ambience

Active managed Buildings with
Energy performaNce Contracting

Deliverable Number (D2.2)

Proof-of-Concept of an Active Building Energy Performance Modelling framework

The AmBIENCe Consortium

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AUTHOR (S)	Chris Caerts, Jef Verbeeck (VITO), Miguel Casas (Energinvest).
OFFICIAL REVIEWER/s	Nilufar Neyestani (INESC TEC), Ricardo Ramos (EDP CNET), Lieven Vanstraelen (Energinvest), Annick Vastiau (VITO).

EXECUTIVE SUMMARY

Deliverable D2.2 “Proof-of-Concept of an Active Building Energy Performance Modelling framework” documents the proof-of-concept version of the ABEPeM (**A**ctive **B**uilding **E**nergy **Pe**rformance **M**odelling) platform that supports the Active Building Energy Performance Contracting (AEPC) concept and methodology.

Specifically, and differentiating it from traditional Energy Performance Contracting (EPC) saving estimation tools, the ABEPeM platform supports a scenario-based model-driven quantification of additional Demand Response (DR) related savings and value streams resulting from the active control of flexible assets. This is coupled with an IPMVP-based M&V functionality to support performance guaranteeing and settlements based on effective and transparent (Non-) Routine Adjustment factors.

The platform is composed of a number of well-defined modules fitting together in a modular and flexible platform architecture, to maximize the replication potential by enabling specific stakeholders to create their own version or flavour of specific modules and functionalities themselves, and/or include modules from specific preferred partners.

In the scope of the AmBIENCe project, only a proof-of-concept platform will be developed to validate the AEPC methodology and to be used in and support the pilots contracting phase. Potential exploitation strategies and routes including specific productization plans will be elaborated in the work package 5 “Economic evaluation, exploitation and replication”. These will consider the learnings and feed-back collected through the work package 3 pilots.

The target users of the ABEPeM platform are Energy Service Companies (ESCOs) that want to quantify the DR valorisation potential for multiple design options including electrification, local renewable generation, flexibility and storage, and combine these results with an economic and financial analysis, embedded in an energy performance contracting concept.

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1. INTRODUCTION – KEY REQUIREMENTS

The two key functionalities that must be provided by the **A**ctive **B**uilding **E**nergy **Pe**rformance **M**odelling (ABEPeM) platform to support the AEPC concept and methodology are:

- The quantification/estimation of the **energy cost cash flow** before and after the EPC measures; specifically taking into account the impact of Demand Response related measures and the active control of demand-side flexibility and storage;
- The calculation of relevant **economic and financial Key Performance Indicators (KPIs)** taking into account the cash flows related to investments and optionally financing, and changed operational expenses and income related cash flows including these energy cost cash flows.

The energy cost **performance guaranteeing and verification** is done in line with the well-established **International Performance Measurement and Verification Protocol** (IPMVP) methodology. The energy cost cash flow quantification/estimation is done for an explicitly defined and agreed scenario and associated **(Non-) Routine Adjustment factors**[1]. This way, the operational phase measured performance can be recalibrated with these (Non-) Routing Adjustment factors to account for deviations between the agreed scenario for which the performance guarantee was given, and the operational phase actual conditions.

While the IPMVP methodology makes it possible to recalibrate the measured operational phase performance to account for deviations between the agreed scenario and the operational phase actual conditions, it does not address the challenge of being realistic (scenario) and not overly optimistic (not all-knowing).

To ensure that realistic and achievable performance forecasts are given, **realistic scenarios** must be used. Furthermore, **operational phase limitations** that may impact the optimality of the operational phase active control, like model or forecast errors, or flex asset control limitations, must as much as possible be taken into account.

To maximize the openness and replication potential of the proof-of-concept version of the platform, a **modular and flexible platform architecture** has been defined that fits together a number of well-defined functional building blocks / modules, each of which could be replaced or developed by a third party.

[1] (Non-) Routine Adjustment factors refers to both Non-Routine Adjustment factors and Routine Adjustment factors.

