MAtchUP

D3.15: Simulation models of the building stock, energy system, transportation, urban infrastructures in Dresden - Final version

WP 3, T 3.15

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Authors: Linda Arnhold (DRE), Torsten Schwan (EASD)

MAtchUP - SCC-1-2016-2017

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Technical References

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1.0	Linda Arnhold, Torsten Schwan, Alexander Haidan	DRE, EASD, DWG	16 August 2019
1.1	Linda Arnhold	DRE	30 August 2019
2.0	Torsten Schwan, Georg Hamann, Alexander Haidan	EASD, ENSACH	08.10.2020
2.1	Torsten Schwan, Ömer Akyürek	EASD, DEM	23.10.2020
2.2	Linda Arnhold	DRE	13.11.2020

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Abbreviations and Acronyms

Acronym	Description
B(E)MS	Building (Energy) Management System
BEST	Building Energy Specification Table
CBCC	Central Building Control Centre
CDD	Cooling degree-days
CHP	Combined Heat and Power
CPT	Clean Power for Transport
CV	Coefficient of Variation
DH	District Heating
DHW	Domestic Hot Water
EASD	EA Systems GmbH Dresden
EEWärmeG	Erneuerbare Energien Wärme Gesetz
EnEG	Energieeinsparungsgesetz (Energy Saving Act)
EnEV	Energieeinsparungsverordnung (Energy Saving Ordiance)
EPBD	Energy Performance in Buildings Directive
EV	Electric Vehicle
FMI	Functional Mockup Interface
GEG	Gebäudeenergiegesetz (Building Energy Act)
GHG	Greenhouse Gas
HDD	Heating degree-days
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communications Technology
IPMVP	International Performance Measurement and Verification Protocol
KfW	Kreditinstitut für Wiederaufbau
KPI	Key Performance Indicator
LFG	Landfill Gas
M&V	Monitoring and Verification
NZEB	Nearly Zero-Energy Buildings
PV	Photovoltaic
RES	Renewable Energy Sources
R2	R-Square value
SCC	Smart Cities and Communication
SCTP	Smart City Technology Packages
SEAP	Sustainable Energy Action Plan
SUMP	Sustainable Urban Mobility Plan
TEST	Transport Energy Specifications Table
WP	Work Package

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0 Abstract

Within the scope of the MAtchUP, very ambitious demonstration will be deployed in Valencia (Spain), Dresden (Germany) and Antalya (Turkey). To coordinate the complex activities within each demo-site, three separate but parallel Work Packages (WP2, WP3 and WP4) have been established. The deliverable 3.2 “Simulation models of the building stock, energy system, transportation, urban infrastructures in Dresden-First version”, submitted in M24, that was the previous version of this deliverable, aimed to identify the need of implementation of simulation models as basis for the definition of the baseline information. This document informs about the approach of the development and implementation of baseline models and introduces the interventions that require baseline simulation.

This report is an outcome of “Task 3.2 Baseline of interventions definition, Subtask 3.2.1 Simulation models (buildings, energy systems, and city infrastructures)” of the work package 3 dedicated to Dresden demonstrator.

The objective of the subtask 3.2.1 is the development of simulations and mathematical models needed to calculate and adjust baselines; since baselines are needed to have a reference period to compare the results gotten during the monitoring period and evaluate the improvement measures implemented in Dresden interventions.

This deliverable includes the description of the methodology and tools used for develop the models, as well as the definition of those interventions that will require simulations and adjustments of its baseline. The updated D3.15 report also includes the correspondent simulations and calculations.

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1 Introduction

1.1 Purpose and target group

This deliverable provides the methodological tools to be used in MAtchUP for determining through mathematical models any data necessary for the calculation of an indicator, when such data cannot be directly measured, obtained from historical records or through well-founded assumptions. The updated report D3.15 also includes an overview of relevant simulation results.

The data obtained through simulation may be used for the calculation of any kind of indicator (either technical, social or economic) defined in deliverables D5.1, D5.2 or D5.3, at action or intervention levels.

A typical use of simulation models is the determination of the baseline of energy consumption of new buildings. In such a case, the simulation must provide the consumption of a building of the same dimensions, use, occupancy, location, operating under the same weather conditions of the real one, but built with the minimum legal requirements for energy efficiency.

This deliverable provides:

- Introduction of the approach for the development and implementation of Baseline Models for energy, mobility, ICT and NTA interventions
    - IPMVP protocol
    - Mathematical models for baseline adjustments
    - Simulation models and tools
- Description of the simulation methodology to be used in each case:
    - Tool used and characteristics
    - Model description and boundaries
    - Input data required
    - Output data obtained
    - Assumptions
    - Calibration/validation of the model
- Identification of the couples indicator-action or indicator-intervention requiring baseline adjustments for their calculation
- Description of the methodology to be used for baseline adjustments in each case:
    - Baseline period
    - Identification of factors requiring routine adjustments
    - Identification of factors requiring non-routine adjustments
    - Baseline data
    - Mathematical model obtained
- Brief description of implemented baseline models as well as a short overview of relevant results

The specific results obtained in each case will be specified and used in D3.3- “Baseline of Dresden demonstrator”.

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This deliverable provides the simulation models for the evaluation of the baseline of the areas of intervention in each LHC. These baselines will be the reference for the final technical assessment to be done in WP5.

1.2 Contribution of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Participant short name	Contributions
DRE	WP Leader. Leading definition of the actions. Is the task leader for T3.2 and will coordinate the efforts in developing the deliverable D3.15.
EASD	Will support the municipality in the definition of the intervention design. EASD will support all energy actions and is involved in monitoring activities.
DWG	Will support the municipality in the definition of the intervention design. Leader of several energy actions and will involve in monitoring activities
DEM	Energy expert of Antalya, discussed about ToC and is responsible for chapter 2.1.1
ITE	Energy expert of Valencia, discussed about ToC and is responsible for chapter 2.1.2

Table 1: Contribution of partners

1.3 Relation to other activities in the project

Deliverable/ Task	Relation to D 3.15
T 3.2	Once implemented the city diagnosis and outlined the complete description of the design of the interventions, a complete baseline describing the initial reference status of the buildings is provided. This will be the basis to the evaluation to be implemented in WP5. D 3.2 is linked with Subtask 3.2.1 “Simulation models (buildings, energy systems, city infrastructures), basis for the definition of the baseline information. D3.2 is also linked with Subtask 3.2.2 “Baseline of interventions”: Once developed the simulation models and established the design and the evaluation framework in WP5, the reference baseline to evaluate the performance is outlined and implemented.
D 3.2	First version of D3.15
T 3.3	High-Performance District and Smart Homes: This task is focused on the definition of a new concept of interventions related to the extensive retrofitting, new construction programmes and smart homes developments for Dresden. These interventions are aimed to lead to a highly energy efficient buildings that create a new concept of high performance district (Johannstadt) in Dresden.
T 5.1	“Technical evaluation framework” informs about indicators that need simulation
T 5.6	The evaluation of T 3.2 will be performed in T 5.6 Technical evaluation process

Table 2: Relation to other activities

This deliverable is linked with Task 3.2 “Baseline of interventions definition”, more specifically Subtask 3.2.1 “Simulation models (buildings, energy systems, city

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infrastructures)". The aim is to identify the need of implementation of simulation models of the building, energy systems and mobility infrastructures as basis for the definition of the baseline information. These simulation models will have enough detail to perform an appropriate evaluation and impact assessment. The outcome of Subtask 3.2.1 will be implemented in Subtask 3.2.2 "Baseline of interventions". Once developed the simulation models and established the design and evaluation framework in WP5, the reference baseline to evaluate the performance is outlined and implemented." In WP5 in T.5.1 "Technical evaluation framework" it is highly recommended to design simulations for indicators selected for technical evaluation of the smart city solutions deployed in the demonstration actions to define expected performances of them. This way, later deviations from design values can be detected. The technical evaluation framework with the indicators and their evaluation procedure is given by T5.1. The evaluation framework consists of 14 energy indicators, 22 mobility indicators and 7 ICT indicators.[1] Especially for expected energy performances of the defined systems, simulation, modelling and calculation are planned in the planning phase. It gives the opportunity to detect later deviations from design values.[2]

Regarding calculated assessments, there are different simulation methods that can be used for different purposes. For the building permit process and energy performance certificates, the assessment tries to minimise the effect of operation and use of the building with standard profiles for occupancy and internal loads. Thus, the buildings can be compared. Completely different use case is tailored energy consumption simulation, which tries to get the consumption that would occur if the building is operated under specific conditions. This approach can be particularly useful for example to set up a baseline for planning renovation actions, when actual measurements are not available.[3]

The definition of the baseline for new buildings is usually developed making use of energy analysis tools, and simulation in particular; and involves some key issues:

- Appropriateness, defining a clear and consistent baseline; based upon energy codes and standards, for instance.
- Rigor, developing the baseline to a level of detail appropriate for the measurement and verification methods and analytical tools to be used.
- Repeatability, being easily adjusted to allow performance comparisons on a broader scale.[4]

[1] D5.1 Technical evaluation procedure, p. 8

[2] D5.1, p. 36

[3] D5.1, p. 46

[4] D5.1, p. 47

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2 Approach for the Development and Implementation of Baseline Models

2.1 Models for baseline in energy interventions

The energy baseline is a reference basis for comparison of energy performance and its adequate definition is essential to evaluate the real improvement derived from an energy intervention. [5]

Sometimes, energy baselines can be directly stablished from consumption measures, without requiring any model. Nevertheless, in most cases, the effect of different variables needs to be taken into account, being necessary the use of mathematical tools to facilitate the adjustment of consumption data to environmental conditions of the evaluating periods. Moreover, other times, when critical information of the reference period does not exist (because of it is not available or the facility is new and there is no historical) it may be necessary to simulate, estimate or calculate the expected energy consumption.

At this regard, the energy baseline could be:

1 – Direct consumption records.

2 – Adjusted consumption from real energy records.

3 – Simulated/calculated consumption.

2.1.1 IPMVP protocol

MAtchUP project involves many actions and interventions under large-scale demonstration projects of innovative technologies in energy, mobility and ICT sector. In line with the objectives of the MAtchUP, performance of each action and intervention needs to be analysed with a systematic approach and framework. The determination of the performance requires both accurate measurement and replicable methodology to reliably determine actual savings created within the project activities. IPMVP (International Performance Measurement & Verification Protocol) developed by the Efficiency Valuation Organization (EVO, 2012) has been identified as one of the suitable methodological tools to be followed for this project activity (MAtchUP D5.1 Technical Evaluation Protocol).

Energy savings can be only determined by making comparison between the state before and after the implemented action. But, this comparison is not enough to determine the savings and, in most cases, will require adjustments to take into account the impacts of the implementation on different conditions (ex. change in number of occupancies due to increased living space).

[5] EnOB, ISO 50006

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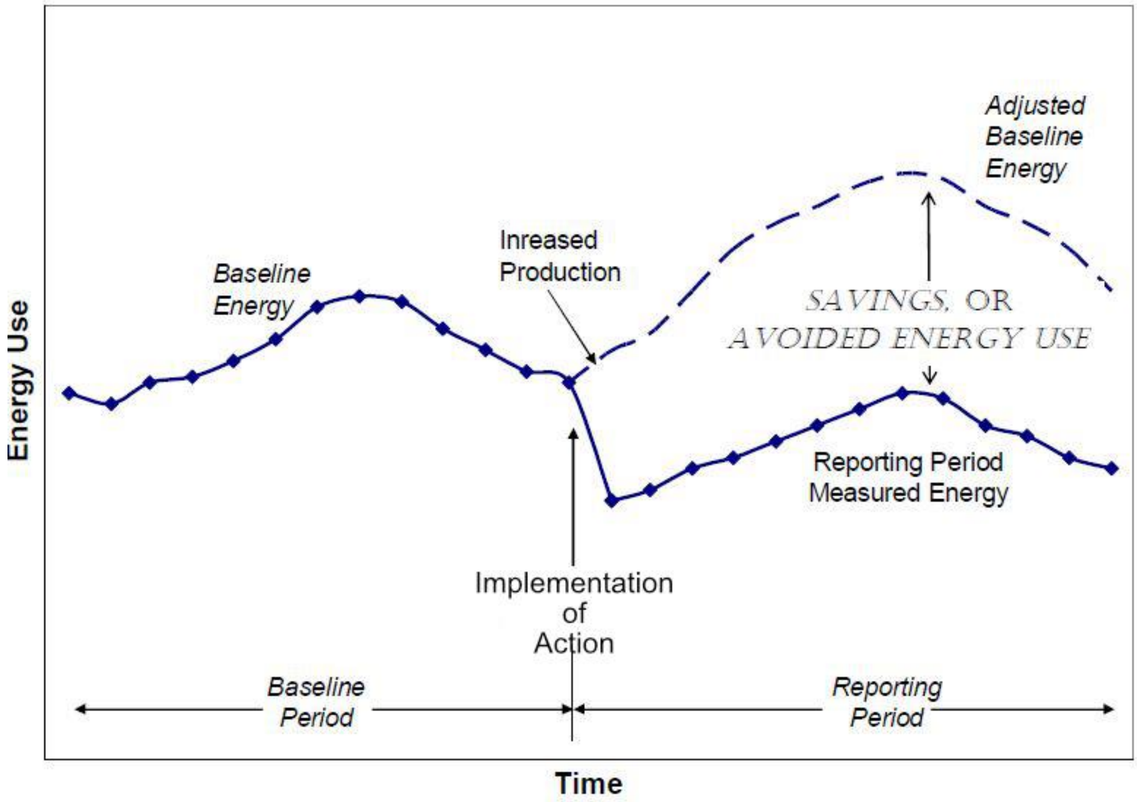

Figure 1 Example energy history[6]

Under the IPMVP Volume 1, the equation for energy savings is generalized as follows:

$$Energy\ Savings = (Baseline\ Period\ Use\ or\ Demand - Reporting\ Period\ \ Use\ or\ Demand) \pm Adjustments$$

[Equation 1]

The term baseline refers to the time period prior to the action[7] (modification or intervention such as insulating a building envelop, installation of a PV system, etc.), that provides a reference to which later performance of the action can be measured. How the baseline period use or demand is identified, depends mainly on which approach is selected for Monitoring and Verification (M&V). The approach is mostly defined, inter alia, by the availability (and/or reliability) of the data itself.

Determination of savings is a necessary part of good design of the actions itself. The basic approach common to all good savings determination involves several steps including;

[6] IPMVP 2012 Volume 1

[7] Under the IPMVP document, the term ECM (Energy Conservation Measure) is used also used to define the action and is described as "*Action or set of actions designed to improve efficiency or conserve energy or water or energy demand*".

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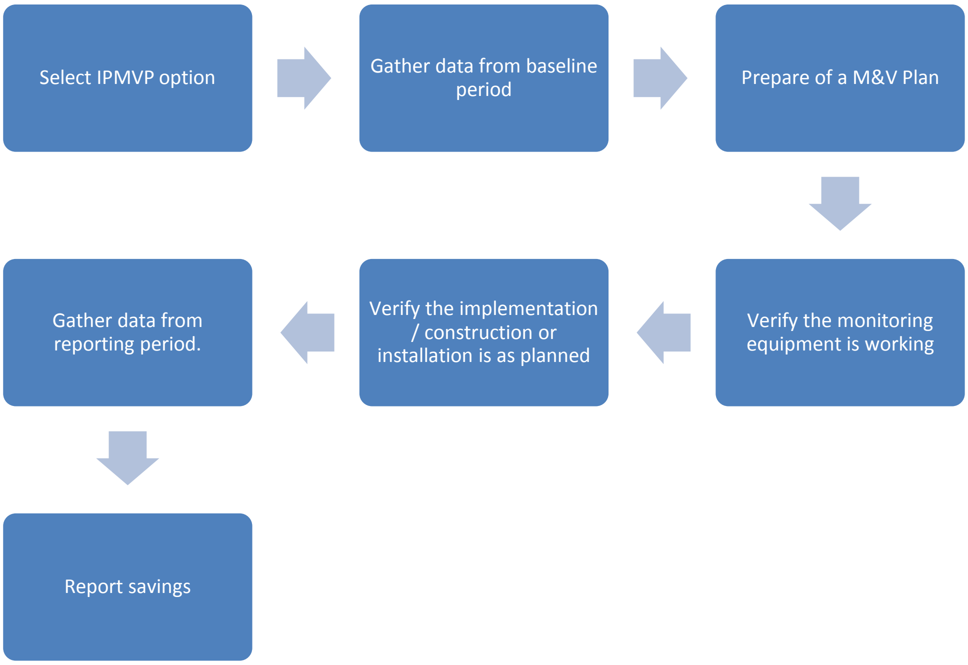

Figure 2 M&V Procedure[8]

This deliverable addresses the selection of IPMVP options as well as simulation requirements for the individual action design and baseline definition. Following the IPMVP options will be introduced.

Overview of IPMVP options

IPMVP provides four Options for determining savings; A, B, C and D. These options determine defining how to measure or quantify the parameters in [Equation 1]. Each requires data on energy consumption, demand and other parameters both for baseline period and monitoring period. They differ in a wide range such as data from invoices, dedicated monitoring devices as well as computer simulations.

The following sections provide summaries of these four options and how to select them as indicated under the IPMVP Protocol Document.

