**, savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This option requires considerable skill in calibrated simulation if applied to the whole facility.

According to CEN 13790, each component of the system is modeled as an efficiency box which models the efficiency of a component depending on the operation mode. In general an efficiency box could be an emitter, a distribution circuit, a hot/cold storage or a generator like a boiler, chiller or a CHP unit. The same approach is made for heating, cooling, domestic hot water and ventilation systems. But also other appliances could be modeled in a similar way.
Each box can in principle be implemented with different level of complexity. The simplest one is to assign a constant efficiency (e.g. efficiency of the distribution circuit), whereas the sub-model for a boiler or a chiller could be more complex.

Figure 5 illustrates the principle input and output data as well as the calculation for a given sub-system (box) through the box characteristic equation. The output (service) of the box is characterised by $Q_{required\ to}$. Each sub-system considers an input of energy (electrical or thermal energy) $Q_{required\ from}$ and auxiliary electricity (W). The auxiliary electricity is converted to thermal energy and partially added to the system output.

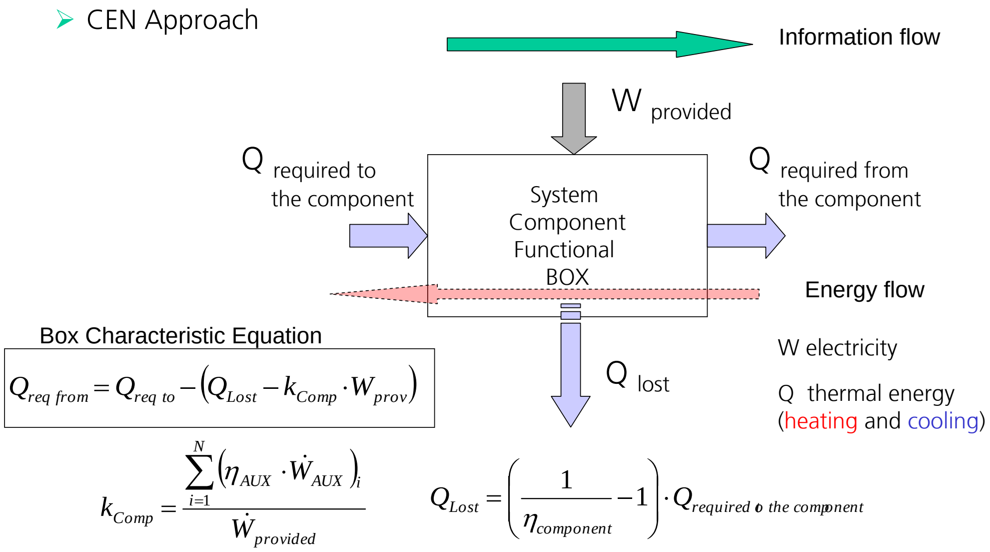


Figure 5: Simplified box model according to CEN 13790 (from BuildingEQ)

The outputs are the energy (electrical or thermal) that is delivered to the next connected component $Q_{required\ to}$ and the thermal losses Q_{lost}.

To generate the appropriate baseline, a model for each component where ECM is applied has to be developed. Then the level of comfort and associated $Q_{req\ from\ before}$ is determined and the model is calibrated using the measured consumption. Finally apply ECM to component and model and recalculate $Q_{req\ from\ after}$.:

Saving = $Q_{req\ from\ before}$ - $Q_{req\ from\ after}$

The simulation option is primarily used to analyse special effects using these models.