2. SCENARIOS, DESIGN OPTIONS AND PERFORMANCE DEFINITIONS

For a complex endeavour as the AEPC concept, consistent naming and use of key terms and concepts is important.

Building/project Baseline

The baseline refers to the as-is situation at the start of the project, before any measures are taken.

Design Options

A design option refers to a – set of – measures that are considered and/or implemented in the scope of an AEPC project, with the purpose to reduce energy, energy cost, and emissions:

- passive envelope measures: e.g. improving wall or roof insulation level, replacing glazing, etc.;
- infrastructure measures: e.g. HVAC replacement, heating distribution upgrades, switching to heat pump (HP), adding photovoltaic (PV), adding electrical vehicle charging infrastructure, adding storage (thermal or electrical), etc.;
- active control (operational) measures: e.g. actively steer demand side flexibility including conversion (e.g. Power-to-Heat) and storage (e.g. thermal storage tanks, batteries).

The ABEPeM platform will be able to quantify the performance impact of a given design option in comparison with baseline building's performance.

Scenarios

A scenario refers to a set of future parameters and influencing factors that have an impact on the building's performance:

- Financial parameter related: price inflation and indexation, financing conditions, etc.;
- Energy price related: changing tariffs, changing tariff structures, changing regulation;
- Weather condition related: temperature, solar irradiation, etc.;
- User behaviour related: comfort setpoints, comfort boundaries (that offer flexibility), sanitary hot water usage, electric vehicle (EV) usage, etc.

Scenarios must be realistic to not raise unrealistic expectations. Scenarios (by definition) are not correct: the impact of deviations between the scenario for which performance is quantified and actual future conditions and events is addressed in the IPMVP methodology through the (Non-) Routine Adjustments.

Performance definitions

- **baseline performance** refers to the building's historical performance before any measures are applied.
- **adjusted baseline performance** refers to the baseline performance adjusted for the (Non-)Routine Adjustments as defined in the IPMVP methodology.
- **reference performance** refers to the forecasted performance resulting from the measures that are defined/selected in the design option and for the scenario that is defined/selected. In our AEPC concept, we will distinguish between reference performance resulting from:
  - passive measures only (= reference performance 1),
  - passive measures plus infrastructure measures (= reference performance 2),
  - passive measures plus infrastructure measures plus operational active control measures (= reference performance 3)
- **actual performance** refers to the measured performance during the AEPC operational phase.

A schematic overview of the four performance definitions is shown in Figure 1.