[8] IPMVP 2012 Volume 1

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Table 3: Overview of IPMVP options[9]

IPMVP Option	Definition	How Savings are Calculated	Typical Applications
A. Retrofit-isolation: Key Parameter Measurement	- Savings are determined by field measurement of the key parameter(s), which define the energy consumption and demand of the ECM's affected system(s) or the success of the project. - Measurement frequency ranges from short term to continuous, depending on the expected variation in the measured parameter and the length of the reporting period. Parameters not selected for field measurements are estimated values. Estimates can be based on historical data, manufacturer specifications or engineering judgement. - Documentation of the source or justification of the estimated value is required. The plausible saving error arising from estimation rather than measurement is evaluated.	- Engineering calculation of baseline period energy and reporting period energy from: short-term or continuous measurement of key parameters and estimated values. - Routine and non-routine adjustments as required. Key parameters measured during both baseline and reporting period.	A lighting retrofit where the power draw is the key parameter measured and secondly, lighting operating hours are estimated based on facility schedules and occupant behaviour.
B. Retrofit-isolation: All Parameter Measurement	- Savings are determined by field measurement of the energy consumption and demand and/or related independent or proxy variables of the action affected system - Measurement frequency ranges from short-term to continuous, depending on the expected variations in savings and length of reporting period.	- Short term or continuous measurements of baseline and reporting period energy, or engineering computations using measurements of proxies of energy consumption and demand. - Routines and non-routine adjustments as required.	Application of a variable speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter installed on the electrical supply to the motor, which reads the power every minute. In the baseline period this meter is in place for a week to verify constant loading. The meter is in place throughout the reporting period to measure power consumption and demand
C. Whole Facility	- Savings are determined by measuring energy consumption and demand at the whole facility utility meter level. - Continuous measurements of the entire facility's energy consumption and demand are taken throughout the reporting period.	- Analysis of the whole facility baseline and reporting period meter data. - Routine adjustments as required, using techniques such as simple comparison or regression analysis. - Non-routine adjustments as required.	Multifaceted energy management programs affecting many systems in a facility. Measure energy consumption and demand with the gas and electric utility meters for a twelve-month baseline period and throughout the reporting period.
D. Calibrated Simulation	- Savings are determined through simulation of the energy consumption and demand of the whole facility, or of a sub facility. - Simulation routines are demonstrated to adequately model actual energy performance in the facility. - This option requires considerable skill in calibrated simulation.	- Energy consumption and demand simulation, calibrated with hourly or monthly utility billing data. Energy end-use metering and metered performance data may be used in model refinement.	- Multifaceted energy management programs affecting many systems in a facility but where no meter existed in the baseline period. - Energy consumption and demand measurement, after installation of gas and electric meters, is used to calibrate simulation. - Baseline period energy, determined using the calibrated simulation, is compared to a simulation of reporting period energy consumption and demand.

[9] 2016 IPMVP Core Concept

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Among all four options available under the IPMVP Protocol, only Option D involves simulation of the energy consumption and demand. The decision-making process for Dresden interventions will be part of chapter 3.

Option D: Calibrated Simulation

Option D is used to determine either one or both of baseline period and monitoring period energy use in [Equation 1]. This option is used when there is no available data from the baseline period (ex. in new constructions). This option could be used to determine both facility level or action level performance. In case Option D is used for individual systems within the facility, energy consumption and demand of the system must be isolated from the rest of the facility by appropriate meters, which will be used for the calibration of the simulation model.

A simulation program that has been evaluated against ASHRAE Standard 140 should be preferred although other proprietary software may also be used. To ensure high accuracy the simulation results must be calibrated. The calibration is made by comparing model results to measured performance data (post-action monitoring), independent variables and static factors.

Calibration of building simulations is usually done with 12 consecutive months' monitored data over a stable operating period. These data might include operating characteristics, occupancy, weather, loads and equipment efficiency.

It should be noted that the calibration of the simulation and the calculations of savings were not within the scope of the deliverable D3.2. Details and results of the calibration process are detailed under D3.15 while calculations will be presented under D3.3.

Selection Guide

The selection of the IPMVP Option is based on several issues including the measurement boundary, project conditions, budget and expert judgement. Following the explanations of section 2.1.1 of this document, each LHC may identify which IPMVP Option to select for its interventions / indicator bundles. The following template illustrated below could be used to summarize the results under Section 3 of this deliverable.

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Table 4: IPMVP Option Template[10]

<table>
<tr><td colspan="4"><Name of the intervention>: *Describe briefly the intervention. This might be a copy paste from DoA or action card.*</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Involved Action</td><td>Savings</td><td>Affected Equipment</td><td>Expected Savings</td></tr>
<tr><td>*Provide a list of involved actions*</td><td>*Describe in brief how the measure saves energy or other resources (e.g., reduction of energy)*</td><td>*Provide a list of affected physical equipment*</td><td>*A preliminary result on expected savings*.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">IPMVP Option Selection Guidance
Follow each question starting from 1. Highlight choice of selection with a colour.</td></tr>
<tr><td colspan="2">Intervention Characteristics</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="2">[1] Need to assess Actions' performance individually?</td><td>Please go to [2]</td><td>Please go to [3]</td></tr>
<tr><td colspan="2">[2] Able to isolate Actions(s) with meter(s)?</td><td>Please go to [4]</td><td>Please go to [3]</td></tr>
<tr><td colspan="2">[3] Are expected savings greater than 10%?</td><td>Please go to [5]</td><td>OPTION D</td></tr>
<tr><td colspan="2">[4] Need full performance demonstration?</td><td>Please go to [6A]</td><td>Please go to [6B]</td></tr>
<tr><td colspan="2">[5] Need to separately assess each Action?</td><td>OPTION D</td><td>OPTION C</td></tr>
<tr><td colspan="2">[6A] Missing baseline period data?</td><td>OPTION D</td><td>OPTION B</td></tr>
<tr><td colspan="2">[6B] Missing baseline period data?</td><td>OPTION D</td><td>OPTION A</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Measurement Boundary
The selection of IPMVP Option needs to be complemented with defining the measurement boundary. A brief description or figure demonstrating the measurement boundary will be included under this section</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="2">Indicators</td><td colspan="2">*Include indicators that are relevant to the simulation scope*</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="2">Baseline Period</td><td colspan="2">*This is the time period over which the facility or system baseline conditions are assessed and documented. This baseline period is often a year but can be any period depending on the specific needs.*</td></tr>
</table>

[10] cf. 2016 IPMVP Core Concept

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2.1.2 Mathematical models for baseline adjustments

Taking into account the typology of the energy interventions developed in the project, where several energy conservation measures need to be evaluated at building/facility level, the more common IPMVP options used to define baselines and estimate energy savings are options C and D.

Option C is oriented to assess energy performance of the total facility, analysing all the direct and indirect effects derived from the implementation of one or several improvements, being the most used for buildings when there is available data of both, reference and demonstrative period. When this information does not exist, simulations models need to be applied through option D, as the following diagram shows.

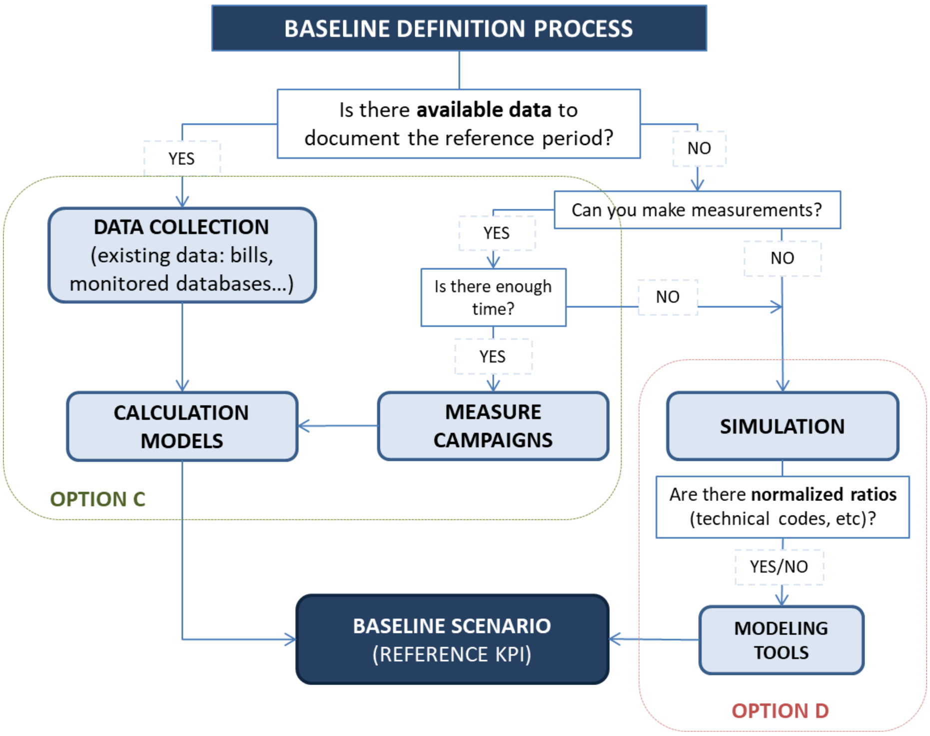

Figure 3: Baseline definition process

Application

According to IPMVP protocol, alternative C is best applied when: (1) energy performance of the whole facility will be assessed analysing savings on global consumption, (2) several improvement measures want to be analysed in the same facility, (3) individual performance is difficult to separately measure, being several cross-effects to consider, (4) a single action affects some equipment of one facility, (5) savings are larger compared to the variance in the baseline and reporting period data (>10%) and/or (6) other options are more complex and expensive.

In this regard, the project interventions combine different kind of measures oriented to reduce energy demand of the building, improve the energy efficiency and increase the use of renewable resources, being not easy to clearly identify the isolated contribution of each improvement to the global energy, socio-economic and environmental impact.

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Required data and calculations

To estimate energy savings through option C, routine and non-routine adjustment are needed to consider the influence of environmental variables in the variation of energy consumption between the comparison periods. At this respect, identify the correct independent variables is essential to develop valid mathematical models, as well as having controlled the facility changes that will require non-routine adjustments.

In this option, the energy data is usually obtained from utility meters, whole-facility meters, or sub-meters, and complete years are needed to determine a correct baseline.

MAtchUP's interventions, reference period values will be gotten when possible from historical monitored data and/or energy bills, while demonstrative data will be gotten from whole-facility meters and sub-meters installed in specific actions of the project.

Influence factors will be either monitored (ambient temperature) or collected via questionnaires.

2.1.2.1 Routine and non-routine adjustments

As explained previously, IPMVP propose calculating energy savings comparing energy consumption before and after applying energy efficiency measures, following the general M&V equation. Nevertheless, baseline energy registered during the reference period cannot be directly compared to measured energy during the reporting period since energy consumption do not happen under the same conditions necessarily. In consequence, adjustments are needed in order to make metered energy directly comparable to baseline energy. In this regard, two types of adjustments are presented, following its nature:

- Routine adjustments, included in order to consider the impact of factors directly influencing energy consumptions, and which are expected to vary following a specified routine.
- Non-routine adjustments, that integrate in the equation the impact of factors also influencing energy consumption, but not expected to change routinely, thus related to occasional and sporadic changes, but never following an identifiable pattern. The current CoViD-19 confinements require adjustments which are typical examples of this type.

An example of M&V process for evaluating energy savings in a typical household is presented in order to illustrate these concepts. There are many possible non-routine adjustments in that case; change of appliances, birth of a new member in the family or absences for trips or during vacation periods are some of them. All this factors should be considered in the model if they are proved to really influence household energy consumption. Nevertheless, some of them like, for example, absences during holidays, could be included as routine adjustments if they are repeated every year during the same dates, thus creating a periodicity of the factor. On the other hand, the most typical routine adjustments for the presented case involve considering the impact of weather conditions, which usually follows some clear trends. In consequence, variables like temperature or even humidity could be integrated in the model so that seasonality

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of the weather is considered, resulting in a variation in cooling and heating consumption.

2.1.2.2 Independent variables

When a relationship between two or more variables is identified, the definition of a simple model involves traducing this relationship into a mathematical equation correlating these variables. In general, a representative example of correlation equation is the multiple linear regressions, which can be described as follows:

$$y = \beta_0 + \beta_1 * x_1 + \cdots + \beta_n * x_n + e$$

In that equation y is known as dependent variable because it considers the measured variable whose values will be studied, and that is intended to be optimized in some cases either to their minimum or maximum possible value. On the other hand, the variables represented as x_n represent the impact of factors affecting the value of the dependent variable and, in consequence, are known as independent variables. Consequently, their value is measured in order to consider their impact on the dependent variable.

In general, some commonly used independent variables in energy consumption regression analysis are:

- Heating degree-days (HDD)
- Cooling degree-days (CDD)
- Number of occupants
- Units produced in a production process
- Ambient dry-bulb temperature

In the example of the household energy consumption model previously described, the dependent variable would be the energy consumption calculated every period defined, for example every month. The independent variables (not all, but the most important ones) would be the exterior temperature and the number of inhabitants each month. Nevertheless, in that case, the impact of the temperature only quantifies the correlation between energy consumption, mainly due to heating and/or cooling systems, and exterior conditions, without considering the impact of user's behaviour. In that sense, an alternative pair of variables such as the Cooling degree-days (CDD) and the Heating degree-days (HDD), which compare the difference between a reference temperature for cooling and heating equipment, can be introduced.

2.1.2.3 Regression techniques

As explained previously, regression techniques serve to verify if different variables have a consistent relationship between them, thanks to the regression analysis. If this relationship is verified, then the regression model selected to make the analysis serve to define how the dependent variable will behave under the influence on the independent variables. The process to follow involves:

1) Identify all independent variables having real impact on energy consumption.

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2) Collect and process data for all variables (dependent and independent) in order to get values for the same number of observations and periods of time, assuring its consistency. During this period, the existence of non-routine events affecting the dependent variable shall be also registered, in order to discard or adjust the corresponding values of the dependent variable accordingly.

3) Select the model and apply it to the collected data

When selecting the regression model, different regression techniques can be chosen, each one serving for different purposes, but the most important ones are those classified as *Linear regression models,* that assume a linear relationship between dependent and independent variables. It can be simple linear regression (a single independent variable) or multiple linear regression (more than one independent variable), and the linear regression equation has already been presented above.

Nevertheless, in some cases systems are dependent on a variable but only above and/or below a specific value. In that sense, simple regression change point models can be described in the same way than simple regression techniques but considering the impact of these changes. A representative example would be the case of certain cooling systems whose energy consumption present linear variations with outdoors temperature up to a certain value below which cooling is not needed.

Other cases may require using non-linear regression equations, whose general equation can be described as follows:

$$y = f(x, \theta) + \varepsilon$$

Where f is a non-linear function base on some unknown parameters θ. A typical example would be the polynomial regression;

$$y = a * x^2 + b * x + c$$

Where a, b and c represent the unknown parameters θ

4) Validate the model using adequate statistical indicators.

Finally, estimation models should be validated using statistical indicators in order to determine if baseline consumption equation is appropriate. Some of the most common ones are:

- R^2
- P-value
- T-statistic
- Net determination bias
- Coefficient of Variation (CV)

These indicators serve to validate the model and describe how its equation fits to real data, each of one providing different measures that must be properly understood. For example, the R-Square value (R^2) measure squares of the differences between estimated and real values, and the final ratio oscillates between 0 (no correlation) and 1 (excellent correlation). There is no general consensus on which should be the threshold to reach in order to validate the model, but commonly used value is 0.75.

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However, when there are two or more independent variables, the R-Square value must be corrected in order to consider the impact of adding more variables to the model.

The main advantages of using regression are its flexibility and the possibilities of extrapolating short-term measurements in order to calculate annual energy. Uncertainty can also be calculated, which allows to assess how accurate the model is, and if estimated savings are trustable or not.

Following the presented example of household consumption modelling, if a multiple linear regression model is selected, the corresponding equation would be the following:

$$y_m = \beta_0 + \beta_1 * x_{1,m} + \beta_2 * x_{2,m}$$

Where y_m represents the monthly energy total consumption, $x_{1,m}$ represents the heating degree-days for each month m considered, and $x_{2,m}$ represents the cooling degree-days, while the error term has not been considered. If the model is validated, this equation would serve to calculate adjusted energy consumption following external conditions and the set-points of cooling and heating equipment. In addition, it would be possible to predict energy consumption assuming future weather conditions. In any case, the linear multiple regression model is obtained from a sample of real data including pair of values of energy consumption, HDD and CDD. The results of this model taking fictitious energy consumption data for a household located in the south of Spain would be the following when represented on a graph:

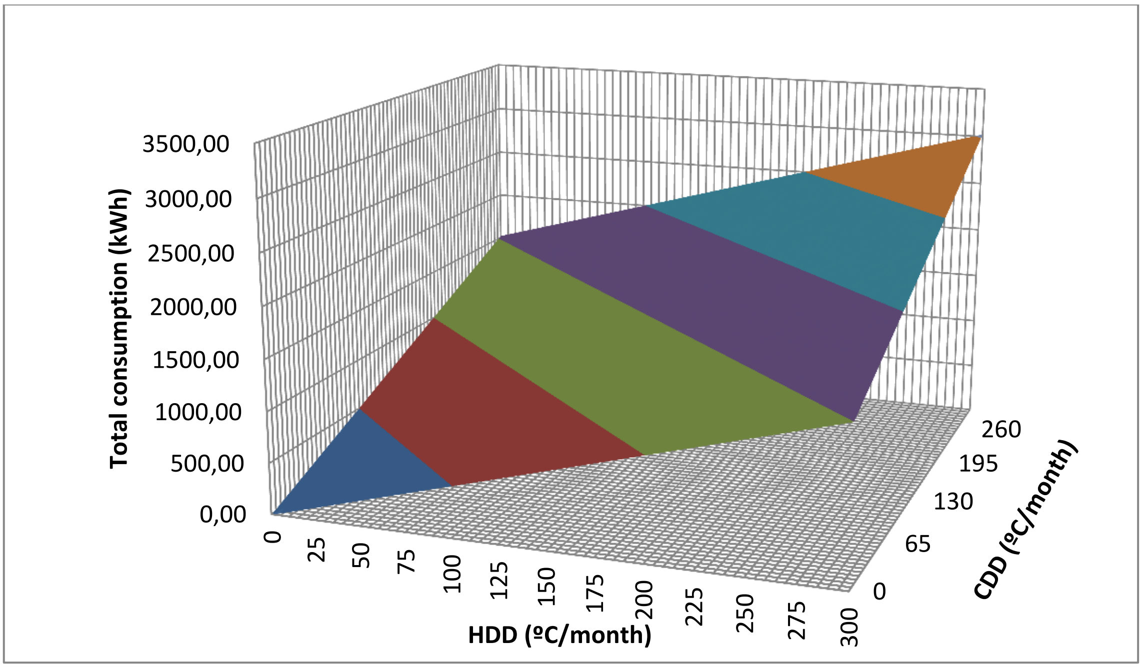

Figure 4: Linear model of monthly energy consumption (example)

2.1.3 Simulation models and tools

As already described in chapter 2.1.1 it is resulted that in several cases there need to be a simulated calibration for the interventions, which has also been defined in Deliverable 5.1 “Technical evaluation procedure “. This subchapter aims to describe

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the simulation methodology to be used where models for baseline in energy interventions are necessary. It is necessary as it is the option D calibrated simulation, which has been defined in 2.1.1.

