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

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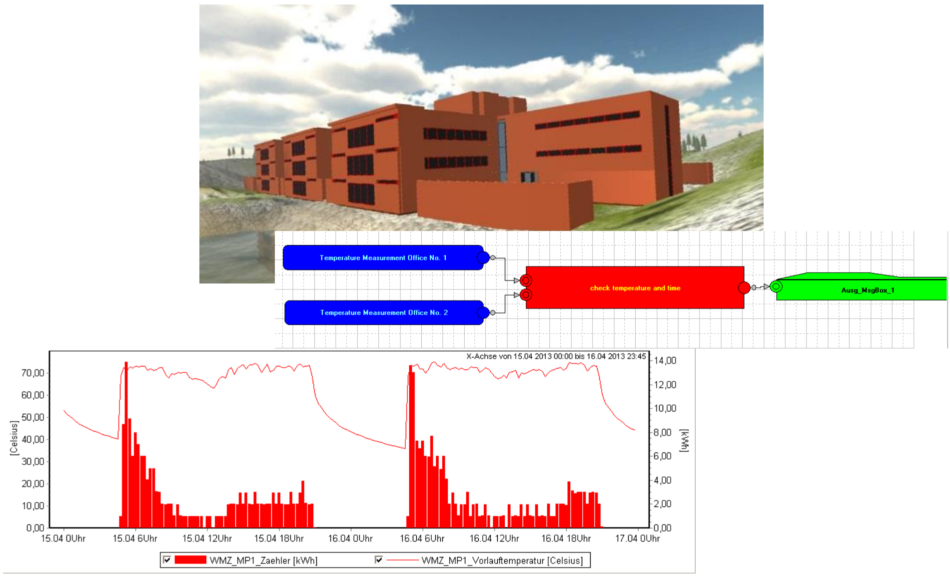
# Energy performance monitoring and operations planning tools: Specifications

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# 1. PUBLISHABLE EXECUTIVE SUMMARY

Within the EEPOS project, a central ICT platform along with several tools connected to is to be implemented and tested. This deliverable is the specification for the tools which should enable an increase in the energy efficiency of the neighbourhood under the control of the system, and also to assess the aforementioned increase.

As these tools are to a certain extend independent of each other, a modular approach was chosen, also easing development. As a common element, a database connected the individual building energy management (BEMS) systems via the ICT platform. This database will store all relevant data used for the different tools, including data from source outside the neighbourhood, e.g. weather forecasts or requests from the distribution system operator for demand response.

The three tools to be implemented are as follows:

- A performance evaluation tool will enable the operator on the one hand to be able to see the key performance indicators for individual components, sub-systems and systems, as well as realized changes in behaviour due to the active involvement of the EEPOS platform. It can be used to facilitate ISO50001 or similar processes, as well as allowing the operator to compare actual and planned operation. Furthermore, it will be used to evaluate the impact of the EEPOS platform in T4.4 during the final phases of the project.
- A data analysis will assess the data gathered on the same granularity as the performance evaluation tool. It has to main objectives, on the one hand to able to identify faults and failures on the same granularity as the performance monitoring tool, on the other hand to compute high level predictions about the energy use of the neighbourhood. For the fault and failure detection, again the knowledge of the component types can be drawn from their representation in the OGEMA system. The same holds for the energy forecasts, where the meters can be identified automatically, as well as the energy meters needed for the consumption and production forecast of the neighbourhood and its systems.
- The visualization tools will make the parameters predictions, faults and failures computed by the other tools easily available to the user operating the neighbourhood, e.g. a central facility manager. It will be able to import building geometries present in common formats, and combine it with the data from the database in a common interactive view. Through suitable representation, occurrences acquiring immediate attention can be easily identifiable from a high level view, while in depth exploration of the systems states are also possible.

This document contains the main functional specifications for these tools along with the database. It will be the basis for a technical design description and documentation of the tools, on which the implantation will be based.

# 2. INTRODUCTION

## 2.1 Purpose and target group

This specification should collect and document all functionalities needed to be able design and document the performance monitoring and operation planning tools to be implemented within the EEPOS project. It is to be used in formulating the detailed technical descriptions which form the base for the implementation of the tools. The target groups therefore can be subsumed as on the one hand the partners involved in the implementation as well as the demonstration, and due to its public nature interested experts from the fields of building automation and facility management.

## 2.2 Relations to other activities

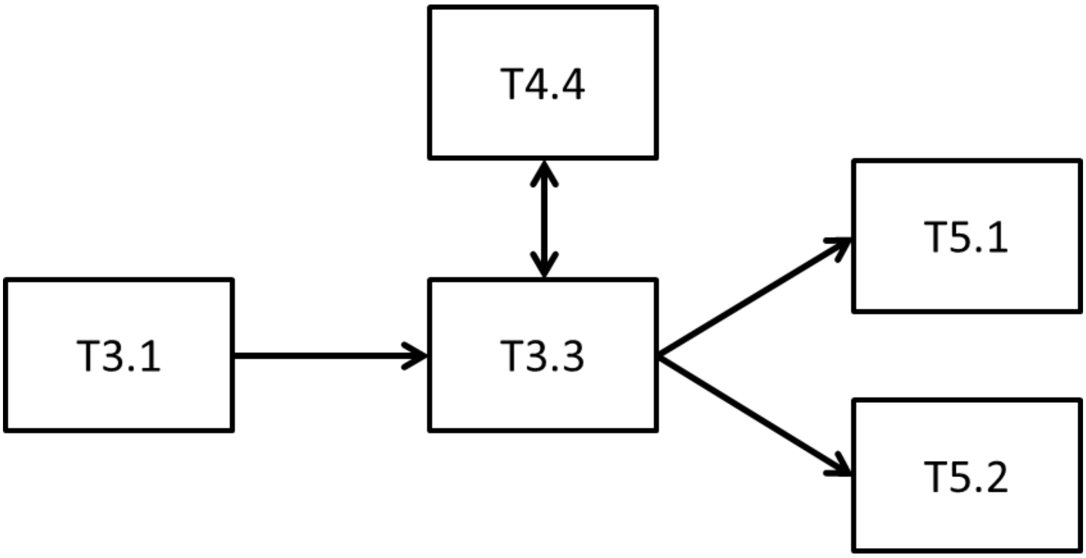


*Figure 1: Relation of T33 to other activities*

As can be seen in Figure 1, the content of D33 is based on the platform specification (T3.1), and the methodology for assessing the energy efficiency impacts of the integrated systems (T4.4). In turn, it will be used in the demonstrators (T5.1 T5.2) and the validation of the the energy efficiency impacts of the integrated systems (T4.4).

# 3. Overall concept

To keep the system more flexible and scalable, the modularized approach of the EEPOS platform will be reflected by the Energy performance monitoring and operations planning tools included in the EEPOS system will in turn be able to work mostly independent on each other, to be able to rapidly adapt the system to the various needs of the users.