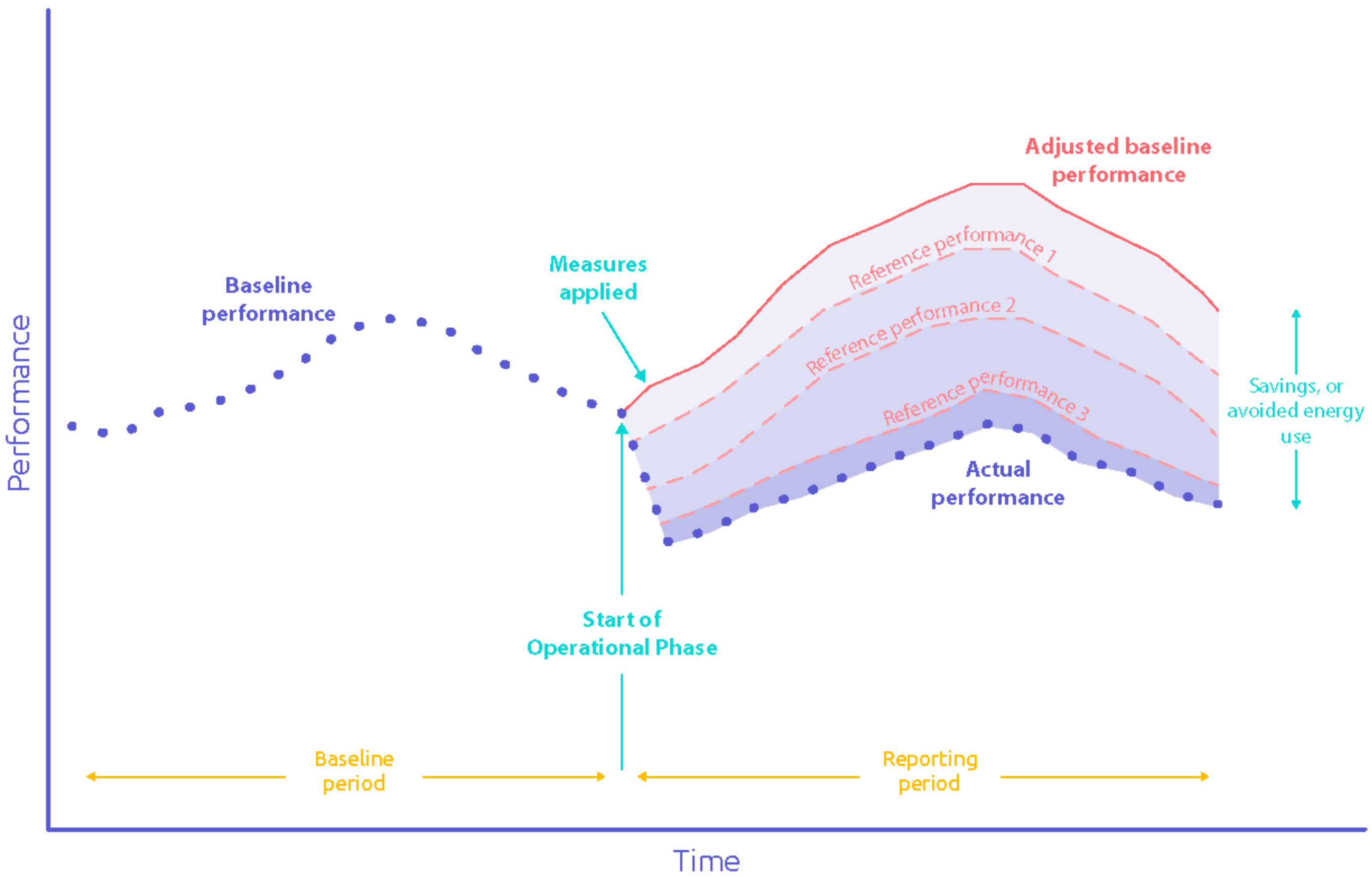


FIGURE 1 – ILLUSTRATION OF THE FOUR ENERGY PERFORMANCE DEFINITIONS

In the case of AEPC, performance does not only refer to energy performance, but also to cost performance, i.e. including energy costs and revenues related to DR.
Multiple options for determining performance and related savings exist, depending on the boundaries of the measurements (e.g. for an individual energy conservation measure; for the whole building) and depending on the availability of data. Measurement of all parameters (e.g. energy consumption) or only some parameters (e.g. power, multiplied by assumed working hours) might be involved. More information can be found in the IPMVP Core document[2] that defines the four common calculation methodologies (A/B/C/D).

Forecast categories

- In the **contracting phase**, **scenario-based forecasts** are created from scenarios and are used as forecast inputs to the scenario-based model-driven MPC (Model Predictive Control) optimization. The **scenarios themselves** are used as forecasts of actual future conditions in the not all-knowing digital twin simulation. See section 3.1 for more details.
- In the **operational phase**, **operational forecasts** are created by a forecaster algorithm/model as input for the active control decisions.

[2] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp.

3. ABEPEM PLATFORM KEY FUNCTIONALITIES AND MODULES

Based on the functionalities and requirements of the ABEPeM platform that are described in the previous sections, the following key modules (functionalities) are defined (see Figure 2).