For each case, a description of the simulation methodology needs to be done and can be implemented in the already given and introduced template of 2.1.1. The description involves the following information:

- Tool set and its characteristics
- Model description and boundaries
- Input data required
- Output data obtained
- Assumptions

Tool set and characteristics

There are several tools that can be used to implement simulation methodologies. The MAtchUP lighthouse cities are free to decide which tool they prefer. Within the column “tool set and characteristics” the responsible partner needs to describe the tool and its characteristics.

These tools must be able to accurately simulate the building performance as well as energy supply system and corresponding energy management behaviour with an hourly or less temporal resolution.

Simulation tool sets and characteristics in Dresden

In Dresden, the linked third party EA Systems GmbH Dresden, which is mainly in charge with the simulation models of most of the interventions / actions, uses the versatile, non-causal, multi-physical, Modelica™-based simulation environment SimulationX and the included Green City simulation library which provides a wide range energy supply and storage systems models as well as an easy-to-use and valid platform for building performance simulation. For occupants’ behaviour simulation this tool set will be coupled via Functional Mockup Interface (FMI) to common multi-agent-simulation tools (e.g. Netlogo).

Besides building and energy system models including energy management as well as co-simulation of probabilistic occupancy models, charging infrastructures as well as electric vehicle fleets are integral part of this simulation environment. It additionally considers security of supply as well as profitableness requirements and regards local building regulations.

All simulation models are furthermore designed to be easily scaled-up from single-building to city-district level. Thus, enables EASD to calculate coupled electricity, heating and cooling grids for city districts as well as the interactions between energy sources, storage facilities, lines and consumers in a large-scale manner. The models therefore, help to realize a MAtchUP core concept regarding the up-scaling of single optimization measures to a whole city district area.

Model description and boundaries

Most important for the deliverable D3.15 is the description of the implemented models and corresponding boundaries that occur with the use of the simulation.

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As the level of calibration is the most important factor for us, it is necessary to ensure that the simulation model should reasonably predict the load shape and energy use of the facility or system.

Because of measurement boundaries of every model, there also need to be a description of the existing ones including their effects.

In Dresden, there are at least 4 energy interventions planned which could use simulation models during the design, baseline definition as well as the monitoring phase. Those models address both buildings as well as city-district levels. Further information about the simulation models can be found within chapter 4.

Besides the analysis and evaluation of single interventions, in MAtchUP all energy interventions need to be scaled-up to be total city-quarter size. Therefore, EASD's simulation approaches will be used to implement a city district model on data base level. Therefore, a huge number of anonymised energy consumption data is used to represent total energy consumption in the MAtchUP city quarter Johannstadt. This model will then be added with the results of the optimization measures of all single energy interventions. Thus helps to evaluate both influences of single interventions on total energy consumption as well as a prediction the total effect of all measures in combination. Within district model, connected interventions from other sectors (e.g. implementation of an e-Mobility charging infrastructure) can be added and evaluated, too. This district model will obviously be less accurate as all single building models. However, the expected results will be accurate enough to compare different measures in the MAtchUP context.

Input data required

The calibration of the models shall be done by collecting the necessary data related to the building characteristics and occupancy. Most likely the data that will be required are operating characteristics, occupancy, weather, loads and equipment efficiency. For different interventions other different input data for the simulation model are required. Within the identification of the simulation models, there will be a listing and definition of input data identified to comprehend the outcome of the simulation.

The developed and required models for energy interventions in Dresden mainly refer to different types of buildings as well as occupancy. These different models require most likely the same set of input parameters, if available:

- Building construction plans; definition of refurbishment measures; building age, characteristic and occupancy type
- Available measurement data of at least one recent year (existing buildings) regarding heat, natural gas, electricity, cold, etc. consumption
- Description and design plans of power supply and HVAC system including brief overview of control schematic
- District plans (for district models) and included grid design (electricity, heat, natural gas, cold, infrastructure, etc.)
- Datasheets of technical systems (manufacturer data) including relevant performance data

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Output data obtained

The obtained output data of the simulation are necessary to identify the baseline of interventions definition. A list of the data will be included for every intervention.

The collected data can include, for instance, the use of sub-metering by placement of monitoring equipment to collect data from the building automation system when available. These data can be useful, for instance for defining operational schedules (e.g. lighting, ventilation), and calibrating the model.[11]

The energy intervention models in Dresden have been designed to provide feasible data and information about the implemented modernization measures for those aspects with missing or non-applicable or at least not available measurement data.

Normally, building performance models as well as HVAC system, power supply and grid models can provide following general list of outputs:

- Gains and consumption of different forms of energy (e.g. local renewables, heating, cooling and power supply, etc.)
- Evaluation of dimensions and feasibility of technical system components (e.g. photovoltaic or battery system size)
- Analyses of total (or individual) costs (operation and investment) and total profitableness
- Evaluation of different strategies for storage control and energy management
- Evaluation and analyses of different performance optimization measures

In MAtchUP, the implemented energy interventions models provide different specific outputs regarding the individual actions / interventions that will be identified in chapter 3.

Assumptions

With every identified intervention of option D that comes along with a simulation of the indicator bundle, several assumptions are related. A description of them can help to identify boundaries and predictions.

Option Template

With the description of the further information about the simulation tools the template given by IPMVP is now enlarged with five more rows:

Table 5: Extended IPMVP Option Template

<table>
<tr><td colspan="4"><Name of the intervention>: *Describe briefly the intervention. This might be a copy paste from DoA or action card.*</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Involved Action</td><td>Savings</td><td>Affected Equipment</td><td>Expected Savings</td></tr>
<tr><td>*Provide a list of involved actions*</td><td>*Describe in brief how the measure saves energy or other resources (e.g.,*</td><td>*Provide a list of affected physical equipment*</td><td>*A preliminary result on expected savings.*</td></tr>
</table>

[11] cf. D5.1, p.50

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	reduction of energy)		
IPMVP Option Selection Guidance *Follow each question starting from 1. Highlight choice of selection with a colour.*			
Intervention Characteristics		YES	NO
[1] Need to assess Actions' performance individually?		Please go to [2]	Please go to [3]
[2] Able to isolate Actions(s) with meter(s)?		Please go to [4]	Please go to [3]
[3] Are expected savings greater than 10%?		Please go to [5]	OPTION D
[4] Need full performance demonstration?		Please go to [6A]	Please go to [6B]
[5] Need to separately assess each Action?		OPTION D	Please go to [6C]
[6A] Missing baseline period data?		OPTION D	OPTION B
[6B] Missing baseline period data?		OPTION D	OPTION A
[6C] Missing baseline period data		OPTION D	OPTION C
Measurement Boundary *The selection of IPMVP Option needs to be complemented with defining the measurement boundary. A brief description or figure demonstrating the measurement boundary will be included under this section*			
Indicators		*Include indicators that are relevant to the simulation scope*	
Baseline Period		*This is the time period over which the facility or system baseline conditions are assessed and documented. This baseline period is often a year but can be any period depending on the specific needs.*	
Simulation models and tools *The following columns need to be filled with information about the simulation models and tools within the intervention*			
Tool set and characteristics		*Name simulation tool and describe its characteristics*	
Model description and boundaries		*Describe model and boundaries that may occur*	
Input data required		*List input data that is required for the simulation*	
Output data obtained		*List output data that is obtained after the simulation*	
Assumptions		*Identification and description of given assumptions of/for the simulation*	

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German Relevant Building Law and Legislation

According to the EU Directive "Energy Performance of Buildings" [EPBD 2010], new residential buildings constructed after 31 December 2020 must be designed as low-energy buildings. The EU Directive defines a "low-energy building" as "house with very high (…) overall energy efficiency". The almost zero or very low energy demand should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced at or near the site. [12] In Germany, the introduction of Nearly Zero-Energy Buildings (NZEB) has already been addressed by the German Energy Savings Act of 2013 [EnEG 2013]. The EnEG provides a further amendment of the Energy Saving Ordinance (EnEV) until 2019 (which comes into force in January 2021). However, an official definition of the NZEB standard is not contained in the EnEG and has not yet been published by the Federal Government. Even though there is still no legally regulated definition, the "KfW Efficiency House 40" can be seen as a suitable standard to represent the lowest energy house for residential buildings in Germany demanded by the EU, since buildings of this or similar quality have already been the subject of KfW funding for more than 10 years.

Two sets of regulations currently apply to the energy requirements for buildings in Germany. The Energy Saving Act (EnEG) and the Energy Saving Ordinance (EnEV) describe the energetic requirements of the building envelope and the energy supply system. The Renewable Energies Heat Act (EEWärmeG) stipulates that renewable energies for heating purposes must be used to a specified extent in new buildings and existing public-sector buildings. The coexistence of these regulations has led to problems in application and enforcement, especially as the two regulations were not fully coordinated. In 2019, a new draft act has been implemented on Energy Saving and the Use of Renewable Energies for heating and cooling in buildings that combines EnEG, EnEV and EEWärmeG, which is called Building Energy Act (GEG).

Table 6: Regulations for buildings in Germany

Residential Buildings	Scale (National, Regional, Local, etc…)	Building requirements
New Buildings	National (EnEV 2016) [13]	All new buildings must be designed as low-energy buildings: the annual primary energy demand for heating, hot water, ventilation and cooling does not exceed 0,75 times the annual primary energy demand value in relation to the useful building area of a reference building having the same geometry, useful building area and orientation as the building to be constructed

[12] European Commission (2019): online

[13] EnEV-online (2019a): online

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Existing Buildings	National (EnEV 2014)[14]	• Equipping central heating system with central, automatic device to reduce and shut off heat supply 6 to switch electrical drivers on and of • Equipping heating systems with water as ah heat transfer medium with room-by-room control • Heating systems with water as heat transfer medium must be equipped with automatic room-by-room control • Insulation of uninsulated, accessible pips for hot water and thermal heat and fittings if the pipes or fittings run in unheated rooms (such as cellars) • Exchange of existing boilers if all statements apply: boiler uses liquid fuel (heating oil, natural gas; boiler was installed before 1 October 1978; its rated output is a minimum of 4 kW to a maximum of 400 kW • Boiler is not one of the EnEV exceptions • Under certain conditions, insulation of the top floor above heated rooms

2.2 Models for baseline in mobility interventions

Within the finding process, we noticed that there is no need of simulation for baseline definition in mobility interventions necessary. Therefore nor mathematical models for baseline adjustments neither simulation models and tools are needed.

2.3 Models for baseline in ICT interventions

Within the finding process, we noticed that there is no need of simulation for baseline definition in ICT interventions necessary. Therefore nor mathematical models for baseline adjustments neither simulation models and tools are needed.

2.4 Models for baselines in non-technical interventions

Within the finding process, we noticed that there is no need of simulation for baseline definition in non-technical interventions necessary. Therefore nor mathematical models for baseline adjustments neither simulation models and tools are needed.

[14] EnEV-online (2019b): online

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3 Interventions / Indicators requiring baseline simulation or adjustment

In Dresden, several energy interventions have been identified as option D regarding IPMVP. These interventions need simulation models to be evaluated at building/facility level. An introduction of the actions of the interventions and information about the identified IPMVP options will be given.

3.1 Intervention 1 - New building constriction (District future House)

This intervention includes 5 actions. Suitable simulation models are used or can be used during intervention design for the individual action's purposes. However, new buildings cannot provide any energy consumption data before the intervention at all one suitable baseline model is required at least.

The following technical indicators (Task 5.1) are intended to be calculated for content-related Actions as Intervention 1.

Table 7: Option Template for Intervention 1

Intervention 1 New building constriction (District future House)			
Involved Action	Savings	Affected Equipment	Expected Savings
A9, A41, A42, A43, A53	*expected own consumption rate of PV of up to 68%, risen by the use of battery up to 76%; expected degree of self-sufficiency up to 40%; large amounts of CO2 emissions and fine dust by using the district heating network heat generated during the production of electricity (combined heat and power)*	*PV system 9.92 kWh; high-performance modules with 320 Wp each; power generation 9,200kWh p.a.; Varta storage system with nominal capacity of 3,3 kWh, Smart Meter/ measurement equipment, energy management systems (Smart Home Real Estate Industry ("RIECON" system)*	*Tenants energy model "MeinMieterstrom" will be offered with a price line 0.5 ct/kWh below the basic supply tariff of "Dresdner.Strom."; savings of about 11 tons/year or 79% of CO2-emissions by district heated building, compared to natural gas based heating system*
IPMVP Option Selection Guidance *Follow each question starting from 1. Highlight choice of selection with a colour.*			
Intervention Characteristics		YES	NO
[1] Need to assess Actions' performance individually?		YES	---
[2] Able to isolate Actions(s) with meter(s)?		YES	---
[3] Are expected savings greater than 10%?		---	---

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[4] Need full performance demonstration?	YES	---
[5] Need to separately assess each Action?	---	---
[6A] Missing baseline period data?	OPTION D	---
[6B] Missing baseline period data?	---	---

Measurement Boundary

As data for baseline is not available (new building), several boundary conditions are needed to describe the entire building:

1. According to the German legislation (EnEV), calculations will base on an “EnEV reference building” which is however heated via district heating grid instead of heating oil.

2. Baseline-Data are taken from the EnEV reference model: National regulations for new building (EnEV 2016 for New Buildings after 2016)

3. Power supply via local grid, no local renewable energy production (neither solar heat nor photovoltaic).

4. Usage of living space as reference base for the floor area.

Following indicators are accordingly analysed:

*E1: Describes the primary energy consumption that is supplied to the system by natural energy sources. Measurement relevant relations consist of the size of the system and the considered time interval. The reporting in the SCIS consists of three phases: refurbished buildings (baseline, design, monitoring), new buildings (reference energy consumption), similar buildings (base of simulations). Unit.: kWh/(m²*year*

E3: Percentage increase in the share of local renewable energy due to the intervention. It is separately determined for thermal (heating or cooling) energy and electricity. Unit.: kWh/month

E4: CO2 emissions can therefore be considered a useful indicator for assessing the impact of urban development in climate changes. Unit.: Change in t/year

E5: The maximum consumption of a building or building groups is analysed and then forecast by an aggregator implementation. Measurement dependencies exist here in the time interval of the measurements. Unit.: %, Interval: before and after intervention

E8: Measured time in hours in case of electricity interruption. Unit.: %, Interval: Monthly or according to the demo period

E11: Monetary savings from the functionality over a period of time / hours in the period of time Unit.: €/h or €/year, Interval: Monthly or according to the demo period

Indicators	- E1. Reduction in primary energy demand and consumption - E3. Increase in local renewable energy generation - E4. CO2 emission reduction - E5 Peak load reduction - E8. Storage capacity factor - E11. Benefit of storage use
Baseline Period	*Baseline M24* *M31*

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	M37 *M43* *M49* *M55* *M60*
Simulation models and tools	
Tool set and characteristics	*In Dresden, the third party EA Systems GmbH Dresden, which is mainly in charge with the simulation models of most of the interventions / actions, uses the versatile, non-causal, multi-physical, Modelica™-based simulation environment SimulationX and the included Green City simulation library which provides a wide range of energy supply and storage systems models as well as an easy-to-use and valid platform for building performance simulation. For occupants' behaviour simulation this tool set will be coupled via Functional Mockup Interface (FMI) to common multi-agent-simulation tools (e.g. Netlogo).* *Additionally, standard DIN 18599 certified modelling tools (e.g. Hottgenroth Energieberater 18599) were used to describe corresponding EnEV reference building characteristics.* *Besides building and energy system models including energy management as well as co-simulation of probabilistic occupancy models, charging infrastructures as well as electric vehicle fleets are integral part of this simulation environment. It additionally considers security of supply as well as profitableness requirements and regards local building regulations.* *All simulation models are furthermore designed to be easily scaled-up from single-building to city-district level and size. Thus, enables EASD to calculate coupled electricity, heating and cooling grids for city districts as well as the interactions between energy sources, storage facilities, lines and consumers in a large-scale manner. The models therefore help to realize a MAtchUP core concept regarding the up-scaling of single optimization measures to a whole city district area.*
Model description and boundaries	*The District Future House model which also describes latest HVAC system design (e.g. controlled ventilation of living spaces) has an additional task within MAtchUP. Besides analyses of technical and economical KPIs (e.g. to evaluate tenant power supply concept), it has been developed to provide the baseline data for the monitoring process. Therefore, the model uses general German law related building envelope and energy system data.* *The model results are also the base of further up-scaled district models describing the behaviour of newly-built buildings with latest HVAC system technology. However, it is obvious that those simulation results cannot be calibrated with existing measurements, the model has only be compared to same-size and type buildings, thus might result in higher deviations between simulation results and measurements in comparison with A1 and A2 models but should be still in an adequate range.*
Input data required	*The developed and required models for energy interventions in Dresden mainly refer to different types of buildings as well as occupancy. These different models require most likely the same set of input parameters, if available:* • *Building construction plans; building age, characteristic and occupancy type* • *Description and design plans of power supply and HVAC*

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	system including brief overview of control schematic • *District plans (for district models) and included grid design (electricity, heat, natural gas, cold, infrastructure, etc.)* • *Datasheets of technical systems (manufacturer data) including relevant performance data*
Output data obtained	*Normally, building performance models as well as HVAC system, power supply and grid models can provide following general list of outputs:* • *Gains and consumption of different forms of energy (e.g. local renewables, heating, cooling and power supply, etc.)* • *Evaluation of dimensions and feasibility of technical system components (e.g. photovoltaic or battery system size)* • *Analyses of total (or individual) costs (operation and investment) and total profitableness* • *Evaluation of different strategies for storage control and energy management* • *Evaluation and analyses of different performance optimization measures* *Intervention 1 – District Future House / newly-built building smaller multi-family residential building:* • *Evaluation of PV system and battery size regarding tenant electricity concept* • *Total energy and peak power demand of building before and after interventions* • *Share of building's self-consumption rate (tenants, general building operation)* • *Evaluation of implemented battery storage control strategy; profitableness of storage integration* • *Economic evaluation of different tenant electricity concepts* • *Baseline for KPI evaluation*
Assumptions	*For intervention 1, simulation models are mainly used to identify a baseline for the comparison of the implemented add-on high-energy-efficiency measures with required basic energy-efficiency ratios of new built buildings in Germany.* *The implemented baseline model therefore bases on German DIN 18599 standard to represent building's thermal energy consumption as well as common occupancy statistics. Furthermore, material data as well as the baseline definition of German EnEV 2016 legislation provides add-on assumption for the baseline model development.*

Action 09: District Future House

District Future House will be a housing cooperative with 2,287 m² (living space 1,191 m²) distributed in 14 dwellings. Its thermal demand will be covered through the DH while up to 40 % of the electric one by the PV installed in the building (Action 41). Several "individual" technologies will be tested together in this new building. The Smart Meter/ Smart Meter Gateway-system (Action 43) will provide opportunities which need to be applied under real conditions to produce several benefits for the tenants.