## 3.1 Overview

As shown in Figure 2, the tools are centred on a database. As all the tools needed will somehow have to rely on and sometimes also manipulate data from the neighbourhood, a common storage instead of separated storages for all modules is sensible. This setup also has the advantage that only the database module has to be connected to the outside as well as the EEPOS ICT Platform.

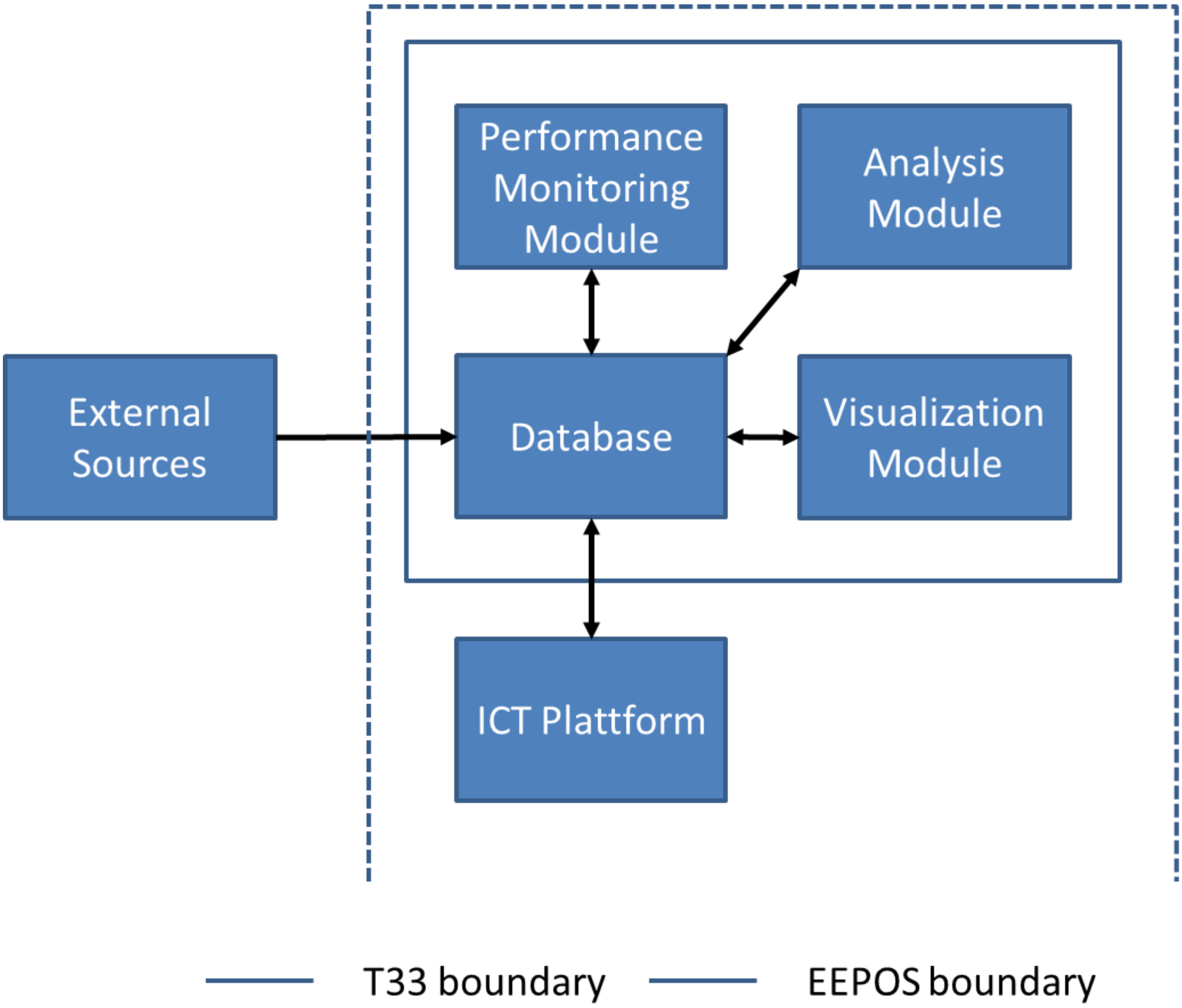


*Figure 2: Overview of the Energy performance monitoring and operations planning tools*

The main content will be divided into three tools for

- performance monitoring,
- data analysis and
- visualization,

in which the functionalities needed to fulfil the goals of the EEPOS project, which are identified on the basis of earlier tasks, can be implemented.

The distinction between the performance monitoring and the analysis module is based on computational complexity of the tasks involved. While in the performance monitoring module almost only very basic computations will be done, the scope of the envisioned analysis module will include data mining and prediction capabilities, which may need a lot of computational power if the neighbourhood monitored is large and / or has complex energy systems.

Finally, the visualization module is to be kept separated from the other functionalities on the basis that a variety of technologies should be supported, ranging from common web browsers on desktop computers to native applications on the major mobile operating systems, with the option to quickly adapt to changes in this environment without the need to make substantial changes to the other modules.

# 4. Main Functionalities

Based on the application scenarios, the stake holder requirements and the requirements of other tasks of the EEPOS projects the major functionalities were identified, which the systems has to fulfil. These functionalities will be distributed among the components described in 3,

## 4.1 Performance evaluation procedures

For the energy efficient operation of a building or room it is essential to have as much information as possible about the energy flow in and out of the building/room. Therefore it is necessary to measure all types of energy consumption which are relevant such as heating consumption and electricity consumption. For additional assessment purposes it might be also very helpful to log data of the room temperature and system temperatures (flow, return, DHW etc.) of the heating and/or air conditioning system of the building. It is also helpful to receive status information from sensors in order to compare the current status with the set status. Until today it is common practice to log all this measurement data in a data logger and/or on a server in a database to be assessed by engineers or technicians who have a certain technical expertise in the area of optimization and energy management for building automation and building supply systems. Nevertheless, the availability of measured data with sufficient quality in existing buildings is low. The following Table 1 gives a rough overview of a minimal data set of measured data in a building which is necessary to perform an analysis of the energetic situation in order to decrease the energy consumption of a building without influencing the indoor comfort.