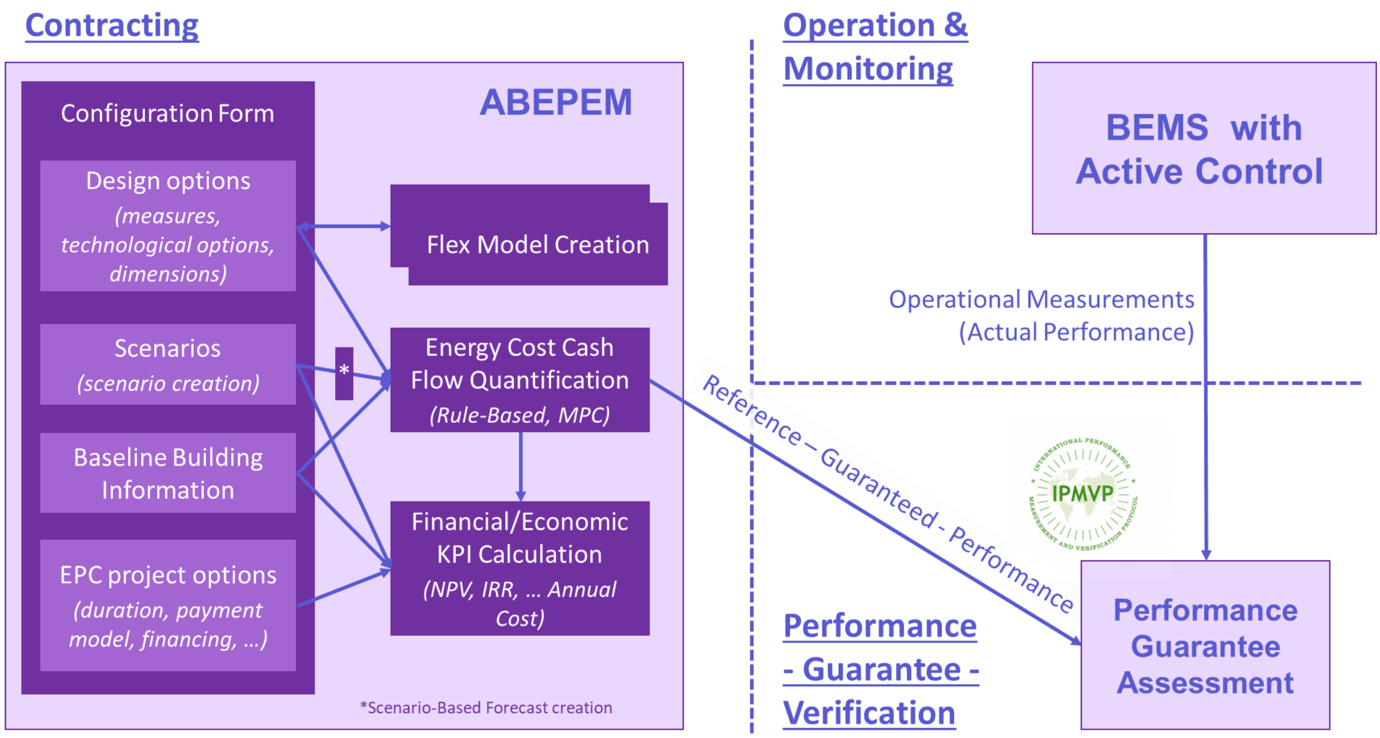


FIGURE 2 – ABEPEM PLATFORM KEY MODULES/FUNCTIONALITIES AND ITS PLACE IN THE AEPC PROCESS.

In the next sections, the following key functionalities/modules will be described in more detail:

- the **Configuration Form** collects all relevant project information including design options and scenarios;
- the **Flex Model creation** module creates the necessary building and asset models that are required for the scenario-driven model-based performance quantification;
- the **Energy Cost Cash Flow Quantification** module performs the scenario-driven model-based performance quantification;
- the **Financial/Economic KPI Calculation** module determines the relevant financial and economic KPIs to compare the impact of selected design options;
- the **Scenario Creation** module provides the scenario that will be used in the performance quantification and for which the performance could be guaranteed;
- the **Scenario-based Forecast Creation** module creates from the selected scenario a forecast that will be used for the performance quantification.