The interaction between the classical supply concepts (district heating station), the technical building equipment (heating system, central domestic hot water preparation) and the additional technologies will be tested both technically and communicatively, and fully monitored among all the building. In addition to the energy-related part

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(consumption "house" and "housing" over all media, tenant electricity model, load-variable tariffs, ...), other services and housing management should also be possible via the energy management system. Data transmission within the property and "outwards" (both for measuring point operation and for sub-meter) is to be carried out through the iMSys system as a modern communication infrastructure. Relating the energy management of this future house, it will be a smart building, which is managed by hierarchic management systems – one for the entire building and one for each single flat. The following functions are more possibilities need to be finalized during the project.

Dwelling Energy Manager, will be the future central information and communication platform for tenants. It will provide information on demand of electricity, heat, water. The tenant will be able to choose ventilation, temperatures and times at this central service unit of for his apartment. There are different sensors for temperature and actors (floor heating valves). All the data are submitted to the Building Management and participate in optimizing the heat consumption. Information of the property management, weather forecast, contact data of housekeeper and others are given on the home display too. Also the consumption of the flat can be monitored by the tenant via his display.

Building Energy Manager: This collects and achieves all relevant data from the Dwelling Energy Manager. It regulates the central district heat feed-in and the central building ventilation.

The District Future House model which also describes latest HVAC system design (e.g. controlled ventilation of living spaces) has an additional task within MAtchUP. Besides analyses of technical and economical KPIs (e.g. to evaluate tenant power supply concept), it has been developed to provide the baseline data for the monitoring process. Therefore, the model uses general German law related building envelope and energy system data.

The model results are also the base of further up-scaled district models describing the behavior of newly-built buildings with latest HVAC system technology. However, it is obvious that those simulation results cannot be calibrated with existing measurements, the model has only be compared to same-size and type buildings, thus might result in higher deviations between simulation results and measurements in comparison with A1 and A2 models but should be still in an adequate range.

Action 41: 9.92 kWp photovoltaic system in District Future House

In the District Future House that will be built inside the project (Action 9), PV energy will be produced and stored in the building itself. With a nominal power of 9.92 kWp and a generation of 920 kWh/kWp the solar panels installed will be able to provide the 40% of the energy demanded by the building. An own consumption rate of appr. 68% will be achieved and risen by the use of battery up to 76%. For the installation of the PV panels, two different concepts will be taken into consideration, aligning south and aligning east-west. Both concepts differ in the installable capacity and the time of production, so the decision will be made by taking into account statics of the roof, the costs and the benefit (maximum use of the RES in the building).

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No mathematical model needed as measurements should be available via monitoring data and a baseline is not necessary, as the output is 0 kWh of PV power. A Simulation model can only be used to optimize the control strategy regarding self-consumption ratio, if necessary.

Action 42: Power storage in District Future House

For a better management of the PV power generated in the District Future House (Action 41), a Varta-Energy Storage system with a nominal capacity of 3.3 kWh will be installed (Action 9). The energy from this storage will be used for covering the building demand, but the possibility to be used for Electrical Vehicle charging will exist in the future.

No model is required for baseline definition as 0 kWh of battery capacity is available. Control strategy optimization (especially eVehicle charging with battery power) might require suitable models.

Action 43: Smart-meter-gateway in District Future House

In the District Future House (Action 9) one of the main project targets is to implement a joint metering concept for all media in the building – such as electricity, natural gas, (district) heat and (hot and cold) water. The energy management systems provide information to the tenant and the entire building. A reduction of the energy demand, hence resource-saving by a control-system is going to be enabled by active involvement of the tenants. The expectations in the — District Future House-project are to find a scalable and useful solution for other apartment buildings in the city of Dresden.

All the flats are going to be integrated into a complete metering and management system by submeters. The projected configuration of electric submeters includes different shared electricity objects such as light, ventilation, circulation pumps, electronic information tables, elevators, smoke evacuator etc. Therefore, submetering systems are needed for heat cost allocation (for heating and domestic hot water) and will be additionally used for the management of drinking cold water. The entire building will be prepared for a future secure and reliable communications infrastructure. Additional equipment with empty conduits is designed for uncertain future communications requirements (wide-area-network – WAN) and future services. This smart-meter-gateway will provide data to Dresden Urban Platform.

Simulation models can show the influences of smart metering and control with baseline models including default (not smart) control strategies.

Action 53: Connection of new buildings to the DH

To increase the smart interaction and smart management of the DH, the smart new building constructed inside the MAtchUP project, the District Future House (Action 9) will be connected to it. With the actual existing infrastructure, new users will be beneficed by the central energy management, increasing efficiency and decreasing costs.

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A simulation model is required to represent the baseline if building's energy consumption is supplied with heat by conventional heat supply system (c.f. EnEV 2016 heating oil fired condensing boiler).

3.2 Intervention 2 - Retrofitting of private residential buildings

This intervention includes four actions. Simulation models are mainly required during the design phase of single actions as well as the evaluation of different control and implementation strategies. Some actions with obviously uneconomical output are only considered with simulation models. Furthermore, those models are used to scale-up intervention results to the whole district level.

Table 8: Option Template for Intervention 2

Intervention 2 - Retrofitting of private residential buildings			
Involved Action	Savings	Affected Equipment	Expected Savings
A1, A4, A5, A18	*Reduction of CO2 emissions, especially by integration of electromobility in conjunction with PV system*	*Smart Energy systems with intelligent linkage of PVs and storage; , Smart Meter/ measuring equipment, PV system with 33 kWp, power generation 30,000 kWh p.a, specific solar yield 900 kWh/kWp*	*With an electricity consumption of 1,400 kWh per year, the electricity costs decrease by up to 10% compared to the previous electricity bill; Tenants energy model "MeinMieterstrom" will be offered with a price line 0.5 ct/kWh the basic supply tariff of "Dresdner.Strom.Privat"; using the CO2 intensity of the German electricity mix (471 g/kWh), this PV system will save approximately 14,1 t of CO2 per year*
IPMVP Option Selection Guidance *Follow each question starting from 1. Highlight choice of selection with a colour.*			
Intervention Characteristics		YES	NO
[1] Need to assess Actions' performance individually?		YES	---
[2] Able to isolate Actions(s) with meter(s)?		---	NO
[3] Are expected savings greater than 10%?		YES	---
[4] Need full performance demonstration?		---	---
[5] Need to separately assess each Action?		OPTION D	---
[6A] Missing baseline period data?		---	---
[6B] Missing baseline period data?		---	---

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Measurement Boundary As data for baseline is not available for all data required, several boundary conditions are needed to describe the entire building: 1. Monthly heat and power consumption data of the considered building during the baseline period is available based on measurement data 2. Maximum peak values of heat and power consumption were not measured with existing meter setup during the baseline period, suitable hybrid-twin simulation models (incl. calibration with measurement data) were necessary to calculated baseline values for the E5 KPI value. These models are based German "IWU Kurzverfahren Energieprofil" method which is based on extensive statistical evaluations of the German building stock. 3. CO2 emissions from electricity consumption are determined on the basis of Germany's energy source mix according to the German electricity labelling system Following indicators are accordingly analysed: *E1: Describes the primary energy consumption that is supplied to the system by natural energy sources. Measurement relevant relations consist of the size of the system and the considered time interval. The reporting in the SCIS consists of three phases: refurbished buildings (baseline, design, monitoring), new buildings (reference energy consumption), similar buildings (base of simulations). Unit.: kWh/(m²*year)* *E3: Percentage increase in the share of local renewable energy due to the intervention. It is separately determined for thermal (heating or cooling) energy and electricity. Unit.: kWh/month* *E4: CO2 emissions can therefore be considered a useful indicator for assessing the impact of urban development in climate changes. Unit.: Change in t/year* *E5: The maximum consumption of a building or building groups is analysed and then forecast by an aggregator implementation. Measurement dependencies exist here in the time interval of the measurements. Unit.: %, Interval: before and after intervention*	
Indicators	- E1. Reduction in primary energy demand and consumption -E3. Increase in local renewable energy generation - E4. CO2 emission reduction - E5. Peak load reduction
Baseline Period	*Baseline M24* *M31* *M37* *M43* *M49* *M55* *M60*
Simulation models and tools	
Tool set and characteristics	*In Dresden, the third party EA Systems GmbH Dresden, which is mainly in charge with the simulation models of most of the interventions / actions, uses the versatile, non-causal, multi-physical, Modelica™-based simulation environment SimulationX and the*

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	included Green City simulation library which provides a wide range of energy supply and storage systems models as well as an easy-to-use and valid platform for building performance simulation. For occupants' behaviour simulation this tool set will be coupled via Functional Mockup Interface (FMI) to common multi-agent-simulation tools (e.g. Netlogo). *To identify baseline values for the monthly peak energy consumption, the German "IWU Kurzverfahren Energieprofil" method was taken into account, too. This statistic-based approach allows to link monthly energy measurement values from the baseline period with specific building characteristics (e.g. U-Values). Using local weather condition data with high temporal resolution from the baseline period then enables the partners to derive standard heat consumption profiles for each baseline month for the peak power identification.* *Besides building and energy system models including energy management as well as co-simulation of probabilistic occupancy models, charging infrastructures as well as electric vehicle fleets are integral part of this simulation environment. It additionally considers security of supply as well as profitableness requirements and regards local building regulations.* *All simulation models are furthermore designed to be easily scaled-up from single-building to city-district level and size. Thus, enables EASD to calculate coupled electricity, heating and cooling grids for city districts as well as the interactions between energy sources, storage facilities, lines and consumers in a large-scale manner. The models therefore help to realize a MAtchUP core concept regarding the up-scaling of single optimization measures to a whole city district area.*
Model description and boundaries	*A simulation model of an existing multi-storey residential building has been implemented which mainly helps to analyse influences of different PV system and battery sizes on both technical KPIs (e.g. energy consumption reduction, peak-load-reduction, autarky rate increase, etc.) as well as economical KPIs and measures, like the newly developed and tested renewable tenant power supply. This model has been calibrated with measurement data of several recent years regarding heat and power consumption and is therefore highly accurate. It includes a co-simulation of tenants' behaviour with the multi-agent-simulation platform Netlogo and SimulationX. The simulation results can further be used to scale-up those measures to the total district for the whole number of existing residential buildings.* *The calibrated baseline data models for peak power calculation collect all calculated building parameters from the IWU method and the power profiles of the multi-agent models in an MS Excel calculation tool which then generates a summarized output of required baseline period heat and power consumption profiles.* *All energy interventions need to be scaled-up to be total city quarter size. Therefore, EASD's simulation approaches will be used to also implement a city district model on data base level. Therefore, a huge number of anonymised energy consumption data is used to represent total energy consumption in the MAtchUP city quarter Johannstadt. This model will then be added with the results of the optimization measures of all single energy interventions. This helps to evaluate both influences of single interventions on total energy consumption as well as a prediction the total effect of all measures in combination. Within district model, connected interventions from other sectors (e.g. implementation of an e-Mobility charging infrastructure) can be added and evaluated, too. This district model will obviously be less accurate as all single building models. However, the expected results will be accurate enough to compare different measures in the MAtchUP context.*

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Input data required	*The developed and required models for energy interventions in Dresden mainly refer to different types of buildings as well as occupancy. These different models require most likely the same set of input parameters, if available:* • *Building construction plans; definition of refurbishment measures; building age, characteristic and occupancy type* • *Available measurement data of at least one recent year (existing buildings) regarding heat, natural gas, electricity, cold, etc. consumption* • *Description and design plans of power supply and HVAC system including brief overview of control schematic* • *District plans (for district models) and included grid design (electricity, heat, natural gas, cold, infrastructure, etc.)* • *Datasheets of technical systems (manufacturer data) including relevant performance data*
Output data obtained	*Normally, building performance models as well as HVAC system, power supply and grid models can provide following general list of outputs:* • *Gains and consumption of different forms of energy (e.g. local renewables, heating, cooling and power supply, etc.)* • *Evaluation of dimensions and feasibility of technical system components (e.g. photovoltaic or battery system size)* • *Analyses of total (or individual) costs (operation and investment) and total profitableness* • *Evaluation of different strategies for storage control and energy management* • *Evaluation and analyses of different performance optimization measures* *A1 – Smart tenant / existing multi-storey residential buildings:* • *Evaluation of PV system and battery size regarding tenant electricity concept* • *Total energy and peak power demand of building before and after interventions* • *Share of building's self-consumption rate (tenants, general building operation)* • *Evaluation of implemented battery storage control strategy; profitableness of storage integration* • *Economic evaluation of different tenant electricity concepts* • *Baseline data of monthly heat and power peaks for the KPI calculation* *A5 / A18 – District model:* • *Evaluation of grid optimization measures (e.g. district heating grid)* • *Analyses of advanced integration of E-Mobility charging infrastructure (sector coupling)* • *Up-scaling of single interventions to total district level* • *Baseline and up-scaled simulation data for KPI evaluation*
Assumptions	*The implemented models, mainly used to evaluate different approaches of action implementation, include a comparatively high number of assumptions. First of all, the occupancy models (A1) are mainly based on multi-agent-simulation model representing occupancy behaviour of tenants. Those models provide statistically-approved results but can significantly differ from real-world data from time to time.* *Further assumptions consider the implemented district models for district storage evaluation (A18). These models include a high number of spatially-distributed input data sets describing total energy*

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	consumption of buildings, grid configuration and infrastructure usage. These data is valid but has a low temporal resolution. The derived model input data sets describing time continuous consumption profiles is based on common engineering assumptions as well as available standard load profiles.

Action 01: Smart tenants

With the objective to increase the flexibility of the Smart Energy Systems, tenant electricity models will be promoted through this action. Through tenant electricity models, tenants are allowed to use the generated energy from renewable energies themselves in their quarters. The intelligent linkage of photovoltaics (Action 4) and storage (Actions 5 & 18) decouples on-site production and consumption and increases the autonomy of the district. This can increase the attractiveness of tenant flows and enable economic and ecological participation in the urban energy market for a large number of tenants. Integration of electromobility (Action 23) in conjunction with the photovoltaic system, the indirect CO_2 emissions from the electric vehicles can thus be further reduced and a positive contribution to the energy balance of the district can be achieved. As a result of the reduction in the feed-in into the public electricity grid, expected peaks in consumption and decentralized production will be reduced in the future (Action 54). The consumption-oriented and -oriented expansion of renewable energies in the district is thus promoted.

For taken decisions among the different stakeholders involved in this action, providing information for tenants and power producers about their feed-in, consumption or efficiency is one of the main aspects to treat. For this, the buildings (Action 7) will have installed Intelligent metering systems (iMSys) that consists of modern measuring equipment (mME) and a smart meter gateway (SMGW), which collects, stores and transmits measured values to authorized market participants (AMT), taking into account the requirements of the BSI (high data protection and data security requirements). The implementation of iMsys provides the basis for the information and communication technology for linking the previously separate energy systems. IMsys are remotely communicable electricity meters that meet the high data protection and data security requirements. The iMSys are connected to the Urban Platform by gateway (SMGW-Smart Meter Gateway), which allows remote access via a communication link (based on the ICT infrastructure). The data from the gateway is then made available through the Urban Platform. The group of producers (CHP, PVA) is integrated into the iMSys via the control box. The active market partners (aAMP) form the authorized subscriber body who communicate the switching operations via the secure ICT infrastructure of the control box. Hence, iMsys allow only the previously sketched concepts as well as the provision of information to among other things on-site production, consumption, CO_2 savings and efficiency for a "smart" tenant.

Additionally to the monitoring of the dwellings, simulation will be used for creating functional connections between modules like photovoltaics, storage batteries, controlled EV charging infrastructure as well as HVAC and district heating adds a lot of complexity to the energy system. Also to layout and test these systems regarding component sizing and functional interaction using dynamic systems simulation based on Modelica, is state of the art. For the simulation, computational models of battery storages, buildings user behavior, etc. are connected in the proposed layout and functionality of the future district. The system is then valuated for typical usage scenarios, and afterwards the model gets adjusted until the system works as desired. Based on the results, the real world components are built. So, this process helps to reduce in site commissioning efforts and greatly improves quality. Currently these technologies are mainly used for high profile buildings.