| item | Data point | unit | Minimal time resolution | remarks |
|---|---|---|---|---|
| Consumption | Total fuel consumption | kWh | 15 min | e.g. gas, biomass, oil etc. |
| | Total consumption of heat | kWh | 15 min | |
| | Total consumption of cold | kWh | 15 min | |
| | Total consumption of electricity | kWh | 15 min | |
| | Total consumption of water | m³ | 15 min | |
| Indoor conditions | indoor temperature | °C | 15 min | In one representative, or more zones |
| | Indoor relative humidity | % r.H. | 15 min | |
| HVAC systems | Flow/return temperature of main heating/cooling circles | °C | 15 min | |
| | Water temperature of DHW | °C | 15 min | |
| | Supply and exhaust | °C | 15 min | |

| | | | | |
|---|---|---|---|---|
| | air temperatures of main AHUs | | | |
| | Supply and exhaust air relative humidity of main AHUs | % r.H. | 15 min | |
| | Status of pumps, drives etc. | 0/1 or 0…100% | 15 min | |
| Weather | Outdoor air temperature | °C | 15 min | From weather station or weather data provider |
| | Outdoor rel. humidity | % r.H. | 15 min | See above |

*Table 1. minimal data set of measured data for a building*

The development of the given data set is based on the following reasons:

- With a minimal data of measurements it is possible to follow the whole "way" of energy through the building from delivered energy to requirements (indoor climate) at least on a basic level.
- The system signals are those that have great influence on energy consumption and also on the comfort
- The minimal data set minimizes cost by exploiting sensors that are inexpensive or even readily available in most buildings with building automation systems.
- It is necessary to have consistent consumption data of the energy consumption for the analysis. Otherwise the estimations and results of the assessment could be wrong.
- The water consumption gives valuable information about the occupancy of the building.
- Weather data must be measured to eliminate weather depending influences on the consumption (e.g. the outside temperature of the heating consumption). With this data further calculations like the calculation of heating degree days
- As indoor climate (temperature and humidity) is the control variable for the HVAC system, it is important to measure at least some reference zones.
- The system temperatures/moistures and control signals help to understand how the load is met. Furthermore, the global control schemes of the heat, cold and air supply can be examined with these measurements.

This data set is recorded with a high time resolution (at least 15 min). This delivers additional information because the profiles e.g. of the energy consumption can also be examined and not only the amount of energy consumed.

To minimize the effort of the manual assessment the project partner ennovatis has started to research a certain automatism of this process by using the data from the minimal data set with its self-developed energy management software "ennovatis Controlling". The methods for an automated detection of mal functions of heating or air conditioning systems to reduce the possibility of energy over consumptions were developed in the beginning exclusively for heating systems. For this objective the following steps are necessary:

1. Definition of possible mal functions

2. Description of characteristics of mal functions
3. Development of methods for an automated detection of mal functions

## Definition and choice of typical mal functions which influence the energy efficiency of HVAC systems

In a first step the mal functions, which shall be detected in a heating system, will be defined. Those definitions will be a basis of the following assumptions.

### Simultaneous heating and cooling

If a building, or a room is equipped with different systems for heating and cooling (e.g. a static heating with radiators and cooling which HVAC unit) and the regulation of both systems is not connected to each other a simultaneous operation of heating and cooling modes can appear. In such case the condition of the room temperature is very inefficient and also uncomfortable for the users. If the energy management system will receive information about the status of heating and cooling systems it may be possible to alarm the manager of the facilities about the mal function of the systems.

### Mal functions of the regulation systems

Regulation systems of HVAC systems in buildings include in most cases a high number of sensors, which are deployed in the whole building. Defect sensors can cause mal functions of the regulation, which may lead to a higher energy consumption of the building.

### Manual switching off and other interventions

Manual switching off may be a reason for higher energy consumption in HVAC systems. With the automated control of system temperatures, room temperatures, status of the devices and control and analysis of the energy consumption it is possible to recognize faulty settings, which may be caused by manual interventions of the user.

### Missing maintenance

The lack of a frequent maintenance of HVAC systems in buildings can cause a decrease of energy consumption. This may be caused by air filters which are not changed frequently and cause a higher pressure resistance or valves which do not close completely. There is also a number of other possibilities which can cause an increasing in-efficiency of the whole system.

### Mal functions of the hydraulic system

If the hydraulic system is not very well balanced then the energy consumption of the overall system can increase due to a higher energy input. Hence more energy is needed to bring the rooms in the building on the necessary comfort conditions.

### Low efficiency factor

A general low energy efficiency factor can be recognized by the constant monitoring of the energy input and output of the whole system.

From the previously described assumptions of mal functions on heating systems a number of possible definitions can be derived.

## Description of mal functions and algorithms for automated detection

In the following the mal functions will be described to derive afterwards the methods for the implementation and automatic detection with the Controlling software.

**Heating systems:**

### Mal function 1 – heating times are not equal to usage times

If the needed room temperature doesn't meet the expectations of the user, there may be a dis-balance with the programmed heating times in the central regulation unit. For the efficiency of a heating system it is essential to meet the operation times of the heating system of a building with the actual heating demand of the users. Nowadays, heating units are operated with DDC-regulation units or by building automation systems. Both, DDC-regulations, as well as older, analogue regulation systems, offer an timetable functionality to switch on the heating system on a certain time and switch it off, when it is obviously not used.

If the using times are known (e.g. by existing time tables or office open hours) this information can be used to compare with the logged data of heating energy consumption and system temperatures of the heating system. With a simple rule, which can be implemented in the energy management software, where the data is being hosted, it is possible to detect wrong starting and stopping times of the heating system.

<u>Description of model to detect wrong heating times:</u>

The energy management software "ennovatis Controlling" offers a visual data analyzer (VDA) to analyze measured and simulated data in real time with formulas, which can be defined freely. The results of the analysis can be either stored as a new data point or generate a message which can be sent by email or SMS. It is also possible to generate a report which could be uploaded on a FTP server or published in the internet.

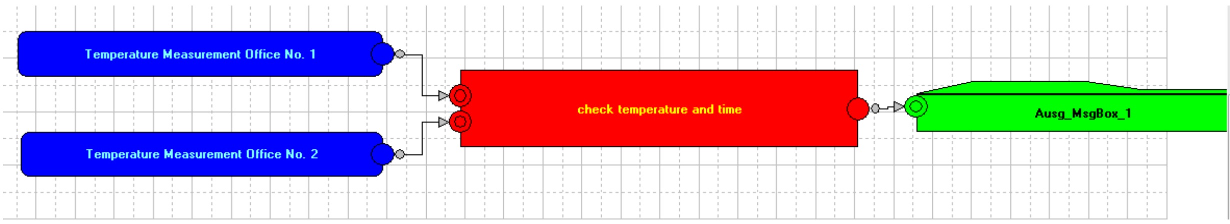


*Figure 3: Example of the visual data analyzer - configuration*

The following diagram shows a significant drop of the flow temperature and the energy consumption at the same time on both days. Hence, a simple rule can be programmed, using the VDA engine of the software to compare the level of the temperature with the time:

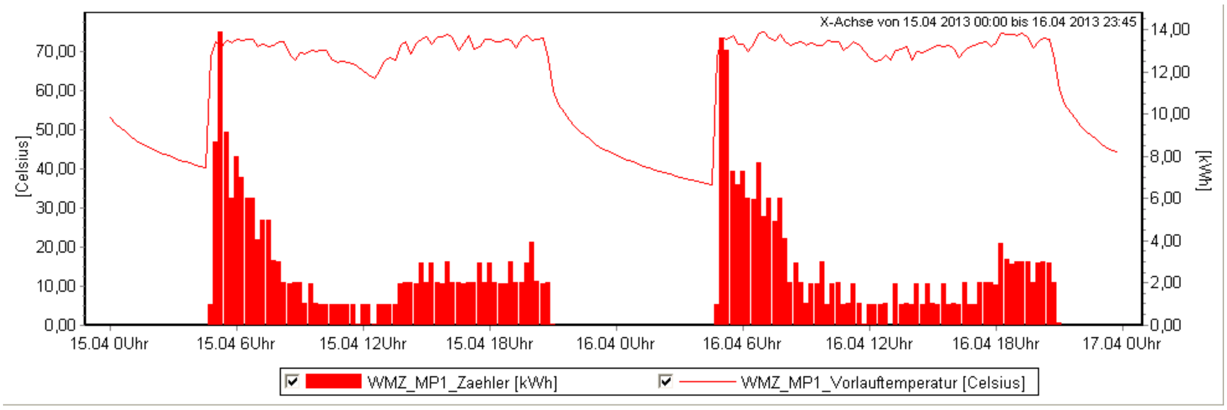


*Figure 4: Example of the visual data analyzer - vizualisation*

With the following formula, which can be implemented in the VDA, the detection of a high flow temperature at a certain time can be done. The software could send an email, if the flow temperature exceeds a set limit e.g. in the evening, where the temperature should be reduced.

$\mathbf{T < 50}\ \mathit{and}\ \mathbf{(WORKINGDATE(\,)\%1) > \ 0{,}95833}$

One step further there are also possibilities to influence the regulation system immediately, after an error was detected. For this purpose the ennovatis Smartbox a building energy management system could be used. The Smartbox needs to be connected with the heating regulation system (e.g. via Modbus) and could, after the error is detected, give a signal to close a valve or to switch of a pump.

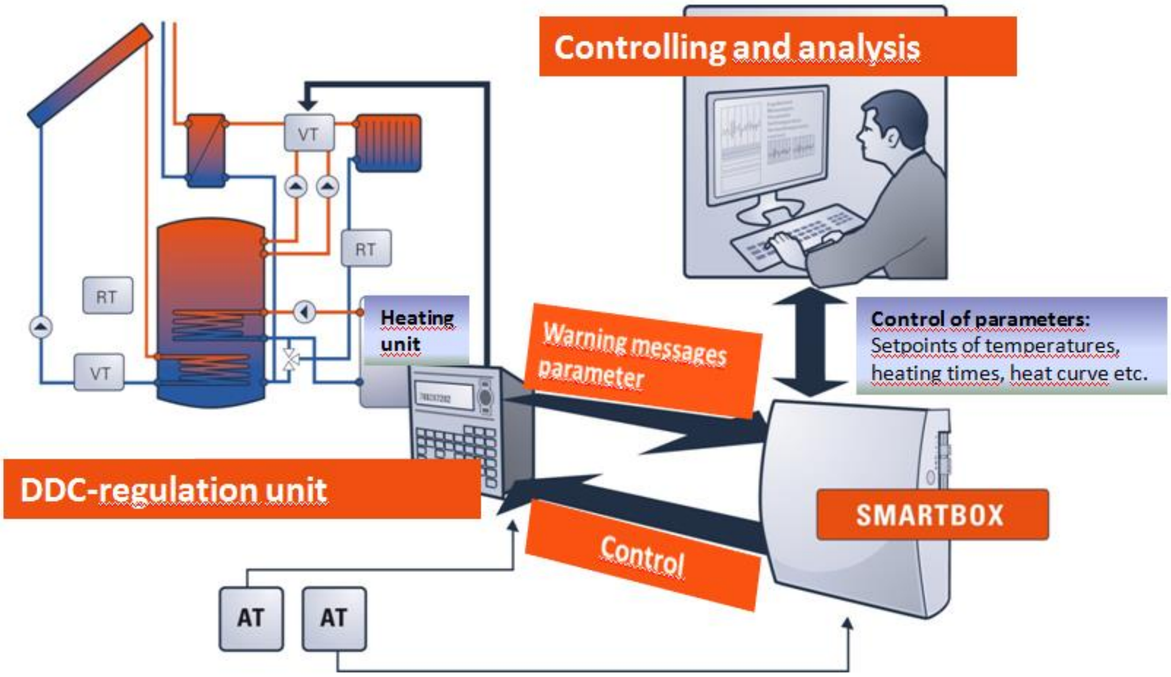


*Figure 5: example architecture*

**Mal function 2 - Too high flow temperatures or not/wrongly adapted heating curves of the heating unit and regulated heating circle**

To high flow temperatures in heating systems are mostly caused by faulty programmed heating curves. The heating curve describes a dependency between the outside air temperature and the necessary heating temperature to heat up the building. Especially in existing buildings the calculation of the heating curve is very difficult. For the calculation of a heating curve it is necessary to know the exact type of heat production, -transmission and –distribution as well as the thermal conditions of the building, which is mostly no less problematic. The condition of the heating pipes or the individual behaviour of the user in the building are factors, which are also important for the heating curve calculation, but very difficult to investigate.

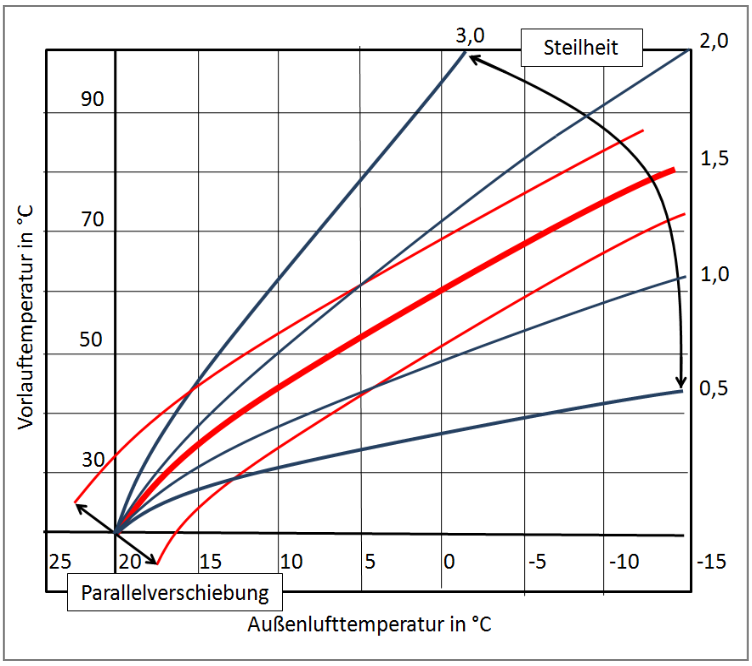


*Figure 6. heating curve (source: Wikipedia , 2007*

The set of the heat curve is mostly done with the existing dimension parameters of the heating system. If this data is not available (like in many existing buildings) it can be calculated according to SIA 384/201 or DIN EN 12831[1] with the following formulas:

Calculation of the heat curve (day):

$$t_{VL} = t_{iT} + \frac{t_{VLa} - t_{RLa}}{2} \cdot \frac{t_{iT} - t_a}{t_{iT} - t_{aa}} + \left(\frac{t_{VLa} + t_{RLa}}{2} - t_{iT}\right) \cdot \left(\frac{t_{iT} - t_a}{t_{iT} - t_{aa}}\right)^{\frac{1}{m}}$$

Calculation of the heat curve (night):

$$t_{VL} = t_{iN} + \frac{t_{VLa} - t_{RLa}}{2} \cdot \frac{t_{iN} - t_a}{t_{iT} - t_{aa}} + \left(\frac{t_{VLa} + t_{RLa}}{2} - t_{iT}\right) \cdot \left(\frac{t_{iN} - t_a}{t_{iT} - t_{aa}}\right)^{\frac{1}{m}}$$

| | | | |
|---|---|---|---|
| $t_a$ | Outside air temperatur | $t_{RLa}$ | Planned return temperature |
| $t_{iT}$ | Room temperature - day | $m$ | Exponent of radiator |
| $t_{iN}$ | Room temperature – night | $t_{VL}$ | Flow temperature depending on outside air temperature |
| $t_{aa}$ | Planned minimal outside air temperature | | |
| $t_{VLa}$ | planned flow temperature | | |

[1] Procedure to calculate the norm heating demand according to SIA 384.201 = EN 12831

The heating regulation of a building maybe controlled with different heating curves. Most heating units, with a connected heating distributer, have two separate heating curves, one for the heating unit itself and one for the connected heating circle.

**Mal function 3 - Too low temperature differences between flow and return temperature on the heating unit or heating exchanger**

The efficiency of a heating unites increases with the difference between flow and return temperature. Generally, heating systems shall be working with lower temperatures. A heating system with a temperature difference 40/30 (flow/return temperature) is much more efficient than one with 90/70. Especially heating units which are condensing boilers need a maximum flow temperature to ensure the condensation of the exhaust. Hydraulic problems in a heating system can cause a reduction of the difference between flow and return temperatures. If the flow and return temperatures are known, the difference can be calculated with the following formula:

$$\Delta T = (a * x + b) - (c * x + d)$$

| | |
|---|---|
| $\Delta$T | difference between flow- and return temperature (K) |
| a | gradient of the heating curve of the flow temperature |
| x | outside air temperature in °C |
| b | Parallel translation of the heating curve for the flow temperature |
| c | gradient of the heating curve of the return temperature |
| d | Parallel translation of the heating curve for the return temperature |

Are more detailed calculation of the return temperature characteristic is possible with the following formulas:

**Day:**

$$t_{RL} = t_{iT} - \frac{t_{VLa} - t_{RLa}}{2} \cdot \frac{t_{iT} - t_a}{t_{iT} - t_{aa}} + \left(\frac{t_{VLa} + t_{RLa}}{2} - t_{iT}\right) \cdot \left(\frac{t_{iT} - t_a}{t_{iT} - t_{aa}}\right)^{\frac{1}{m}}$$

**Night (reduced):**

$$t_{VL} = t_{iN} + \frac{t_{VLa} - t_{RLa}}{2} \cdot \frac{t_{iN} - t_a}{t_{iT} - t_{aa}} + \left(\frac{t_{VLa} + t_{RLa}}{2} - t_{iT}\right) \left(\frac{t_{iN} - t_a}{t_{iT} - t_{aa}}\right)^{\frac{1}{m}}$$

**Mal function 4 - Too high, or too low temperatures of the domestic hot water system**

Too low water temperatures between 30-45 °C may be a basis for Legionella bacteria. Therefore the water temperature in the hot water system shouldn't be lower than 60°C. It can be measured directly with temperature sensors inside or outside of the pipe. With the use of a thermal disinfection, while the system will be heated up to 70°C the Legionella bacteria will be destroyed with such a high temperature. If the temperature of the hot water is constantly too high (>60°C) there is not only an increased energy consumption but also an increase of calcination of the pipes, boilers and heat exchangers of the hot water system, which also brings forward the grow of Legionella bacteria.

### Mal function 5 - Too low efficiency of the heating unit

The efficiency of the heating unit is a very important factor to rate the efficiency of the whole heating system. It is calculated from the heating load (output) and the energy input in a defined period of time.

$$\eta = \frac{heating\_load(output)}{energy\_input} = \frac{Q_H}{Q_F}$$

With a continuous monitoring of the energy consumption and the produced heating load the real efficiency of the heating unit can be controlled. The efficiency is depending on the necessary temperatures in the heating system and the energy demand, which is dependent on:

- The weather conditions
- The thermal construction type of the building
- The user requirements
- The type of the heating unit including heat exchange and distribution

### Mal function 6 - Too many on/off cycles of the blower of the heating unit

The number of switch on/off cycles has a certain influence of the efficiency of a heating system. If there's a demand lower than the actual available heating power, then the heating unit switches frequently from operation mode to stand-by mode. Frequently is defined as 6 to 10 times per hour. The frequent on and off can be seen on all heating units independent from the type of energy source. Because of the high deployment of heating units with one and two phase gas- or oil burners the on/off cycle problem is very common with this systems. With the further deployment of wood pellets heating systems and combined heating and power plants (CHP) as well as heating pumps, this problem is going to affect also those systems. In case of wood pellets heating units the problem is even more dramatic, because the wood pellets heating unit requires longer running times of the burner. Constant on and off of such systems reduce the energy efficiency of such heating units.

### Mal function 7 - Disuse of the condensing heating effect

Gas condensing boilers are using the condensation heat, which exists in the water vapour of the exhaust of the heating unit. The use of the condensing heating effect is achieved by the fact that the temperature on the input of heating water of the heating unit (return temperature) is lowered until the dew point of the water vapour in the exhaust on the surface of the heat exchanger (gas approx. 57°C, oil approx. 47°C). Another system is the pre-heating of the combustion air, where to condensation happens in a synthetic heat exchanger (full condensing heating effect) and/or in a air-exhaust-system, which is resulting in a pre-heating of the combustion air.