3.1. ENERGY COST CASH-FLOW QUANTIFICATION MODULE

3.1.1. SCENARIO-DRIVEN MODEL-BASED QUANTIFICATION

The Energy Cost Cash Flow Estimation module provides a **scenario-driven model-based** quantification of a building's energy cost by doing an MPC based optimization[3] to determine the optimal power consumption profile at a sufficiently high time resolution (e.g. 15 minutes) for a given objective. The optimization mimics the decision taking in the operational Building Energy Management System (BEMS). For this, it uses models of the flexible assets that describe in which ways their consumption profile can be altered, in combination with relevant forecasts that are derived from the selected scenario. The optimization objective typically is an energy cost minimization, but other objectives like maximizing self-consumption or self-sufficiency or minimizing carbon emissions are supported as well. The resulting power consumption profile is combined with financial information (i.e. tariff information and DR incentives) to calculate the energy cost cash flow. Besides, this power consumption profile can be combined with carbon intensity profile information (e.g. gram CO_2/kWh) to calculate the corresponding emission profile.

For a given design option, i.e. selected measures including asset selection and dimensions, this module determines the optimal power consumption profile from which the energy cost cash flow profile and emission profile are derived. This can be done taking into account passive envelope measures only, or with added infrastructure measures, or with added simulated active control measures that apply DR optimizations. The current interface between the Energy Cost Cash-flow Quantification module and the Economic and Financial and Economic Calculation Module only communicates performance related to energy efficiency measures plus infrastructure measures (EEM), and performance related to additional DR optimizations (EEM + DR). This way, the impact of DR valorisation can be quantified, and multiple design options of passive envelop measures and infrastructure measures can be compared against each other. Besides varying the building design options, also multiple scenarios related to future conditions and evolutions can be applied, and their impact of varying assumptions can be analysed as well. An example quantification is shown in annex 1.

3.1.2. IMPROVING REALISM BY INTRODUCING NOT ALL-KNOWING QUANTIFICATION

The MPC optimization mimics the decision taking in the operational BEMS, based on forecasts and models. When quantifying the valorisation potential of Demand Response activations this way, the obtained result may be overly optimistic because it implicitly assumes an all-knowing optimization based on perfect forecasts and models and a fully deterministic control. To obtain more realistic results, a two-step approach of an MPC optimization followed by a simulation has been implemented. By feeding the simulation with scenario data, and the MPC optimization with scenario data with a superimposed error signal, the impact of forecast errors can be analysed. By using a different building model in the MPC optimization and the

[3] Also a simpler rule-based optimization approach is supported.

simulation, the impact of model errors can be analysed. And by driving the simulation with a power consumption profile that deviates from the optimal power consumption profile that was determined by the MPC optimization, the impact of non-deterministic control can be analysed. This way, a not all-knowing value quantification can be done, that can account for the impact of non-perfect forecasts and models, and non-deterministic control.

In the first step, an MPC optimization is done that uses forecasts that are derived from the scenarios by applying a stochastic perturbation on them. The resulting consumption profile is then also undergoing a perturbation before it is fed to a Digital Twin simulation that uses (slightly) different models than the ones used in the MPC. The resulting simulated next state is then fed back to the next MPC optimization cycle. By implementing this combination of optimization and simulation, we can account for the impact of non-perfect models, non-perfect forecasts, and even for non-deterministic control[4].