A simulation model of an existing multi-storey residential building has been implemented which mainly helps to analyse influences of different PV system and battery sizes on both technical KPIs (e.g. energy consumption reduction, peak-load-reduction, autarky rate increase, etc.) as well as economical KPIs and measures, like the newly developed and tested renewable tenant power supply. This model has been calibrated with measurement data of several recent years regarding heat and power consumption and is therefore highly accurate. It includes a co-simulation of tenants' behaviour with the multi-agent-simulation platform Netlogo and SimulationX. The simulation results can further be used to scale-up those measures to the total district for the whole number of existing residential buildings.

Action 04: 33 kWp photovoltaic system on existing buildings

A photovoltaic system will be installed on the existing buildings at Blasewitzer Str. 36 a-c that were constructed in 1990. Other apartment buildings at Pfotenhauer Str. will be retrofitted inside the MAtchUP project (Action 7).

In the 61 flats that comprise the buildings located on Blasewitzer Str., the total roof surface is about 570m². Given the architecture, about 33 kWp of PV generation may be installed, depending on the actual circumstances. These will be included in the potential energy storage and total annual electricity generation should sum up at around 30,000 kWh. As the total electricity consumption of the building (its inhabitants) is around 105,000 kWh/a, 100 % of PV generation will theoretically be used in the building itself. Due to the planned storage (Action 5), the generation and demand mismatch should be covered. A CO_2 reduction of around 28 % can be reached due to the use of PV generation.

Measurements should be available via monitoring data; baseline is not necessary as the PV power output counts 0 kWh PV.

Simulation model can only be used to optimize control strategy regarding self-consumption ratio, if necessary.

Action 05: Integration of the power supply system of the retrofitted buildings with the District Storage System

For an integrated energy management of the PV energy generated by the Action 4 and a high level of sustainability in A1 a District Storage System is aimed to be analyzed in the project (Action 18). Therefore, the variant analysis of decentralized and centralized District Storages will be developed to evaluate proper technical, economical and repeatable storage solutions. The variant analysis will be focused on two feasible possibilities. First option is a mix of virtual connected smaller local storages connected to the EMS. Second option is one larger district storage with interfaces to the EMS. As

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larger energy storage systems are more efficient in terms of investment cost than smaller units.

The connection of this district storage system to the individual apartments and demand management is crucial in order to guarantee optimum service and achieve the highest energy efficiency values. This action manages the housing demand, the individual electric mobility demand and the public electric mobility demand (semi-public) in order to ensure the supply of the housing.

This Action and Action 18 are both only evaluated with models from EASD (c.f. District Model in paragraph 2.1.3) for both baseline and optimized system configuration.

Action 18: Reference Solution for a Multi-Dimensional Electric district storage

Battery supported home power supply currently takes place in private real estate comprising storage capacities of e.g. 5 kWh. Future energy market developments as well as increasing requirements on grid stability will change this situation within the upcoming decade. To already meet these challenges, the considered retrofitted buildings will be analyzed with the developed simulation models to identify break-even conditions and future state of the market regarding suitable storage sizing and integration measures. We will model the integration of a larger district storage system > 100 kW with interface to EMS (Action 5). In addition to this: Since physical integration of a multi-dimensional district storage of larger capacity > 100 kWh is not possible due to the existing technical restrictions (ratio of generated energy to consumed energy), two different feasible approaches are pursued:

(1) The use of suitable smaller storage units at the Blasewitzer Str. 36 (Action 1), will be analyzed and is aimed to be integrated into the energy system of the apartment building (Action 5) to increase the ratio of self-sufficiency for clients of the tenant energy model.

(2) The use of bigger storage systems in our lighthouse district for grid stabilization at fast charging stations is going to be implemented at the Mobility point Fetscherplatz.

In order to compare different scenarios of storage capacities and number of tenants participating, EASD has built a simulation model with *SimulationX GreenCity*. The model and the real building parameters are described in A1. This model of the energy system allows to variate the scenarios in a very fast and easy way and is the base to research the following use cases:

- Energetic optimization
    - increase the energy self-sufficiency
    - increase the own use proportion of solar energy
- Economic optimization

In this simulation, 66 scenarios were carried out, which should determine a useful integration of a battery storage for the apartment Blasewitzer Straße 36 a - c.

A District Model is required.

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3.3 Intervention 3 - District Heating

The intervention includes three actions. These actions do not necessarily require simulation models for baseline definition. However, such models can be helpful during intervention design and pre-evaluation of different technical and economical solutions.

Table 9: Option Template for Intervention 3

Intervention 3: District Heating			
Involved Action	Savings	Affected Equipment	Expected Savings
A13, A17, A36	• *Improvement of thermal storage operation – increased CHP-production and reduction of energy losses due to increased fuel efficiency* • *Integration of RES into District heat (DH) system*	• *Thermal storage units* • *DH-pipeline to RES-generation site* • *Central district-heat system incl. heat transfer stations*	1. A13, A36: Thermal storage optimization: - < 3% reduction of thermal energy losses - Relevant reduction of CO_2 emissions for district heat related production due to higher share of CHP instead of uncoupled production of heat and electricity - improvement of economics by 3..5% 2. A17: By subsequent implementation of a solar thermal unit at the Nickern site RES share can be rise, thus a reduction of conventional CHP-heat. This will affect the primary efficiency and the CO_2 emissions. 3. A17: Relevant reduction of energy losses in the central district heat system are expected through lowering the temperatures of the central DH-system "low ex"
IPMVP Option Selection Guidance *Follow each question starting from 1. Highlight choice of selection with a colour.*			
Intervention Characteristics		YES	NO
[1] Need to assess Actions' performance individually?		---	NO
[2] Able to isolate Actions(s) with meter(s)?		---	NO
[3] Are expected savings greater than 10%?		YES	---
[4] Need full performance demonstration?		---	NO
[5] Need to separately assess each Action?		---	NO

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[6A] Missing baseline period data?	---	NO
[6B] Missing baseline period data?	---	NO

Measurement Boundary

A complete measurement of the impact of the MAtchUP-actions on the district heating system and the operation of the thermal storage units is neither available nor feasible. Several data needed to simulate the impact of the actions on the district heating system are based on the following assumptions:

1. Baseline uses the current primary energy factor of DREWAG (certified by external auditor).

2. While using RES for heat production, in accordance to the German legislation (EnEV) the primary energy factor for this share will be equal to 0.

3. RES heat production substitutes CHP generated heat.

4. Operation of heat storage system is derived from a system-technical and economic optimization of the Dresden district heating system.

Following indicators are accordingly analysed:

*E1: Describes the primary energy consumption that is supplied to the system by natural energy sources. Measurement relevant relations consist of the size of the system and the considered time interval. The reporting in the SCIS consists of three phases: refurbished buildings (baseline, design, monitoring), new buildings (reference energy consumption), similar buildings (base of simulations). Unit.: kWh/(m²*year)*

E4: CO2 emissions can therefore be considered a useful indicator for assessing the impact of urban development in climate changes. Unit.: Change in t/year

Full-load hours: Calculated value for the utilization of a thermal plant, which describes the sum of hours that a heat generator operates at full power. Unit: h, Interval: /, Reporting to SCIS: no

Utilization ratio: The share of Full-load hours in the related time period (year). Unit: % (in h), Interval: /, Reporting to SCIS: NO

Indicators	- E1. Reduction in primary energy demand and consumption - E4. CO_2 emission reduction - Full-load hours - Utilization ratio
Baseline Period	*Baseline M24* *M31* *M37* *M43* *M49* *M55* *M60*

Simulation models and tools

Tool set and characteristics	DWG is using the “BoFit”-model to simulate the impact of district heat actions, as there is no opportunity to measure them in a meshed and complex system. The BoFiT Optimization tool is an instrument which is used by DWG to map generation or trading portfolio into a mathematical model. Based on this model optimization tasks can be formulated and

	calculated for the various business processes. On the one hand, it allows investment planning, on the other hand, trading flexibilities can be optimized at short notice vis-à-vis current markets. A basic model can be used for all business processes by creating variants. DWG is using this model to optimize operation of the DH-system and to evaluate new assets for it, such as storage systems, RES-feed-in-options, optimization of power-plants daily operation.
Model description and boundaries	*BoFit is based on a mixed integer linear optimization model. That means, all equations and inequalities underlying the model must be linear.*
Input data required	*There is a wide variety of data included into the BoFit-system, concerning the storage and CHP-power plant operation as well as the central district heat system.* *E.g.* • *External temperature-dependent power plant characteristic curve, efficiencies of CHP-plants, power and capacity limits, minimum running times and minimum downtimes, CO2 and primary energy factors* • *Time series: Heat demand, electricity price, outdoor temperature, solar yield*
Output data obtained	Time series: • Optimal schedule for generators and storage, • Operating costs, • Fuel consumption, CO2 emissions, primary energy • List output data that is obtained after the simulation
Assumptions	*perfect preview of future prices, heat demand, consumption etc. (no forecast deviations) and model immanent deviations*

Action 13: District Energy Monitoring

In order to increase the number of feed-in options, a long-term program for lowering the temperature parameters in the district heating network runs. This improves the prerequisites for the integration of renewable heat input and reduces the distribution losses. These measures are a prerequisite for the district heating network to fulfill its role as a system-related complementary set for the expansion of electricity in the electricity sector.

The optimal operation of a network of many customers and feed-in points, good storage scheduling, consideration of even very short-term requirements from the regional power grid for the use of CHP and power-to-heat and a current- Data networking, controllability, intelligent control circuits and data security. In data management, the connection to smart-home applications for temperature control is also available in the individual apartments. It is conceivable from a perspective point of view that the temperature profiles predefined by the customer to his heating system can be directly used to improve the forecast quality of heat generation but also to optimize the optimization of virtual power plants.

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On the basis of the further development of the thematic plan, new information on energy consumption from the Smart Meter Gateway (Actions 1 & 43) is to be prepared and used as an information basis for the energetic development of neighborhoods. For a better management of the DH, spatial representation of energy consumption by neighborhood and block will be monitored and thus control possibilities, means of public relations and the prerequisite for energy saving.

SUBCONTRACT

- Research program on primary efficiency and residual load – Budget: 15,000 €
- Measuring program on operating behavior and efficiency of thermal storage – Budget: 20,000 €

Scope of the subcontract (three different subcontracts will be needed to implement these actions: In order to increase the number of feed-in options, a long-term program for lowering the temperature parameters in the district heating network runs. This improves the prerequisites for the integration of renewable heat input and reduces the distribution losses. These measures are a prerequisite for the district heating network to fulfil its role as a system-related complementary set for the expansion of electricity in the electricity sector

The subcontracting (15.000€) will cover costs for a study on primary efficiency and residual load (need to be done by a research organization).

Among others, this action is closely linked to action 7: Pfotenhauer Str. Retrofitting project (leader: VON). In the context of district energy systems, changes in a building's heat demand also affect the energy efficiency of the whole district heating network. Various measures for temperature profile (supply and return) and mass flow rates must be planned, carried out and analyzed. For that, there has to be designed a long-term measuring program in district heating stations as well as in retrofitted blocks itself. That will provide concrete suggestions about the opportunities to lower the temperatures in defined sectors of the district heating system for Johannstadt. The complexity of this task is getting even higher by taking into account the feed-in-option, such as the use of the thermal storage. Furthermore, the calculation and certification of primary efficiency has to be carried out by an independent certified organization.

The subcontract (20.000€) covers the measuring of operating behavior and the analyses of the efficiency of thermal storage (need to be done by a research organization). For that an installation of a glass fibre measuring system (wall-system-measurement, U-bend) is required. This will allow to control of the dynamic of the temperature profile of the new thermal storage. The subcontract partner is responsible for the entire measuring system – planning, installation, analysis and reporting.

Cost estimation: The costs have been estimated based on previous installations and previous analyses provided by research organizations.

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Type of procedure: The subcontracts will be awarded according to the principles for best value for money and absence of any conflict of interest (according to Articles 10, and 13 of AMGA).

A District heating grid model is actually not required for baseline definition and intervention evaluation. But again, those models can help to pre-evaluate different control strategies and system design parameters, if required.

Action 17: Increase of RES in District heating system

RES will be increased in the district heating in Dresden, the integration of different sources is to be developed more intensively.

Integration of large-scale solar thermal energy will be tackled rapidly in addition to other options such as geothermal heat/ heat pumps, waste-to-energy and the use of industrial waste heat, even in the low-temperature range.

Planned analyses by DWG on the use of large-scale solar thermal energy on an open area in Dresden Nickern of 20,000 m² with a gross collector surface of 7,000 m² require a connection to the Dresden district heating grid.

Within this action, an anticipatory feasibility study on the district heating pipeline through Dresden's urban area over a distance of approx. 1 km is to be realized. Further options for the conversion of the existing drinking water tanks at the site, as well as for the integration of solar thermal technology, are to follow depending on the positive project prospects.

SUBCONTRACT

Installation and commissioning for the energy efficiency improvement measures and coupling with the DH management system – Budget: 60,000 €

One major challenge is the integration of RES into the presently CHP-based DH-system. Within the duration of the MAtchUP-project DWG the integration of various RES into the district heat system as well as the lowering of temperatures will take place.

RES are excesses from wind and solar-power via Power-to-Heat and geothermal deep heat, large heat pumps, utilization of non-recyclable residual parts, the use of waste heat even in the low temperature range and solar thermal energy. These developments cause the urgent need for a measuring-program on temperatures (supply and return at DH stations) and flows in certain DH grid-areas. On the other hand, the effects of these RES-integration-measures on efficiency and primary energy use have to be monitored on a timescale. All actions have to be proven to fulfill the bordering conditions of the meshed hydraulic system and hygienic (Legionella bacteria).

The subcontracted scientific partner is in charge of the design and the measurement equipment and also for carrying out a model-based analysis. All this aims to improve the energy efficiency of the DH system.

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Baseline is defined by existing measurement data. No renewables are currently integrated. The monitoring with later measurement data will define all relevant KPIs. Anyhow, models can help to identify optimal design solutions and control strategies (prediction, retrodiction, etc.).

Action 36: New thermal storage of 7,800 m³ for DH

In parallel to the approach of increasing the RES ratio, an increasing share of regenerative energy is also one of the objectives for the near future and the realization of a continuous sectoral link between heat and power system is central. To existing capacities of thermal storage in the Reick Innovation Power Plant (2 MW_{el} CHP-plant with 813 kWp of photovoltaics and 460+540 MW_{th} @ 60 K of heat storage), DWG is going to add new thermal storage capacities of 7,800 m³. With this expansion and the examination of further options (long-term heat storage, demand peaks and demanded power reductions of the coupled electricity generation) can be realized more ecologically and through lower utilization of heating plant.

Baseline is defined by existing measurement data. No renewables are currently integrated. The monitoring with later measurement data will define all relevant KPIs. Anyhow, models can help to identify optimal design solutions and control strategies (prediction, retrodiction, etc.).

3.4 Intervention 4 - Smart Controls

This intervention only considers one action, Action 2 – Building Control Center. It mainly includes the development of a consistent energy consumption data acquisition with high temporal resolution of different public buildings. The main aim is to improve system control by gathering and evaluating a broad set of available data.

Baseline definition does not require any models. But again, suitable simulation models have although been built to pre-evaluate different measures of system control in an exemplary public school building with respect to available measurement data and suitable technical control elements.

Table 10: Option Template for Intervention 4

Intervention 4: Smart Controls			
Involved Action	Savings	Affected Equipment	Expected Savings
A2		*Central Building Control Center, intelligent metering devices, measurement tool*	
IPMVP Option Selection Guidance *Follow each question starting from 1. Highlight choice of selection with a colour.*			
Intervention Characteristics		YES	NO
[1] Need to assess Actions' performance individually?		YES	---

[2] Able to isolate Actions(s) with meter(s)?	YES	---
[3] Are expected savings greater than 10%?	---	---
[4] Need full performance demonstration?	YES	---
[5] Need to separately assess each Action?	---	---
[6A] Missing baseline period data?	---	OPTION B
[6B] Missing baseline period data?	---	---

Measurement Boundary

High-resolution measurement of energy systems data, in heating and cooling as well as power supply systems of buildings, basically does not ensure any energy savings at all. However, it enables the integration of smart control algorithms which utilizes available degrees of freedom of local renewable power production and storage, fluctuating energy prices as well as volatile energy demands. Furthermore, the conscience of energy consumption share and potentials of energy savings gained via suitable measurements can further lead to minor consumption reductions due to an improved occupancy and energy usage.