To ensure the full condensation (and the full efficiency of the system) it has to be controlled that the level of return temperature is well under the dew point temperature. Depending on the heating unit it is necessary to have return temperatures under 50°C for gas heating systems and under 40°C for oil heating systems.

### Mal function 8 – Mal function in the operation of a hydraulic separator

A hydraulic separator is a technical solution for a hydraulic connection of different flow rates in a heating system. A problem which can be seen very often on such systems is that the systems are not set up very well. In most problematic cases the primary return temperature is heated up, undesired. This mal function arises, if the flow rates of the primary circle (from heating unit) are not balanced with the secondary flow rates (heating circles). Is this the case, the primary return temperature is heated up by the flow temperature of the primary or secondary circle and transports the hot flow water back to the heating unit. If a condensing heating boiler is used this effect has additionally and negative effect, because the condensing heat effect will be terminated.

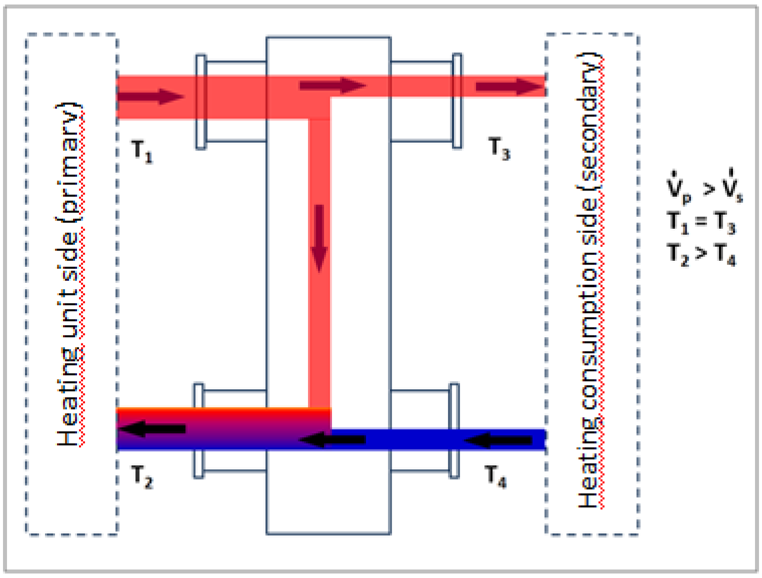


*Figure 7 mal function of hydraulic separator*

### Mail function 9 - Missing summer switch off / heating threshold temperature

A missing automatic or manual summer switch off, or a heating threshold temperature, which is set too high causes unnecessary heating consumptions. If the heating threshold temperature is too high there are stand-by energy consumptions of the heating unit. The heating threshold temperature can be calculated according DIN V 4108-6 in dependency of the insulation standard of the building and the solar thermal gain of heat. It describes the limit of the outside temperature where a heating of the building is not necessary anymore. In this case the thermal heat gain is equal with the thermal loss to the outside. For recently built buildings with a high insulation standard a heat threshold temperature of 10°C may be used. The heat threshold temperature is calculated with the following formula:

$$\vartheta_{ed} = \vartheta_i - \eta_0 * \frac{Q_{g,M}}{(H_M * t_M * 0{,}024)}$$

| | |
|---|---|
| $\vartheta_{ed}$ … | heat threshold temperature [°C] |
| $\vartheta i$ … | room temperature [°C] |
| $\eta_0$ … | degree of efficiency |
| $Q_{g,M}$… | monthly heat gain [kWh] |
| $t_M$... | number of days per month [days] |
| $H_M$… | the specific heat loss [W/K] |

In addition to the correct set of the heat threshold temperature in the regulation unit a complete switch off of the whole heating system should be done during the summer period.

**Mal function 10 - No or insufficient heating-interruption operation**

Missing or to low reductions of system temperatures in the night, during weekends or bank holidays lead to a waste of energy. Looking at school buildings it can be seen that there is a need for heating only for 30% of the time in the heating period. The other 70% of time the building is not used due to holidays or no usage in the evening. Nowadays, the more and more use of low temperature- or gas condensing boilers offers the possibility to switch off the heating, if it is not used. The heating system can be switched off until a certain level of room temperature is reached. If the room temperature drops further on, the heating unit will be switched on, but with a significantly lower flow temperature.

## 4.2 Interactive visualization for decision support

The energy performance monitoring tool should be able to visualize 3D virtual neighbourhood including the landscape, buildings, energy production units and the energy grid with 3D game type navigation, online monitoring, historical data visualisation, benchmarking, and fault detection support.

The flesh out scenario from D1.1 is as follows. The user can navigate in this 3D game engine based neighbourhood and start real time monitoring by clicking the item (building, energy production unit, energy grid component, etc.) and selecting the monitored variable (e.g. available measurements, calculated KPIs, etc.). Example of the possible monitoring variables are index of energy positive neighbourhood, neighbourhood level energy reduction, neighbourhood and building level energy performance index, neighbourhood and building level energy consumption and power (heat and electricity), neighbourhood and building level energy production and power (heat and electricity), related costs, RES part of the used energy and load shifting done (moved demand from peak hours to off-peak hours of the day). The results can be shown in the reports, diagrams or in the 3D model by colouring the best value related items by green and the worst ones by red.

Almost identical sub use case is the visualizing historical data. In that case the user must also give the start time and the end time.

The user can also do benchmarking between buildings. The results can be shown by colouring the most energy efficient items by green and the least energy efficient ones by red.

The tool can also detect some energy consumptions related faults and show the target item(s) in virtual neighbourhood by colouring it red and by linking it. For more information the user can click the alarming target.

The monitoring tool related use case for Finnish demonstration is shown also in use case diagram in the EEPOS deliverable d2.2.1.

### 4.2.1 Import of geometry data

The next geometry models are needed to visualise the neighbourhood related geometry data

- Landscape model of the neighbourhood
- Building models (all buildings in the neighbourhood)
- Energy grid model (electric and heat) including energy production units
- Optionally some supporting geometry models like human, trees, furniture etc.

The import of the geometry data should work as follows

- Import landscape model of the neighbourhood
- Import building models and place them in the right place of the landscape
- Import energy grid model (electric and heat) including energy production units and place them in the right place of the landscape
- Optionally import some supporting geometry models like human, trees, furniture etc. and place them in the right place of the landscape
- Save the whole integrated neighbourhood 3D model
- When using EEPOS monitoring tools the whole integrated 3D geometry model of the neighbourhood should be able to import automatic

There are some existing solutions how to import and combine the neighbourhood level 3D model. On the other hand the implementation of this is not in EEPOS score so this function should not be developed in EEPOS. Instead of it an existing solution should be preferred. . For example Unity is already tested by VTT and it will make it possible to build 3D model of neighbourhood very easily without a lot of work.