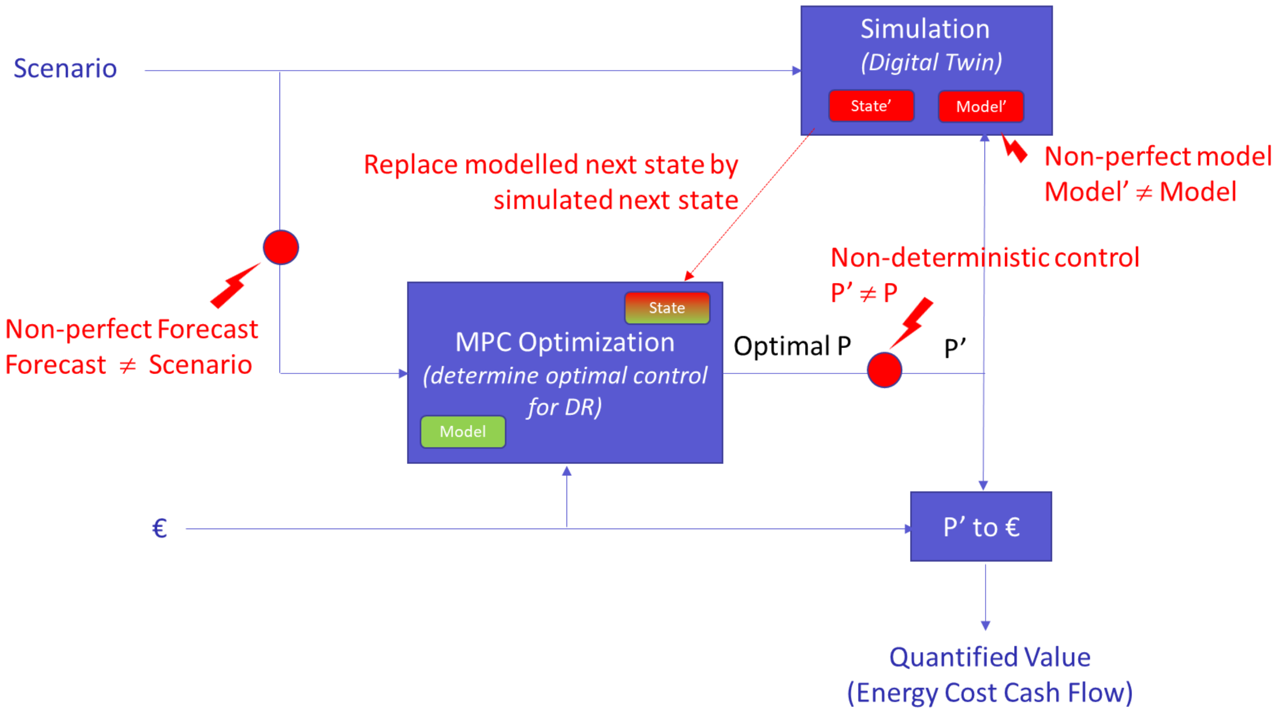


FIGURE 3 – TWO-STEP MPC OPTIMIZATION FOLLOWED BY DIGITAL TWIN SIMULATION TO CORRECT FOR OVERLY OPTIMISATIC ALL-KNOWING QUANTIFICATION.

[4] The actual power consumption profile, hence the system's state change resulting from that, may deviate from the optimal power consumption profile that was determined by the MPC optimization. This can be due to non-modelled asset limitations (like modulation step granularity) or errors in the 'control signal to power consumption' models that are used in the MPC optimization.

The MPC optimization can be done for both Implicit and Explicit DR. The Implicit DR optimization is based on a tariff structure scenario that may contain dynamic prices, a capacity tariff, or a differentiation between offtake and injection tariffs. This gives the opportunity to minimize the energy cost by actively steering consumption to times when the prices are low, to self-consume self-generated PV energy, and/or to avoid consumption peaks. I.e. when energy is consumed, is important. The Explicit DR optimization is based on a flexibility activation request scenario, that gives the opportunity to earn incentives by altering consumption in line with the received request.

Typically, an analysis hence quantification must be done for a long time period (e.g. 20 year to over 40 year) with a small-time resolution to capture the dynamic nature of flexibility, tariffs and other influencing factors. To speed up the analysis time, a limited number of 'typical days' may be derived from the provided scenario to speed up the process.

The performance quantification is done in such a manner that performance guarantees can be monitored and verified through the IPMVP process based on the agreed (Non-) Routine Adjustment parameters.