Following indicators are accordingly analysed:

*E1: Describes the primary energy consumption that is supplied to the system by natural energy sources. Measurement relevant relations consist of the size of the system and the considered time interval. The reporting in the SCIS consists of three phases: refurbished buildings (baseline, design, monitoring), new buildings (reference energy consumption), similar buildings (base of simulations). Unit.: kWh/(m²*year)*

*E2: Considers, in opposite to E1, the final energy consumption that is supplied to the system by different energy sources which are evaluated individually. Measurement relevant relations consist of the size of the system and the considered time interval. The reporting includes the collection of baseline data as well as measurements after intervention implementation. Unit.: kWh/(m²*year)*

E3: Percentage increase in the share of local renewable energy due to the intervention. It is separately determined for thermal (heating or cooling) energy and electricity. Unit.: kWh/month

E6: Degree of local renewable energy supply can match hourly energy demand over the whole year. Unit: kWh

E7: Ratio between the highest values for hourly demand to the lowest ones in each month. Unit: ratio/month

E8: Describes the ratio between battery utilization and available battery capacity. Unit: ratio/month

E14: Defines if requirements of NZEB 2020 directive are complied. Unit: yes/no

Indicators	- E1. Reduction in primary energy demand and consumption - E2. Reduction in annual final energy consumption - E3. Increase in local renewable energy generation - E6. Maximum hourly deficit - E7 Monthly ratio of peak hourly demand to lowest hourly demand

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	- E8. Storage capacity factor - E14. Compliance with Nearly Zero Energy Buildings (NZEBs) requirements
Baseline Period	*Baseline M24* *M31* *M37* *M43* *M49* *M55* *M60*
Simulation models and tools	
Tool set and characteristics	*In Dresden, the third party EA Systems GmbH Dresden, which is mainly in charge with the simulation models of most of the interventions / actions, uses the versatile, non-causal, multi-physical, Modelica™-based simulation environment SimulationX and the included Green City simulation library which provides a wide range of energy supply and storage systems models as well as an easy-to-use and valid platform for building performance simulation. For occupants' behaviour simulation this tool set will be coupled via Functional Mockup Interface (FMI) to common multi-agent-simulation tools (e.g. Netlogo).* *To increase the model accuracy the developed building models have been additionally evaluated in comparison to and calibrated with measurement data from the example public building, the 102nd Elementary School. These Hybrid Digital Twin models were then the base of any analyses of optimized or higher-order control algorithms.* *Besides building and energy system models including energy management as well as co-simulation of probabilistic occupancy models, charging infrastructures as well as electric vehicle fleets are integral part of this simulation environment. It additionally considers security of supply as well as profitableness requirements and regards local building regulations.* *All simulation models are furthermore designed to be easily scaled-up from single-building to city-district level and size. Thus, enables EASD to calculate coupled electricity, heating and cooling grids for city districts as well as the interactions between energy sources, storage facilities, lines and consumers in a large-scale manner. The models therefore help to realize a MAtchUP core concept regarding the up-scaling of single optimization measures to a whole city district area.*
Model description and boundaries	*A2 uses a simulation model of local standard Dresden-type school building to evaluate different technical measures of energy consumption reduction as an example for suitable optimization measures in public buildings in the Johannstadt city district. Like in A1, the model results will further be used to scale-up resultant performance optimization and to evaluate corresponding technical KPIs for all existing public buildings, especially similar school buildings, in the city district Johannstadt. Again, this model was validated with available measurement data of recent years for heat and power consumption and is thus as accurate as the corresponding A1 model.*

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Input data required	*The developed and required models for energy interventions in Dresden mainly refer to different types of buildings as well as occupancy. These different models require most likely the same set of input parameters, if available:* • *Available measurement data of at least one recent year (existing buildings) regarding heat, natural gas, electricity, cold, etc. consumption* • *Description and design plans of power supply and HVAC system including brief overview of control schematic* • *District plans (for district models) and included grid design (electricity, heat, natural gas, cold, infrastructure, etc.)* • *Datasheets of technical systems (manufacturer data) including relevant performance data*
Output data obtained	*Normally, building performance models as well as HVAC system, power supply and grid models can provide following general list of outputs:* • *Gains and consumption of different forms of energy (e.g. local renewables, heating, cooling and power supply, etc.)* • *Evaluation of dimensions and feasibility of technical system components (e.g. photovoltaic or battery system size)* • *Analyses of total (or individual) costs (operation and investment) and total profitableness* • *Evaluation of different strategies for storage control and energy management* • *Evaluation and analyses of different performance optimization measures* *A2 – Public building / exemplary school building:* • *Evaluation of different optimization and refurbishment measures* • *Profitableness of different interventions*
Assumptions	*Influences of a smart control system always depend on the available degree of freedom of the controlled system as well as existing energetic standard. This intervention assumes that additional smart control inputs can significantly improve the energetic standard and have some degree freedom to be controlled.* *Further assumptions consider the implemented models of the evaluated public school building. Again, the energetic behaviour is simulated in high temporal resolution, assumptions are mainly made regarding occupancy rate of different rooms inside the building but results have always been recalibrated with available annual measurement data.*

Action 2: Building control center – 12 Public buildings energy managed

5 schools, 6 children's day care facilities and 1 administrative building, all of them located in Dresden's high-performance district Johannstadt, will be connected to a Central Building Control Center (CBCC), which although currently being constructed in another Dresden district, will allow increasing the effective energy management of the selected 12 public Johannstadt buildings. This increment will be obtained through the permanent timely adaptation of the building heating systems with the current internal and external climatic conditions, exhausting the existing energy savings potential. All data acquired by the CBCC will be integrated into the Dresden Urban Platform and will be released as Open Data.

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Role of the Third Party EASD:

Main goal of Action A2 is to improve the energy efficiency of public buildings. Therefore, EASD models one representative school building in the district using the A1 modeling approaches. Besides building performance analyzes and optimization, the models are used to implement and test predictive heat control algorithms, mainly regarding a permanent adaptation of heating depending on outdoor and indoor conditions. Dresden wants to add the public buildings to its Central Building Control Center (CBCC), a platform for data monitoring and evaluation and building energy management. To support a permanent high energetic standard of the connected buildings, EASD exemplary shows efficient measures of data evaluation and system optimization including models and monitoring data for the selected representative school building.

A2 uses a simulation model of local standard Dresden school building to evaluate different technical measures of energy consumption reduction as an example for suitable optimization measures in public buildings in the Johannstadt city district. Like in A1, the model results will further be used to scale-up resultant performance optimization and to evaluate corresponding technical KPIs for all existing public buildings, especially similar school buildings, in the city district Johannstadt. Again, this model could be validated with available measurement data of recent years for heat and power consumption and is thus as accurate as the corresponding A1 model.

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4 Models for Baseline in Energy Interventions

In MAtchUP, mathematical simulation models are sometimes necessary to test and evaluate different technical or economical aspects of different valid solutions. Besides the actual work on different actions, MAtchUP has also a great focus on the individual monitoring of the implemented measures. This monitoring consists of two phases, a baseline period and a monitoring phase.

However, some interventions cannot provide sufficient (measurement) data to define a suitable baseline characteristic. Especially, in the energy section, some interventions require add-on methods to find the right data. These can be simulation models. Following paragraphs describe the implemented baseline models in some of the conducted energy interventions (c.f. paragraph 3).

4.1 Intervention 1

Intervention 1 (c.f. paragraph 3.1) regards the construction of a new multi-family residential building (i.e. District Future House) in the MAtchUP demo-district Johannstadt in Dresden. It includes latest technologies of building internal ventilation systems, energy management and local renewable power production as well as local storage.

Figure 5: District Future House

Its energetic standard corresponds to the German EnEV 2014 standard. It provides a net floor space are of about 1,100 m^2. It is heated via the local district heating grid and produces its own power via a 9.92 kWp photovoltaic system on the roof-top. A 3.3 kWh

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stationary battery in the basement gives the energy management an additional degree of freedom for the power supply system control.

This energy management thus especially provides the tenants additional information about their own energy consumption as well as their opportunities to increase self-sufficiency rate and personal energy costs.

All these measures are the bases of the intervention 1 design which shall be evaluated via a long-term monitoring period during the MAtchUP project. However, this monitoring process requires a baseline against which to compare. For this baseline, no measurement data are obviously available since the building is newly built. Suitable simulation models are thus necessary instead.

This baseline model must represent the energetic behaviour of a suitable "reference building". In context of German energy legislation, it has to be the reference building of the same energetic standard, EnEV 2014.

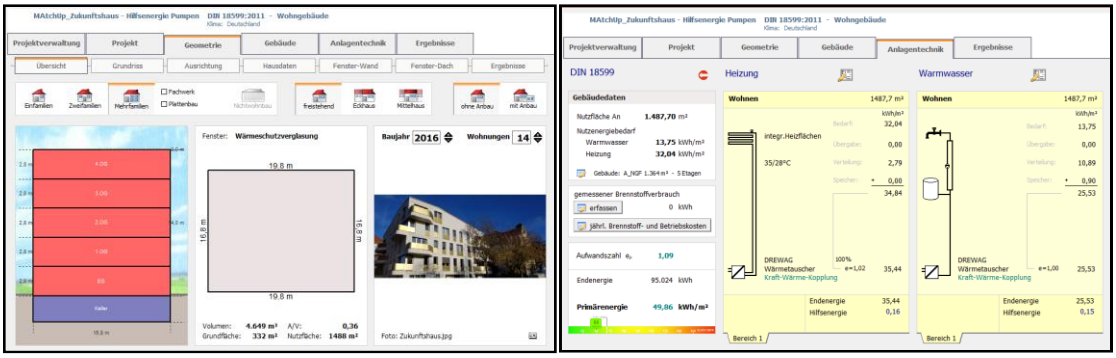

Figure 6: Simple DIN 18599 model of EnEV 2014 reference building

The monthly energetic behaviour of this reference building was calculated with the help of the Hottgenroth "Energieberater 18599" tool. This reference building has the same size like the actually built District Future House.

Endenergiebedarf - Monatsbilanzierung:

in [kWh]	Gesamt	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Heizung	**68843**	14650	12293	8341	1775	108	105	108	108	270	3897	11361	15827
Kühlung	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Lüftung	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Beleuchtung	**0**	0	0	0	0	0	0	0	0	0	0	0	0
Warmwasser	**24606**	2586	2256	2147	1448	1898	1574	1587	1833	1938	2129	2427	2782
Gesamt	**93449**	17235	14549	10488	3223	2006	1679	1695	1941	2208	6026	13788	18609

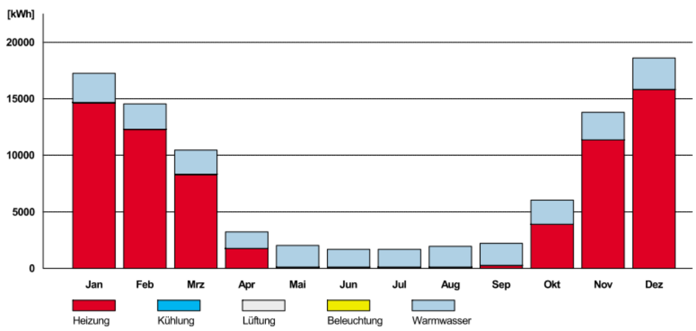

Figure 7: Results of monthly heat demands

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All building envelope sizes as well as heat transfer and occupancy characteristics are derived from existing building construction and floor plans as well as energy supply system schematics. However, the individual parameters (e.g. U-Values of walls, radiator characteristics, etc.) are based on the existing DIN 18599 limit values.

The implemented simple building model (i.e. reference residential building which only corresponds to the size of the actual building construction) only provides monthly results (c.f. Figure 7) of heat and domestic hot water consumption. These monthly values only provide less information about the power consumption inside the building. Only power demands of energy system components, like circulation pumps and ventilation systems, are available. However, the actual main power consumption share inside the individual flats by the inhabitants is unknown. Furthermore, the required information about monthly peak values for heat (in 1h temporal resolution) and electricity (in 15 min temporal resolution) consumption is not available, too.

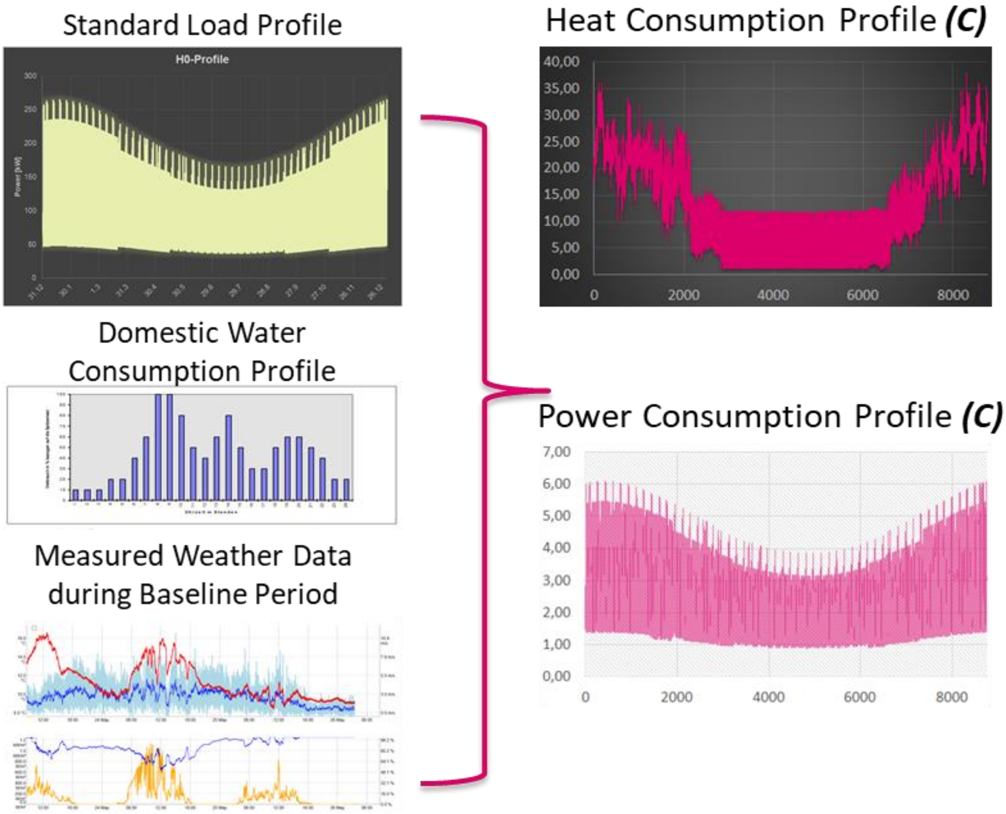

Figure 8: Enrichment of monthly model data with available profile characteristics

At the end, two annual profiles with the above mentioned temporal resolution for the total heat and power consumption of the reference building are needed to define suitable baseline values for all KPIs (i.e. also E5 indicator representing peak power reduction).

Therefore, different data sources have been taken into account. On the one hand, local measurements of weather conditions from the MAtchUP weather station in Dresden were used to represent the weather behaviour during the baseline period. Especially,

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the outdoor temperature characteristics during each month were used in a simple time-series-based model to distribute the monthly heat consumption on a 1h temporal resolution.

Besides space heating, the domestic hot water consumption has additional impact on the total heat consumption, especially during summer times. Therefore, a characteristic profile of the daily domestic water consumption based on German standard VDI 6002 which represents the average consumption in multi-family residential buildings was used to distribute the pre-calculated monthly occupancy-depending heat demands on this 1h temporal resolution. The sum of both profiles then represents the total heat consumption of the reference building with a suitable representation of the resultant monthly heat consumption peaks.

The power consumption of the building is much more difficult to model as the share of the occupancy-depending demands is significantly higher. As circulation pumps and ventilation systems run almost constantly during their operation times, the corresponding profiles remain constant, too.

The most significant power consumption share depends on the inhabitants' behaviour. Although, individual influences of single persons can be very different, the sum of all influences always results in temporally distributed average power consumption profiles. Such profiles are provided by different stakeholders in the energy sector, like utility companies, the so-called standard load profiles for different domains or occupancy characteristics. However, even if the standard load profile directly refers to residential buildings, it is anyway highly smoothed which has major influences on the resultant power peaks per month in the developed modelling framework.

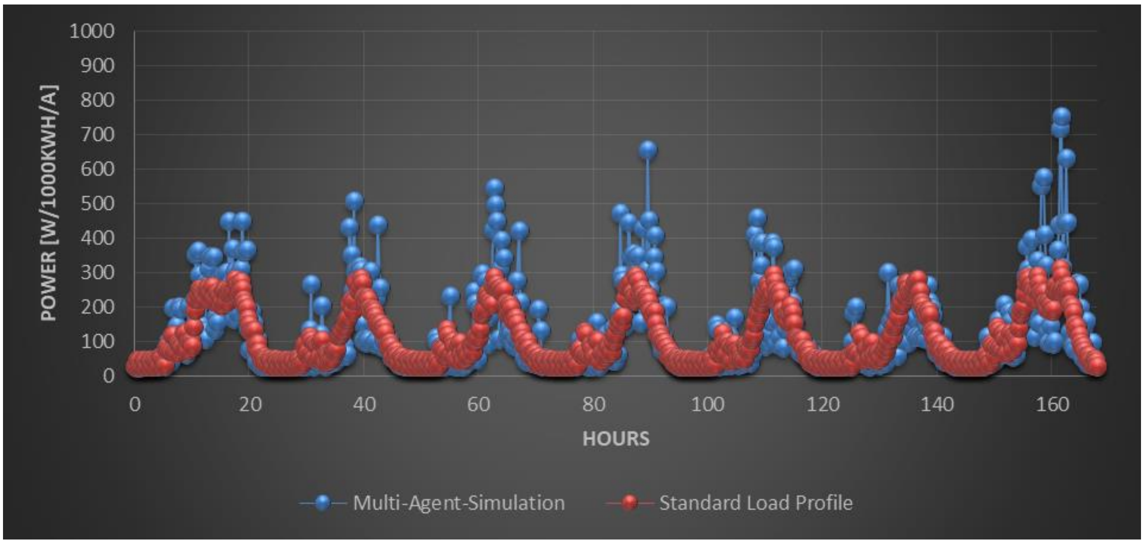

Figure 9: Comparison of power consumption profiles

Scientific analyses (c.f. Eckhardt, 2017) and a comparison to available measurement data of equal buildings showed significant deviations to resultant monthly power peaks calculated with the standard load profile. Therefore, some suitable result profiles of the multi-agent simulation model of the occupancy characteristics developed by EA Systems Dresden GmbH were used as a better representation instead (c.f. Figure 9).