Using **Option D, the Demand Response Methodology**, the benefits & impacts of this methodology are similar to the energy savings determination according option B:
Savings: baseline – consumption after demand response program ± Adjustments
Attention should be paid on the baseline, which has to be established in a different way for this case. If the average power, and therefore the consumption over a suitable time interval for households (e.g. hours) is used. For easier understanding, those values well be referred to p(d,h), with d denoting the day and h the quarter-hour. The Load Factor (LF) is defined as the value obtained by dividing the minimum power demand over the maximum power demand of a facility:

$$LF = \frac{\min_{h=1..24} P(t,h)}{\max_{h=1..24} P(t,h)} \leq 1$$

A high load factor is an indicator for very constant energy consumption, while a high load factor means a huge peak in consumption (in either or both directions).
Following the ideas of the 3e-HOUSES project we introduced the procedure described in Figure 6:

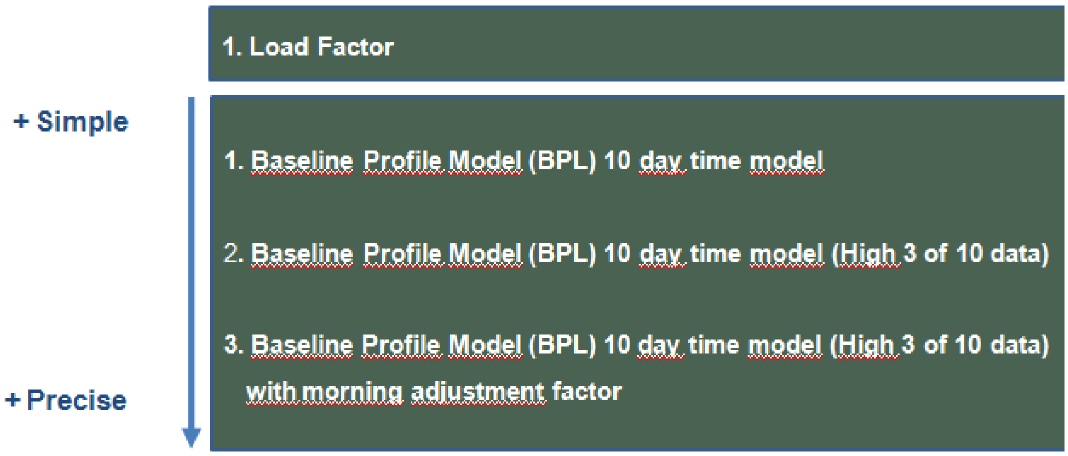


Figure 6: Demand response baseline methodology

In three levels the procedure allows three models rising from simple to precise. Baseline Profile Model 10 day time model:

> It is generally accepted that a period of approximately 10 (non-event) business days reasonably represents consumption for normal operations and therefore makes up a preferred baseline window for resource adequacy and demand programs. Using a 10 day time window provides an appropriate balance – short enough to account for near – term trends and long enough to limit opportunities for manipulation

$$b_1(t,h) \coloneqq \frac{1}{10}\sum_{i=1}^{10} p(t-i,h)$$

1. Baseline Profile Model 10 day time model (high 3 of 10 data)

   If i, j and k are the three days with the highest energy consumption among the last 10 day, excluding event days and holidays, the baseline is given as

$$\mathrm{b}_2(\mathrm{t},\mathrm{h}) \coloneqq \frac{1}{3}\big(\mathrm{p}(\mathrm{i},\mathrm{h}) + \mathrm{p}(\mathrm{j},\mathrm{h}) + \mathrm{p}(\mathrm{k},\mathrm{h})\big)$$

2. Baseline Profile Model 10 day time model (high 3 of 10 data) with adjustment factor

   Changes in load are most often necessary on days not quite different from the last days, e.g. with extremely high values in wind (for production) or very low temperatures (for demand). A simple way to address this need is through an adjustment based on a correction based on the two previous hours.

$$b_3(t,h) \coloneqq b_2(t,h) + \frac{1}{2}\big(b_2(t,h-1) - p(t,h-1) + b_2(t,h-2) - p(t,h-2)\big)$$

3.4.3 Criteria and Methods chosen for EEPOS

In summary, it depends on the project and especially the project targets, which method to calculate the energy savings is appropriate. The two Demonstrator Sites in EEPOS fulfill both different targets – therefore the options A, B and D are obviously the most suitable choice for both demonstrators. Regarding energy data of potential tenants, which will participate in the EEPOS project, the data which has been collected in the 3e-Houses project can be used for baseline calculations and as the measurements are still ongoing, also for calculations of energy savings with option B.