### 4.2.2 Embedding of performance data into 3D models

The setting up of the integrated 3D neighbourhood model is done by combining the separate landscape, building and energy grid models into one neighbourhood level 3D model. Only 3D CAD models of those buildings are needed or if not possible existing models which are as close as possible can be substituted. The monitoring tool needs this integrated 3D model and related data access to historical database and real time data (maybe by means of historical database).

The embedding of that historical, real time or related performance data into neighbourhood 3D models can be based e.g. on id based data mappings between the performance data related ids and neighbourhood 3D model related ids shown in Figure 8.

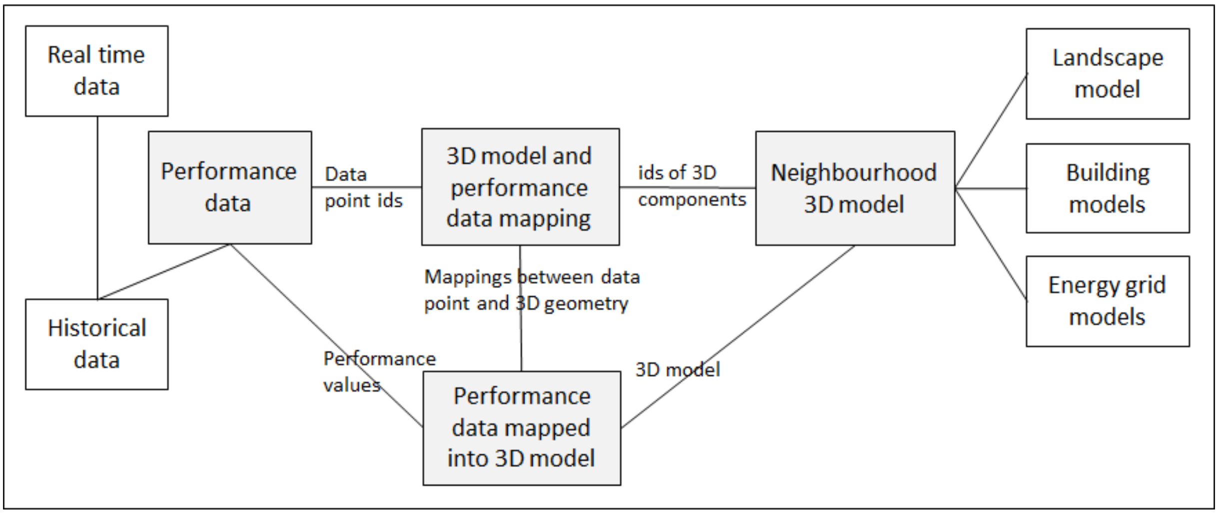


*Figure 8* Conceptual diagram of mapping between performance data and 3D model

This means that we need to have a data model that allows this kind of mapping information. We also need a way how to configure this mapping related data model. An easy solution is a simple data base table(s) which includes that mapping information. And we need an API for using that information when navigating in 3D model and selecting and colouring different items (buildings, energy production units, etc.) from the model.

## 4.3 Fault detection

### 4.3.1 Simple system faults

The fault detection will be based on analysing heating (and cooling) related power consumption related to outdoor temperatures. It utilises mainly EN 15603 standard (Energy performance of buildings) and some common rules related to electric power and neighbourhood level heating, cooling and electric energy and power.

The fault detection method includes three different scale fault detection which are apartment, building and neighbourhood. It does not need any extra sensor, but some basic information of buildings, information of heating and cooling power and energy consumption in apartment, building and neighbourhood level. Also local outdoor temperature is needed. Optionally also information of electric power and consumption of electricity in apartment, building and neighbourhood level is needed.

The basic idea is to realise the result in 3D virtual environment by colouring the fault target in red and blinking it. By clicking the alarming target the user can get more information of the fault. From the software architectural point of view there is one 3D virtual environment using different kind of services like fault detection, benchmarking etc. by means of APIs.

Additionally the detected fault event should be mapped with time moment (timestamp) as well as weather status, which is then used to correlate with energy consumption and detected fault events. This method would enable to monitor the performance and health of the system and provide notifications about upcoming potential failures or maintenance need. The energy consumption data together with fault events will take into account the context of the event (time of the day, time of the year, weather status etc.) to create relations with past data to understand current status of the system. Short and long term memory or contextual understanding should be created.

### 4.3.2 Knowledge based detection

As all the data acquisition for the buildings and their systems is done through OGEMA with the EEPOS platform, it is very intuitive to assign sensor readings etc. to components an event to specific locations within the components. Therefore standardized error cases can be defined, using expert knowledge about the system. They errors can be classified in several layers

1. Individually physically impossible data is data which through the physical limits of the system cannot be possible, e.g. negative radiation values, temperatures below absolute zero etc. and may be used to identify broken sensor equipment or wrong data conversion.
2. Data individually impossible in the context of the system is well out of reach of the usual working conditions, e.g. a gradient with the sign between return and supply lien may be used to identify faults either in the system or controls.
3. The same holds for data which leads directly to a bad performance of the system, e.g. very high pressure in a ventilation system.
4. Finally, the operation may lead to a medium to long term degradation of the system involved, e.g. too much duty cycling in a heat pump.

Many of the error above can already be identified by knowing the component involved, and the data points measured. Depending on the amount of data points available, the system should decide which calculation can be performed. Furthermore, depending on the seriousness of the error, data can be either marked, automatically interpolated or alarms may be triggered in case of more serious faults.

## 4.4 Predictions for operational planning

To support high level operational by building manager or similar users, predictions for energy production and consumption for the neighbourhood have to be established. While the production of the individual RES units will be taken care of by the “Supervisory and Predictive Control Methods and Applications” developed within T2.3 and are solved on a component level within the OGEMA platform, predicting the consumption of the neighbourhood with respect to thermal and/or electrical energy is to be solved within T33. Due to huge variety among neighbourhoods, with respect to complexity of the houses and energy system, several techniques are possible.

### 4.4.1 Descriptive Statistics

In this variant, the consumption data gathered is grouped by various parameters, especially outdoor conditions, time of the day and day of the week, as well as special occasion, such as holidays. The usual parameters for descriptive statistics are then derived from this data. Combining this statistics together with weather forecast information makes it possible to compute predictions for the energy consumption of the neighbourhood or parts thereof. These predictions will become better over time, as more and more data is collected. On the other hand, changes in the neighbourhood have to be taken into account, as the information value of the historical data may diminish during time, or may even be radically wrong in case of larger changes. Therefore models where the importance of a data point lessens over time are to be preferred, together with the possibility to reset certain parts of the forecast system.

As this distribution based on the outdoor condition may at first be not very feasible, as certain combination may not happen very often, especially the more extreme ones, in the start-up phase of the NEMS system a very rough classification may be chosen. With the amount of data increasing, the classification can be refined, e.g. by running Analysis of Variance tests in regular intervals to automatically identify possibilities to split up classes into several smaller ones, which are clearly distinct from each other.