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Table 11: Summary of resultant monthly heat demand and power peaks from the model

	JAN	FEB	MRC	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DEZ	YEAR
Monthly Values	1	2	3	4	5	6	7	8	9	10	11	12	
	744	1416	2160	2880	3624	4344	5088	5832	6552	7296	8016	8760	
Domestic Water Heating from EnEV [kWh]	2.569	2.241	4.021	3.867	4.012	3.872	4.000	4.009	3.886	4.021	2.411	2.765	41.674
Average Heat Consumption per day [kWh]	83	80	130	129	129	129	129	129	130	130	80	89	
Domestic Water Heating [kWh]	2.569	2.241	4.021	3.867	4.012	3.872	4.000	4.009	3.886	4.021	2.411	2.765	41.674
Max. Domestic Water Heating Power [kW]	7,60	7,34	11,90	11,83	11,87	11,84	11,84	11,86	11,88	11,90	7,37	8,18	11,90
Summary													
Total Heat Consumption [kWh]	**16.906**	**14.255**	**12.159**	**5.502**	**4.014**	**3.877**	**4.004**	**4.016**	**4.051**	**7.752**	**13.489**	**18.279**	**108.306**
Total Heat Power Peak [kW]	**36,14**	**33,09**	**28,81**	**16,33**	**11,88**	**11,89**	**12,04**	**12,23**	**12,70**	**21,22**	**30,52**	**37,96**	**37,96**

Table 12: Summary of resultant monthly power demand and power peaks from the model

	JAN	FEB	MRC	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DEZ	YEAR
Monthly Values [kWh]	1	2	3	4	5	6	7	8	9	10	11	12	
[kWh]	31	28	31	30	31	30	31	31	30	31	30	31	365
	744	1416	2160	2880	3624	4344	5088	5832	6552	7296	8016	8760	
Pump Power Demand Heating from EnEV [kWh]	51	46	43	29	15	16	15	15	18	37	46	53	385
Pump Power Demand Domestic Water from EnEV [kWh]	17	15	93	114	102	109	115	105	95	94	16	17	893
Ventilation Power Demand form EnEV [kWh]	262	232	160	111	90	83	88	86	87	128	237	260	1.825
Ventilation [kWh]	262	232	160	111	90	83	88	86	87	128	237	260	1.825
Max. Ventilation Power [kW]	0,35	0,35	0,21	0,15	0,12	0,12	0,12	0,12	0,12	0,17	0,33	0,35	0,35
Pump Heating [kWh]	51	46	43	29	15	16	15	15	18	37	46	53	385
Max. Pump Power Heating [kW]	0,10	0,10	0,08	0,06	0,03	0,03	0,03	0,03	0,03	0,07	0,09	0,10	0,10
Pump Domestic Water [kWh]	17	15	93	114	102	109	115	105	95	94	16	17	893
Max. Pump Power Domestic Water [kW]	0,03	0,03	0,15	0,20	0,17	0,19	0,19	0,17	0,16	0,15	0,03	0,03	0,20
Inhabitants Power Consumption [kWh]	2.139	1.878	1.960	1.750	1.648	1.476	1.462	1.499	1.534	1.745	1.821	2.089	21.000
Max. Power Consumption Inhabitants [kW]	5,63	5,58	5,28	4,69	4,26	3,83	3,55	3,73	4,08	4,55	5,16	5,64	5,64
Summary													
Total Power Consumption [kWh]	**2.469**	**2.172**	**2.256**	**2.004**	**1.856**	**1.685**	**1.680**	**1.705**	**1.734**	**2.004**	**2.120**	**2.419**	**24.103**
Total Power Peak [kW]	**6.11**	**6.05**	**5.73**	**5.09**	**4.58**	**4.16**	**3.89**	**4.05**	**4.39**	**4.94**	**5.61**	**6.11**	**6.11**

Table 11 and Table 12 show the summary of the models results regarding the monthly heat and power consumption and corresponding maximum peaks representing the energetic behaviour of the reference building. These tables combine the results of the DIN 18599 model analyses and the evaluation of different load profiles for peak power representation.

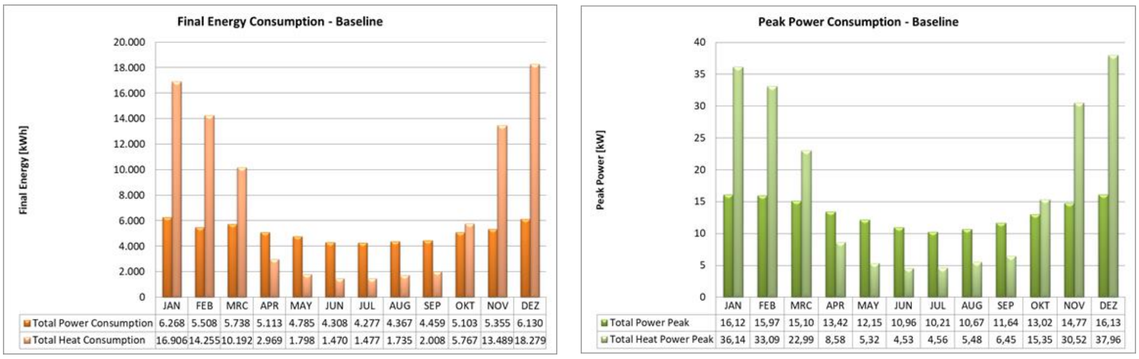

Figure 10: Graphical representation of monthly baseline data (final energy consumption and power peaks)

However, the model only calculates the monthly final energy consumption and the corresponding power peaks for both domains heat and electricity.

These results must then be post-processed to provide the required baseline data for all relevant KPIs. Therefore, the framework adds all necessary standard adaption factors, like primary energy factors, energy costs, CO_2 emission factors, etc. (c.f. red area in Figure 11).

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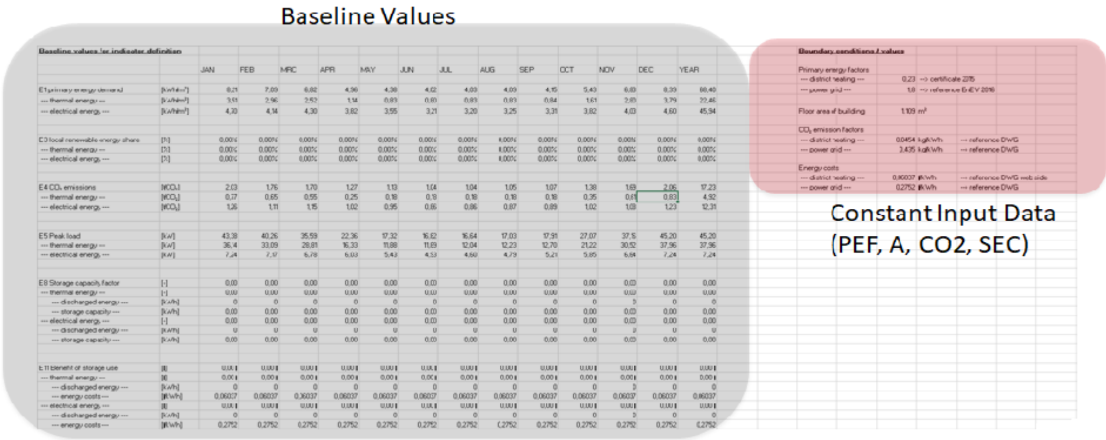

Figure 11: Calculation of baseline values based on model results

With the help of these factors the baseline values will be calculated directly within the modelling framework depending on the requirements of the MAtchUP KPI calculation framework (c.f. Deliverable 5.1).

4.2 Intervention 2

In opposite to Intervention 1, Intervention 2 (c.f. paragraph 3.2) regards a private residential building in the demo-district Johannstadt which will not be newly built but only retrofitted depending on latest technical standards. These measures only consider the power supply system with the installation of a modern PV system on the roof-top and the participation of all tenants in the tenant electricity model. Because of the late construction year in 1990, the building envelop will not be improved during the MAtchUP project as it already corresponds to a good energetic standard. The focus of baseline data definition is thus put on the power supply system.

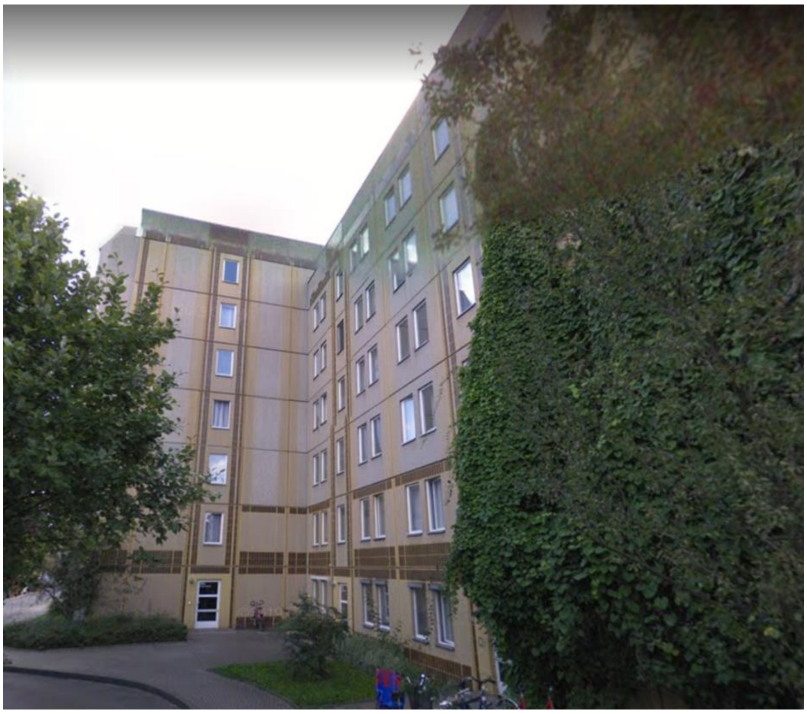

Figure 12: Retrofitted building in the demo-district in the Johannstadt

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The building is based on the GDR construction standard WBS 70. It has a total net floor space are of 3,120 m^2 and is thus about three times bigger than the Intervention 1 object.

It will be equipped with a 33 kWp photovoltaic system on the roof-top which will mainly supply the power to the inhabitants of the 61 flats inside the building. The developed tenant electricity model is thus again in focus of the considerations of all corresponding actions of this intervention. Though, there are monthly measurements of total power and heat consumption available for the baseline period. But measurement data with higher temporal resolution to identify monthly power peaks are missing and must be calculated via suitable simulation models.

This baseline model needs to take into account the existing measurement values during the months of the baseline period as well as again a model-based distribution of monthly consumption values on a higher temporal resolution (i.e. 1h for heat, 15min for power supply). This synchronization is one of the main aspects of the chosen modelling approach.

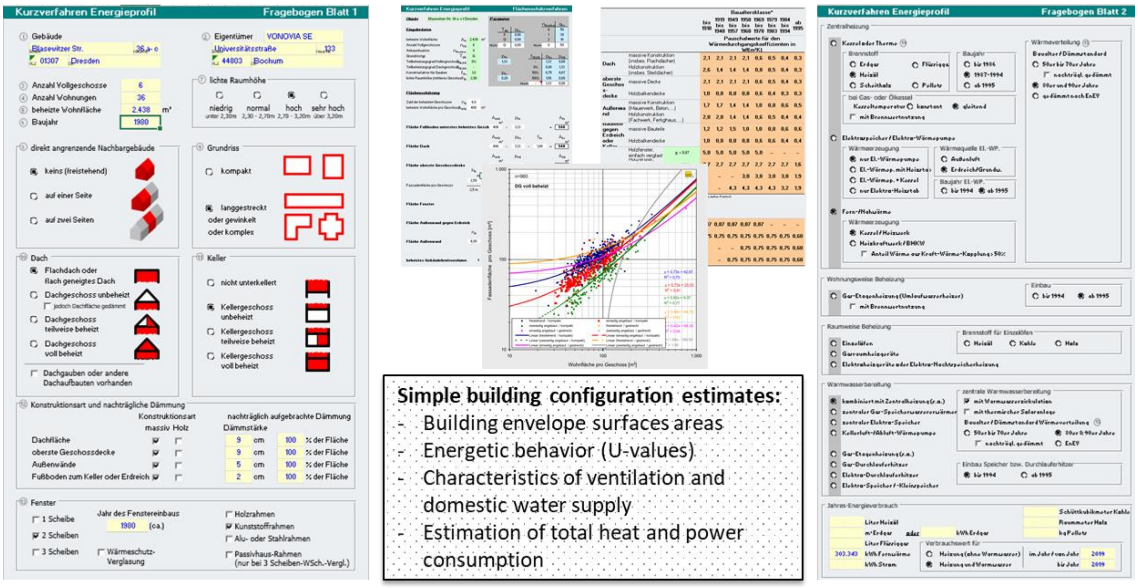

Figure 13: Parameterization template of the building model

Figure 13 shows the parameterization template of the applied modelling approach. It is based on the IWU “Kurzverfahren Energieprofil” method (Loga et. al., 2005). This method uses results of a scientific study which collected a wide range of data of the German building stock, especially regarding residential buildings. These data correlate building envelop parameters (i.e. wall, floor, ceiling sizes) with basic characteristics (e.g. net floor space area, number of storeys, etc.) and thus provides a statistically valid representation of the considered building with a minimum number of required parameters.

The method also correlates building age as well as different energetic standards and types of the heat supply system with average annual heat consumption. This correlation furthermore indicates suitable values of specific heating system parameters

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(e.g. heat losses of heat and domestic water supply) and thermal building characteristics (e.g. U-values).

This method is especially valid for the aim of baseline data definition because the considered residential building represents a standard building type with high conformity with energetic statistics.

However, those monthly or annual assumptions of the final energy demand for space heating and domestic water supply are not the actual results needed to define the required missing baseline values. Especially the case that monthly measurement data for total heat and power consumption of the building during the baseline period are available, again highlights this aspect.

But the presented statistics-based building simulation approach can be used in an inverse way to derive the required parameters for a detailed high-temporal building simulation model after an iterative model calibration with the available measurement data. These parameters were then used again in an MS Excel-based approach (c.f. intervention 1 in paragraph 4.1) to define the necessary load profile for total heat consumption based on measured weather characteristics and standard domestic hot water consumption profiles.

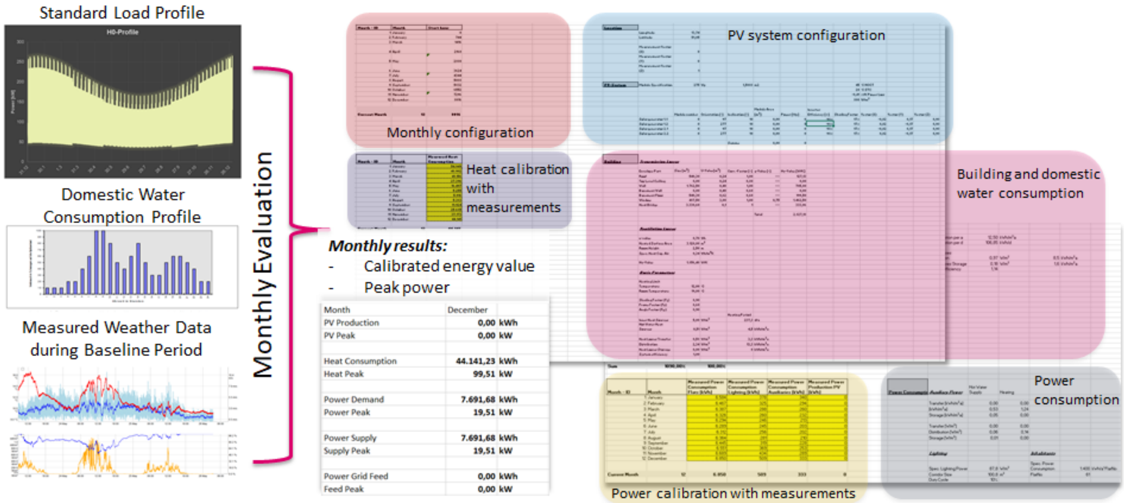

Figure 14: Enrichment of identified building parameters with available profile characteristics

Like in Intervention 1, heat and domestic hot water supply is not the only aspect of the baseline data definition. The total power demand is the second important domain to be monitored within the energy interventions in the MAtchUP project. Again, monthly power consumption data of the considered building of Intervention 2 is available from measurement data but monthly power peaks do not exist.

The above described building simulation model provides besides the thermal building and energy system parameters also some additional information about the building's auxiliary energy consumption for the circulation pump operation and so on. These parameters will be added to the MS Excel calculation framework as an almost constant power consumption profile during their operation time. The same approach is used for the building internal lighting outside the flats during the night times.

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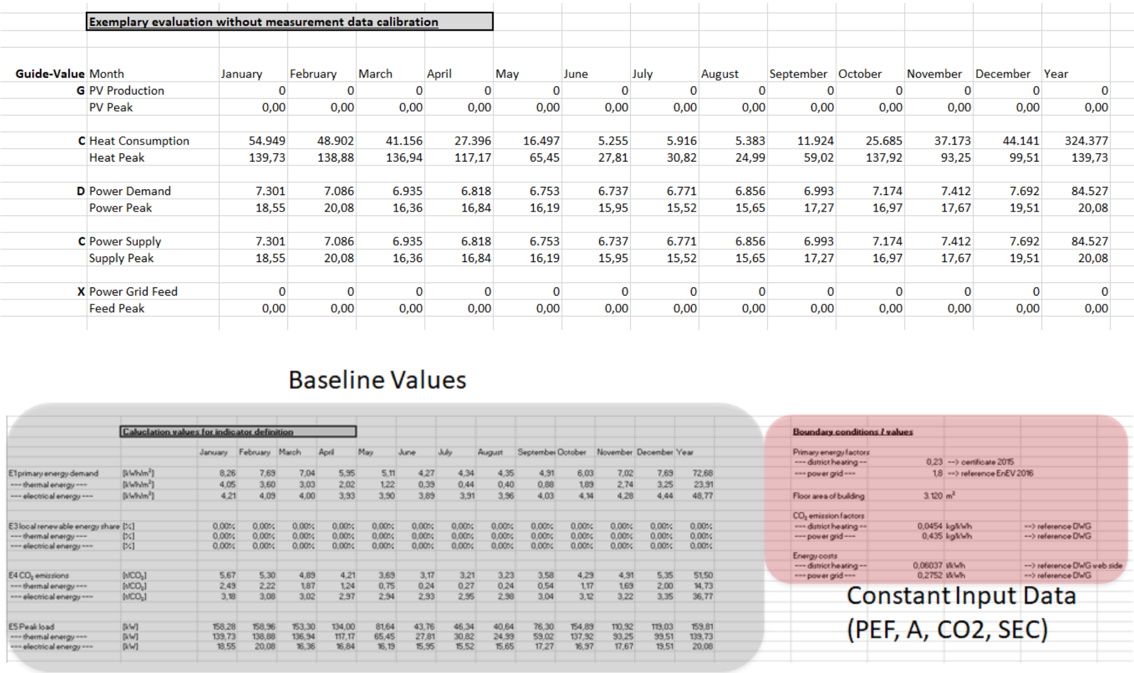
However, the total power consumption of the building again mainly depends on the power consumption by the inhabitants in the flats which are separately measured. To ensure GDPR conformity, these data are only available and used in an anonymous and accumulated way. Individual rights within the meaning of the GDPR are not affected. To find a right representation of the final power consumption in the flats with the required temporal resolution of 15min, the already presented approach of Intervention 1 (c.f. paragraph 4.1) was used, again. Based on a comparison of available measurement data of similar building types as well as available profile types, a hybrid approach was used to define the resultant inhabitants' power consumption with a multi-agent-simulation based power profile (c.f. Figure 9).