4. CONCLUSIONS

The main goal of the task, using only norms and already established methods for the evaluation of the EEPOS project, was fulfilled. The system will need a certain degree of transparency to be able to satisfy the various national standards, but these problems will mainly have to be solved during the configuration of the system, and are not expected to have a huge influence on the system itself. The envisioned full integration into the EEPOS system will hopefully lead to a product which is able to support all energy related process with standardized values. This will enable the use of methodology originally created just to evaluate the EEPOS project to support the IPMVP and the ISO 50001 process on a neighbourhood level, greatly reducing the efforts for continuous improvement of actual neighbourhoods where it is implemented.

5. ACRONYMS AND TERMS

B – Boiler

CDD – Cooling Degree Days

CH – Absorption Chiller

CHP – Combined Heat and Power

DE – District Energy

DHW – Domestic Hot Water

ECM – Energy Conserving Measure

EEM – Energy Efficiency Measurement

EPBD – European Directive on the Energy Performance of Buildings

FC MCHP – Fuel Cell MCHP

GHG – Green House Gases

HC – Heating Coil

HDD – Heating Degree Days

HVAC - Heating, Ventilation and Air Conditioning

HRS – Heat Recovery System

HS – Heating System

ICE MCHP – Internal Combustion Engine MCHP

MCHP - Micro Combined Heat and Power

NEMS – Neighbourhood Energy Management System

PE- Primary Energy

PEC – Primary Energy Consumption

PES – Primary Energy Saving

PGU – Power Generation Unit

PV – Photovoltaics

RES – Renewable Energy Source

VC – Vapour Compression System

WtE – Waste to Energy

6. REFERENCES

Alanne K, Saari A, Ugursal IV, Good J. The financial viability of an SOFC cogeneration system in single-family dwellings. J Power Source 2006;158:403–16

Reiner Braun et al., “Review of Methods for Evaluation of Building Energy Enhancements (in Proof)” (presented at the 2nd Central European Symposium on Building Physics, Vienna, Austria, 2013).

Bruckner T, Groscurth HM, Kümmel R. Competition and synergy between energy technologies in municipal energy systems. Energy 1997; 22(10):1005–14.

Cochrane, R., et al. (2012). SmartCoDe - Evaluation report. Hannover: Smartcode Consortium.

Cockroft J, Kelly N. A comparative assessment of future heat and power sources for the UK domestic sector. Energy Convers Manage 2006;47: 2349–60

Dentice d’Accadia M, Sasso M, Sibilio S, Vanoli L. Micro-combined heat and power in residential and light commercial applications. Appl Therm Eng 2003;23:1247–59

Dorer V. Review on existing residential cogeneration systems performance assessments and evaluations. IEA/ECBCS annex 42 report; 2007. ISBN 978-0- 662-46950-6.

EPA, “Building Improvement Tracking,” 2012, https://www.energystar.gov/istar/pmpam/help/Building_Improvement_Tracking.htm

EVO, *International Performance Measurement and Verification Protocol Concepts and Options for Determining Energy and Water Savings. EVO 1000 – 1:2012* (Washington DC, USA: Efficiency Valuation Organization (EVO), 2012), http://www.evo-world.org/index.php?option=com_docman&task=doc_view&gid=1543.

Großklos, M. (2009, Januar 14). IWU: Energiebilanzen für Gebäude. Retrieved Juni 12, 2013, from http://www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/kea.pdf

Hawkes A, Aguiar P, Croxford B, Leach MA, Adjiman CS, Brandon NP. Solid oxide fuel cell micro-combined heat and power system operating strategy: options for provision of residential space and water heating. J Power Source 2007;164:260–71

Hawkes A, Leach M. Impacts of temporal precision in optimisation modeling of micro-combined heat and power. Energy 2005;30(10):1759–79.