### 4.4.2 Advanced Methods

While the method describe above is simple to implement and nor very costly in terms of computational power, more advance methods can be used for better results.

Instead of trying to separate the data in classes due to the outside conditions, and predicting the behaviour based on the single classes, here all the influencing parameters are used calibrate an overall model. Here, parameters which may change considerably over time, e.g. the overall amount of tenants in the neighbourhood, or even the amount of buildings or square meters of indoor area controlled by the systems can be taken into account from the start. This will negate the need to restart the model under changing conditions, and make the overall system more flexible.

- Multiple linear regression is a well-established statistical method. Here, a linear impact of all governing factors on the output variable is assumed. While this may be an oversimplification, it reduces the computational complexity a lot. Due to the well understood statistical theory behind this method, it is possible to judge the quality of the forecast as well.
- Artificial Neural Networks as well as
- A Support Vector Machine Regression are machine learning technologies. In both cases, generalized models are trained on existing data, and try to adapt themselves to be able to reproduce the input data. They have the advantages of being able to reproduce also highly nonlinear effects, as well as multiple outputs. This ability is bought with higher computational cost the multiple linear regressions.

While not all of the methods described above will actually be implemented in the EEPOS platform, due to the modular specifications provided in this document, the tools will remain open enough for chance, addition or improvement of the used techniques.

## 4.5 Data Storage

As a backbone for all the applications above, a robust data storage solution has to be implemented as a basis for the various analysing tools describe up until now. The data storage to be used has integrated within the EEPOS platform with a minimum amount of engineering. Therefore, the following features have to be covered by the database / data storage solution

- It has to be easy to store time series along with metadata. This will enable the data storage to incorporate the data about the system behind the measured data e.g. sensor accuracy, to be able to further improve the capabilities for error detection and performance analysis.
- The tree-like structure in which the OGEMA system organizes the components of buildings and neighbourhoods should be intrinsically supported. These is in line with the storage of meta data, as most components will only have a few sensors, but a lot of fixed parameters. Acquiring the every time through the OGEMA interfaces is quite unfeasible compared to collecting the information of every BEM once, and centrally storing the whole neighbourhood, especially with respect to the visualization.
- (Meta)Data I/O has to be possible using web services. This is needed to be able to connect to the ICT platform feasibly, and to generate the database structure out of the OGEMA data model.

Furthermore, the following features are desirable to be already incorporated

- The ability to clean data during the import and
- the ability to derive data series, e.g. performance indicators, on the run during the data import is desirable, because it distributes the computational power needed over time.

This may be used to react on the changes of KPIs or major discrepancies between forecasts and monitored values which goes along with

- the ability to send alarms base on values which should also be implemented very close to the storage solution.
- Alarming based the lack of connection prevents major data losses, and may also indicate a breakdown of sensing equipment.

# 5. INTERFACES

To connect the database, a web interface able to receive data from the OGEMA platform is needed. This also holds for the metadata, to enable the quick configuration of the database from the information model.

The monitoring tool should be able to visualize all KPIs, historical and real time data which are available by EEPOS monitoring tool data base APIs. It would help if the data point names in historical database would include some naming convention and the EEPOS historical data base API would support wild cards.

From fault detection point of view the time the historical values of outside temperature and apartment, building and neighbourhood level heating, cooling and electric energy consumption as well as real time heating, cooling and electric power in different levels is needed.

# 6. Technologies

## 6.1 Vizualisation

The visualization should work as described in the chapter “4.2 Interactive visualization for decision support”. This means that visualisation display for EEPOS should be a 3D game type view of neighbourhood with support of free navigation and item clicking and colouring items by selected KPI or measurement point values. One potential solution for this is Unity game engine [1].

Unity is a commercial cross-platform game development ecosystem (over 1 million registered developers in April 2012 [2]) including a powerful rendering engine developed by Unity Technologies. The ecosystem includes also tools to create interactive 3D content, multiplatform publishing, asset store (thousands of assets, also free ones) and a knowledge-sharing community. Supported platforms are mobile ecosystems (iOS, Android, Windows Phone 8, BlackBerry 10), desktop operating systems (Windows, OS X, Linux), game consoles (Wii U, PlayStation 3, Xbox 360), web browsers and Flash.

As mentioned Unity is not open source game engine, it is a commercial product. On the other hand the 3D visualisation is not in EEPOS core so it should not take too much time from other development work. By using Unity this can be done because the 3D model building up from existing landscape and building models is very straightforward. In addition Unity has thousands of ready-made assets in asset store like buildings, landscapes, human characters, furniture, trees, wind turbines, pipes, valves, joints, power station props like transformers and circuit-breakers and add-on components, different types of generators, turbines, air conditioning units etc.

Unity can import 3D models in FBX, OBJ, DAE (COLLADA), 3DS and DXF formats. Unity can also import propriety 3D application files from 3D Studio Max (.Max) and Blender (.Blend). Through conversion Unity can also import 3D models from Maya, Cinema4D, Modo, Lightwave, Cheetah3D, Softimage and ZBrush files (e.g. .MAX, .MB, .MA etc.). This means that most of the existing 3D CAD models of real neighbourhood related buildings and landscape can be utilised.

In other words Unity makes it possible to build easily and cost-effective manner EEPOS demonstration related neighbourhood 3D model. The model can include the draft models of energy grids by adding those 3D models from asset store if the models are not possible to obtain from neighbourhood designers. But of course at least the landscape and building models should look as realistic as possible.

In addition the same Unity game engine will be used also in EEPOS task 3.4 (End user collaboration tool). This makes it possible to use same neighbourhood 3D models and same basic implementation in both EEPOS tools.Conclusions

# 7. SUMMARY OF ACHIEVEMENTS

The main functionalities the performance monitoring and operational planning tools need to include to satisfy the use cases as well as the needs of other Tasks and work packages were identified and described. In some cases, technology choices were already reached and documented.

## 7.1 Relation to continued developments

D3.3(1) will be developed further into a technical description of the system within the next 6 months of the project and the be implemented within the demonstration sites in Germany and Finland.

# 8. ACRONYMS AND TERMS

| | |
|---|---|
| API | application programming interface |
| BEMS | building energy management |
| CAD | computer aided design |
| DDC | direct digital control |
| DHW | domestic hot water |
| HVAC | heating cooling ventilation air conditioning |
| KPI | key performance indicator |
| NEMS | neighbourhood energy management system |
| OGEMA | open gateway energy management alliance |
| RES | renewable energy source |
| VDA | visual data analyser |

# 9. REFERENCES

[1] http://unity3d.com, 3.9.2013
[2] http://www.marketwired.com/press-release/unity-reaches-one-million-registered-developers-1641486.htm, 3.9.2013