Exemplary evaluation without measurement data calibration

Guide-Value	Month	January	February	March	April	May	June	July	August	September	October	November	December	Year
G	PV Production	0	0	0	0	0	0	0	0	0	0	0	0	0
	PV Peak	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C	Heat Consumption	54.949	48.902	41.156	27.396	16.497	5.255	5.916	5.383	11.924	25.685	37.173	44.141	324.377
	Heat Peak	139,73	138,88	136,94	117,17	65,45	27,81	30,82	24,99	59,02	137,92	93,25	99,51	139,73
D	Power Demand	7.301	7.086	6.935	6.818	6.753	6.737	6.771	6.856	6.993	7.174	7.412	7.692	84.527
	Power Peak	18,55	20,08	16,36	16,84	16,19	15,95	15,52	15,65	17,27	16,97	17,67	19,51	20,08
C	Power Supply	7.301	7.086	6.935	6.818	6.753	6.737	6.771	6.856	6.993	7.174	7.412	7.692	84.527
	Supply Peak	18,55	20,08	16,36	16,84	16,19	15,95	15,52	15,65	17,27	16,97	17,67	19,51	20,08
X	Power Grid Feed	0	0	0	0	0	0	0	0	0	0	0	0	0
	Feed Peak	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure 15: Calculation of baseline values based on model results

The resultant baseline value calculation framework integrates the monthly measurement data of total heat and power consumption as well as the developed calibrated consumption profiles. The framework results then provide the required monthly peak values which are correlated with the available measurement data.

4.3 Intervention 3

The Dresdner district heating system is a networked asset, consisting of various producers of heat (cogenerated/ CHP or non-cogenerated/ heating plants as well as electrode boilers), networks, distribution and customer stations. Individual actions can only be sensibly evaluated by considering the entire system. There is a multitude of technical and economic dependencies between the linked assets. In Intervention 3 it initially is planned to demonstrate the ecological and economic benefits of the extension of the district heat storage and to evaluate them with the help of KPI's, for which complex simulation models were developed in BoFit. The existing heat storage capacity of 6,600 m³ was extended to 13,600 m³. The advantage of this storage extension was determined and proportionally related to the MAtchUP development area "Johannstadt" during the project period.

Further actions are implemented (LowEx or feeding RES into the district heating network) and integrated and evaluated in the simulation tool BoFit.

Simulation using the mathematical model „BoFit“

As already described in chapter 3.3, complex optimisation tasks can be modelled, solved, exported into common formats and graphically prepared by means of BoFit. In this way, energy plants can be modelled and their optimum design point determined, with temporal resolutions ranging from a few days to a year. With the help of the simulation software BoFit, two sensitivity analyses of the Dresden district heating supply are presented under consideration of the two storage tank sizes, thus enabling a comparison.

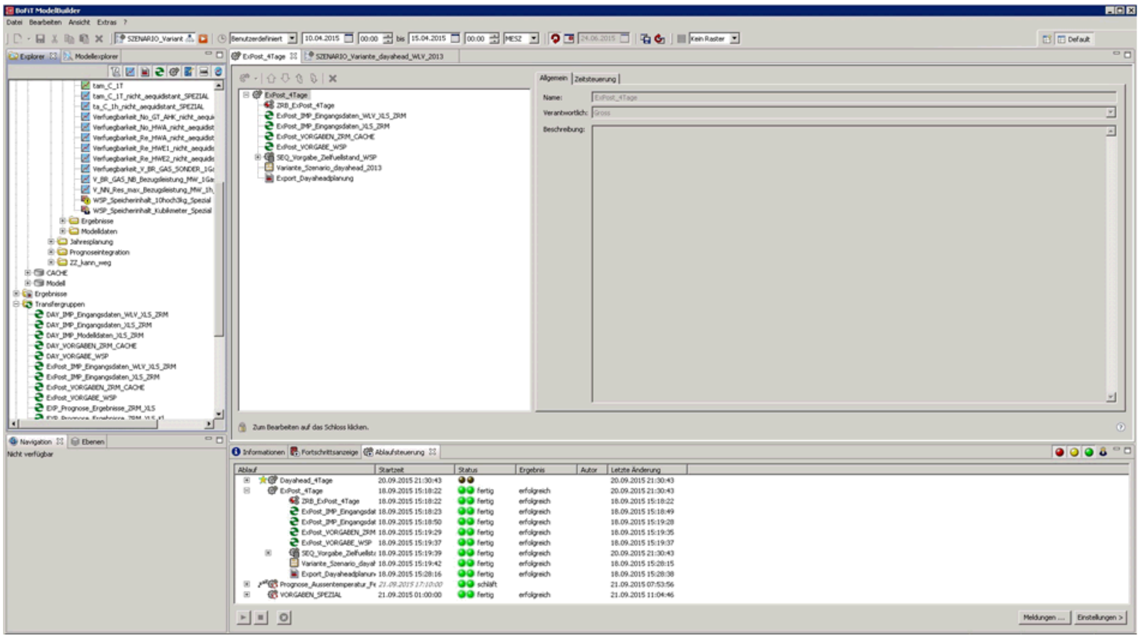


Figure 16: graphical surface of the simulation model software

The created model defines an objective function with linear dependent parameters, which is defined by the input of the following boundary conditions:

- load profiles
- time series of heat demand district heating network, outside temperatures, air pressure and spot market prices of electricity
- capacities, characteristic curves, availabilities, minimum running times and downtimes of the power plants and their components
- capacity, or volumes, maximum charge/discharge capacity, heat losses of the thermal heat storage
- characteristics and capacities of hot water pumps
- outdoor temperature-dependent inlet and return temperatures of the district heating network
- maximum gas supply
- prices for natural gas, CO_2 certificates, fees for avoided grid usage

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While the boundary conditions in the model are in turn stored by functions, the balances of the model are maintained by the formulation of inequalities. The objective function is to minimise the total cost of the simulation model, which is solved with the help of the solver GUROBI[15].

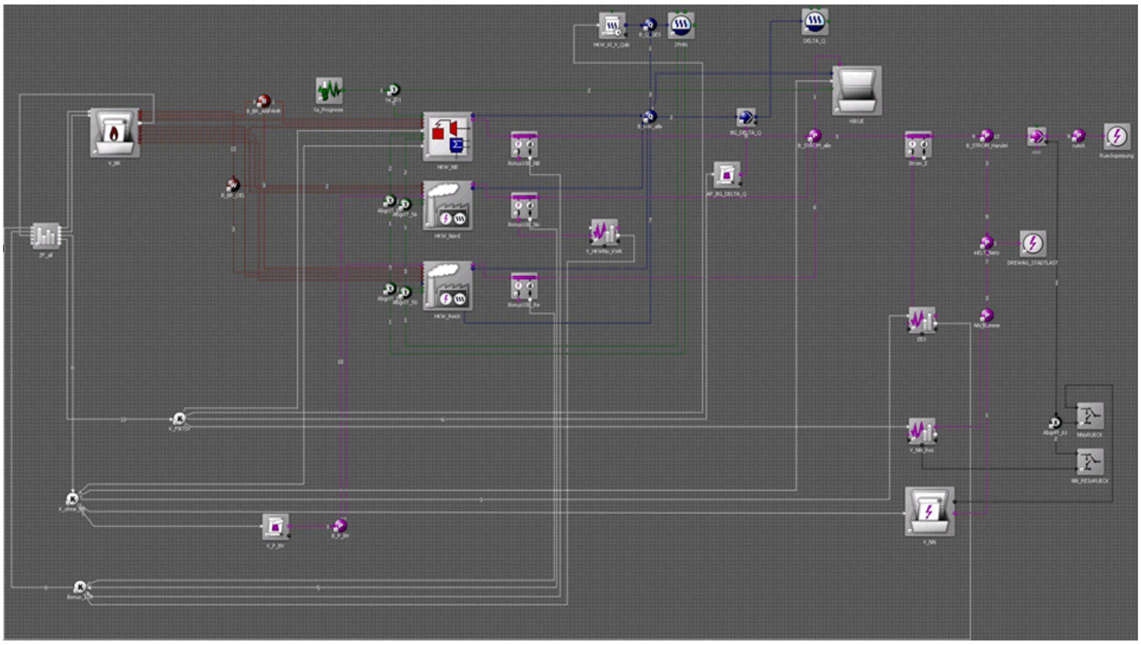

Figure 17: simulation model for optimisation in BoFit

The results of the simulation are hourly granulated energy balances for the Dresden cogeneration plants for a period of one year, taking into account storage loading and unloading processes. Figure 18 shows the simulated heat load curve for the storage tank expansion for one week as an example.

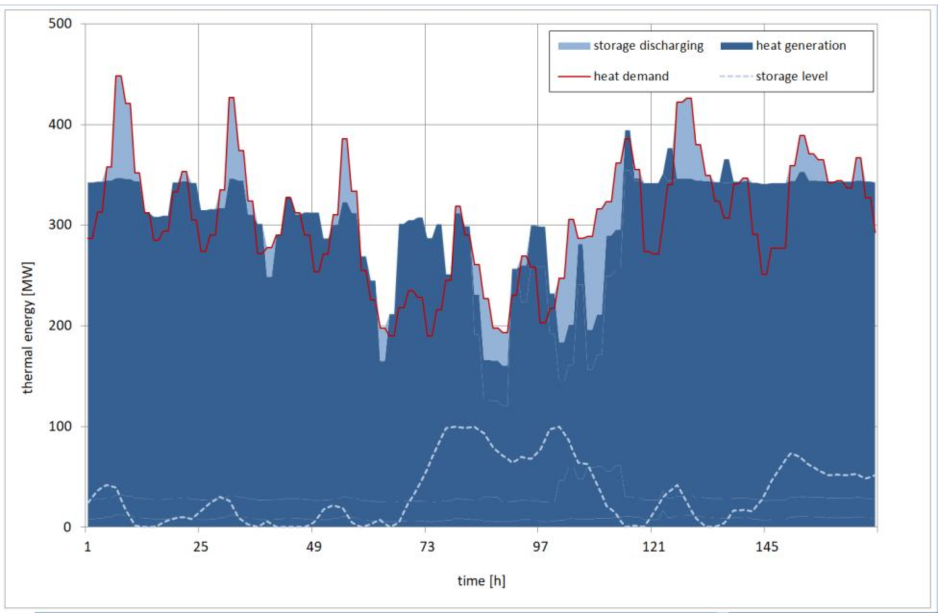

Figure 18: heat load profile with 13.600m³ thermal storage

[15] https://www.gurobi.com/de/, date: 16/09/2020

This simulation is carried out for two storage volumes and forms the basis for some Technical Indicators of Intervention 3. The effectiveness of the simulation in BoFit is determined by considering the difference with vs. without their implementation.

Calculation of primary energy savings

Within the city of Dresden, heat is generated almost entirely by combined heat and power generation. The city of Dresden can therefore prove a low primary energy factor of p_{PEF} = 0.23 for its own heat supply. The advantage is that the fuel utilisation of the energy source natural gas is significantly improved when electrical and thermal energy are produced in a combined system. With the enlargement of the storage facility it is possible to increase the CHP share in the energy supply. The energy saving represents the difference in the thermally stored energy with different storage tank sizes.

Table 13: increased thermal energy depending on the storage size (simulation)

in MWh_{th}/month	April	May	June	July	August
storage 6,600 m³	9,153	6,882	7,660	9,824	9,968
storage 13,600 m³	10,685	8,300	8,625	11,043	11,964
delta	1,532	1,418	966	1,219	1,996

This difference represents an additional expenditure on combined heat and power generation, which leads to primary energy savings in comparison to a normal combined heat and power plant. For the partial calculation of the MAtchUP lighthouse district Johannstadt, the district heating requirement of Dresden was procured retrospectively for the reference year 2018 from the DWG/ENSO internal accounts. From these values, the share of the MAtchUP test area was isolated and the ratio to the total demand of the lighthouse city Dresden was calculated for each month. Depending on the month, the share of the MAtchUP assisted area "Johannstadt" is approx. 1.0 - 2.5 % of the city's total district heating requirements. With the help of this ratio, it is ultimately possible to determine the primary energy savings of the storage facility in relation to the MAtchUP lighthouse district Johannstadt on a proportional basis.

Table 14: savings in primary energy in the MAtchUP district

in MWh_{PE}/month	April	May	June	July	August
ratio district heating MAtchUP/Dresden	2.02 %	1.75 %	1.33 %	1.13 %	1.03 %
Saving MAtchUP lighthouse district Johannstadt	30.9	24.6	12.8	13.7	20.3

Reduction of CO_2 emissions

Heat accumulators as a component of linked CHP systems can respond better to price signals from the stock exchange. As a result, emission-saving CHP generators can be

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used for longer. The simulation shows that more electricity is generated from combined heat and power generation when the storage capacity is expanded, which in particular displaces conventional non-combined power plant capacities (coal-fired power or gas-fired power plants). As the emissions for a combined heat and power generation are lower than in conventional power plant units, the CO_2 savings can be calculated by using a factor for the displacement mix. According to the German "Forschungsstelle für Energiewirtschaft", the factor is "a simplified approach that assesses the environmental impact of the electricity generation mix that can be displaced by additional (marginal) electricity generation from combined heat and power plants".[16] This factor is p_{Mix} = 0.624 t_{CO2}/MWh_{el} and refers only to the electricity share of CHP. Electricity from renewable energy sources is not displaced, as this has priority in the grid feed-in by legal regulations. From the BoFit simulation results, a difference can be calculated between the electricity and heat quantities for different storage sizes and multiplied by the factor for the displacement mix, or the emission factor for natural gas p_{NG} = 0.202 t_{CO2}/MWh_{fuel}. The emissions for non-coupled supply are added together.

Table 15: emissions of non-combined energy generation

per month	April	May	June	July	August
electric power generation in MWh_{el}	1,840	1,502	2,334	3,456	3,374
fuel demand for heat generation in MWh_{th}	2,271	1,854	2,882	4,267	4,165
Resulting emissions non-CHP in t_{CO2}	1,607	1,312	2,039	3,018	2,947

In contrast, there are emissions from CHP. The difference between non-CHP and CHP energy supply relates to the entire urban area and can be calculated proportionally for the MAtchUP lighthouse area.

Table 16: avoided emissions by enlargement of storage

per month	April	May	June	July	August
Equivalent emissions CHP in t_{CO2}	923	753	1,171	1,734	1,693
delta non-CHP/CHP in t_{CO2} (avoided emissions)	684	559	868	1,284	1,254
part of MAtchUP district in t_{CO2}	13.8	9.8	11.5	14.5	12.9

[16] taken from the German „Forschungsstelle für Energiewirtschaft", date: 16/09/2020, https://www.ffe.de/themen-und-methoden/erzeugung-und-markt/797-eu-verdraengungsmix-ein-vereinfachter-marginaler-ansatz-zur-bestimmung-der-umweltwirkungen-fuer-gekoppelte-waerme-und-stromtechnologien

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The sensitivity analyses of the BoFit simulation with different memory sizes are continuously updated for the coming reporting periods.

4.4 Intervention 4

The Intervention 4 describing the development of the Building Control Center (BCC) in the city of Dresden which provides higher-order control functions and optimization of the energy supply systems of the public buildings in the demo-district Johannstadt didn't need any simulation models for the baseline data definition.

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5 Conclusion

This deliverable introduces the methodological tools for determining through mathematical models any data necessary for calculating an indicator, when data cannot be directly measured. It provides information about those actions of Dresden that need simulation and also informs about the actions that use mathematical models for the calculation of indicators defined in deliverable D5.1.

The deliverable is linked with Task 3.2 “Baseline of interventions definition”, more specifically Subtask 3.2.1 “Simulation models (buildings, energy systems, city infrastructures) and in continuation of D3.2 (M24), D3.15 is the final version of the document (M38). It mainly adds the description of developed models for the baseline data definition as well as a summary of the simulation methodology that includes tools used and characteristics, model description and boundaries, input data obtained as well as assumptions and calibration/validation measures of any type of developed simulation model within the energy-related actions in MAtchUP.

The IPMVP has been introduced with its options A to D, how energy savings can be measured. With the help of the IPMVP protocol those actions have been identified that are considered as option C and D and use mathematical or simulation models.

This IPMVP based analyses show that simulation models are only required in four out of five energy interventions in Dresden. Furthermore, only three of them need such mathematical models for the baseline data definition. Interventions of transportation and urban infrastructure, so as ICT-related and non-technical-related interventions don’t require no simulation models for defining the baseline.

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