Hawkes A, Leach M. Solid oxide fuel cell systems for residential microcombined heat and power in the UK: key economic drivers. J Power Source 2005;149:72–83.

Hawkes A, Leach M. Cost-effective operating strategy for residential microcombined heat and power. Energy 2007;32:711–23

Hawkes AD, Leach MA. The capacity credit of micro-combined heat and power. Energy Policy 2008;36:1457–69.

ICT PSP, *The ICT Methodology for Energy Saving Measurement - A Common Deliverable from Projects of ICT for Sustainable Growth in the Residential Sector. Version 2.* (Bruxelles, Belgium: European Commission, September 2011), http://esesh.eu/fileadmin/eSESH/download/documents/News/CIP_Common_deliverable_eSESH_2011.pdf.

ISO, *ISO 50001:2011 Energy Management Systems - Requirements with Guidance for Use* (Switzerland: International Organisation for Standardisation (ISO), June 15, 2011).

Krewitt W, Pehnt M, Fischedick M, Temming HV, editors. Fuel cells in cogeneration: life cycle analysis scenarios market potentials. Berlin: Erich Schmidt Verlag; 2004 [In German], ISBN 3 503 07870 3

Lindenberger D, Bruckner T, Groscurth HM, Kuemmel R. Optimization of solar district heating systems: seasonal storage, heat pumps, and cogeneration. Energy 2000;25:591–608.

Lohmann, G., Heilmann, G., Hacke, U., & Robinson, S. (2011). THE ICT PSP METHODOLOGY FOR ENERGY SAVING MEASUREMENT - A common deliverable from projects of ICT for sustainable growth in the residential sector. Bonn: eSESH consortium.

Onovwiona HI, Ugursal VI, Fung AS. Modeling of internal combustion engine based cogeneration systems for residential applications. Appl Therm Eng 2007;27:848–61.

Palazzi F, Autissier N, Marechal F, Favrat D. A methodology for thermoeconomic modeling and optimization of solid oxide fuel cell systems. Appl Therm Eng 2007;27:2703–12.

Peacock AD, Newborough M. Impact of micro-combined heat-and-power systems on energy flows in the UK electricity supply industry. Energy 2006;31(12):1804–18

Peacock AD, Newborough M. Effect of heat-saving measures on the CO2 savings attributable to micro-combined heat and power (lCHP) systems in UK dwellings. Energy 2008;33:601–12.

Possidente R, Roselli C, Sasso M, Sibilio S. Experimental analysis of microcogeneration s based on reciprocating internal combustion engine. Energy Build 2006;38(12):1417–22.

Porto, M. R., Gonzalez, A., Hildebrandt, D., Silvero, R., Hartung, M., Fuentes, A., et al. (2011). D1.2. – Definition of methodologies. Barcelona: 3e-Houses Consortium.

Ribberink H, Mottillo M, Bourgois D. Performance assessment of prototype residential cogeneration systems in single detached houses in Canada. IEA/ ECBCS annex 42 report; 2008. ISBN 978-0-622-47618-4.

Sibilio S, Possidente R, Roselli C, Sasso M. Assessment of micro-cogeneration potential for domestic trigeneration. Int J Environ Techn Manage 2007;7(1/ 2):147–64.

Voorspools K, D’haeseleer W. Reinventing hot-water? Towards optimal sizing and management of cogeneration: a case study for Belgium. Appl Therm Eng 2006;26(16):1972–81

Wallmark C, Alfors P. Design of stationary PEFC system configuration to meet heat and power demands. J Power Source 2002;106:83–92.

Worley Parsons, *Energy Savings Measurement Guide: How to Estimate, Measure, Evaluate and Track Energy Efficiency Opportunities. Department of Resources, Energy and Tourism. Australian Government.*, 1st ed. ([Canberra]: Commonwealth of Australia, 2008).