3.1.3. SUPPORTED FLEX ASSETS

The MPC Optimization module is created as a modular and highly configurable multi-energy multi-objective optimization engine (see Figure 4). It can handle a wide variety of consumption, generation and storage assets, including conversions between energy carriers like Power-to-Heat. Specific examples of flexibility usage resulting from demand side flexibility, storage and conversion are:

- Sheddable, shiftable and interruptible loads,
- Space heating/cooling,
- Sanitary hot water production,
- EV charging,
- Stationary batteries,
- Thermal storage tanks.

These flexible assets have the capability that their consumption profile can be altered (increased/decreased, shifted, modulated) within certain limits. The optimization determines for each of them the optimal consumption profile taking into account asset related constraints (e.g. battery maximum charging/discharging power) as well as state constraints (e.g. comfort setpoints or hot tap water profiles) in combination with relevant forecasts.

The Energy Cost Cash Flow Quantification module gets the relevant information pertaining to the available flex assets and their connection to energy vectors, as well as their relevant characteristics and constraints, from a JSON[5] configuration file.

[5] JSON (JavaScript Object Notation) is a lightweight data-interchange format that is easy for humans to read and write, and easy for machines to parse and generate.

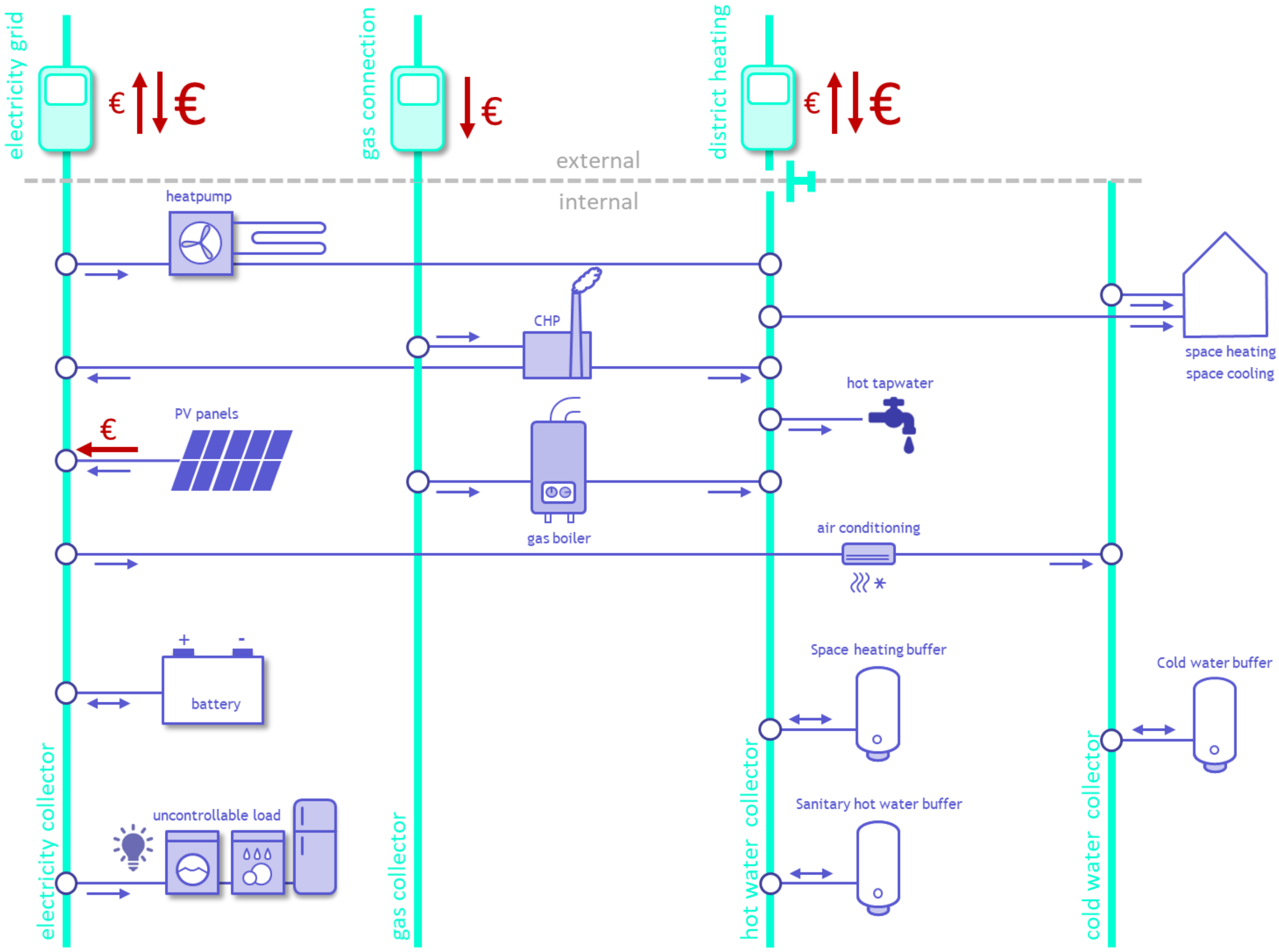


FIGURE 4 – MULTI-ENERGY MULTI-OBJECTIVE OPTIMIZATION ENGINE.

3.1.4. SUPPORTED PERFORMANCE METRICS AND OPTIMIZATION OBJECTIVES

The MPC optimization algorithm of the Energy Cost Cash-flow optimization module can optimize for either one of the supported optimization objectives: minimal kilowatt hour (kWh), minimal energy cost, minimal grid injections, maximal self-consumption, minimal emissions.

As the result of the optimization for a selected objective, it provides as well the quantified metrics for all other performance metrics.

3.2. CONFIGURATION FORM

The configuration form contains all relevant information that is required for the Energy Cost Cash Flow Quantification module, the Flex Model Creation module, and the Economic/Financial KPI Calculation module. This information can be grouped into:

- EPC Project Options information:
  - Beneficiary type: Owner-Occupier or Owner-Lessor;
  - ESCO contract duration;
  - Total investment;
  - Financing related information:
    - ESCO payment model: First In, First-Out, Shared Savings, or Third Party/ESCO financing based on reimbursement fee.
    - Loan amount, loan term/duration, loan interest.
- Building Information:
  - Asset value information: baseline and after measures (ESCO maintenance fee[6]);
  - Operational Cost information: baseline and after measures;
  - Rent related information (if applicable): baseline and after measures;
  - Building model parameters (characteristics of its dynamic thermal behaviour);
  - (Adjusted) Baseline energy consumption and cost information.
- Measures information including associated investment costs:
  - Envelope Measures information;
  - Infrastructure Measures information: e.g. related to the heating/cooling system and PV installation;
    - HVAC infrastructures,
    - Domestic hot water (DHW) tank parameters,
    - Space Heating buffer parameters,
    - Battery parameters,
    - EV parameters,
    - Shiftable load parameters;
  - Active Control Measures information including optimization objective: minimal cost, minimal injection, minimum emissions, maximum self-consumption, maximum self-sufficiency
- Optimization objective: one of minimal kWh, minimal energy cost, minimal grid injections, maximal self-consumption, minimal emissions.

[6] For preventive and curative maintenance; likely including a guarantee risk fee.

- Scenario information:
  - Energy price profiles, created from a tariff structure scenario (including Implicit DR incentives) and price evolutions scenario. This includes also Explicit DR request profiles and incentives;
  - Price indexing and inflation profiles;
  - Exogeneous parameter profiles:
    - Outdoor temperature profile,
    - Solar Irradiation profile;
  - User usage profiles:
    - Non-controllable load profile,
    - Comfort setpoints and flex setpoint,
    - Sanitary hot water usage profile,
    - EV usage profile.
  - Note: for each of the scenarios, a (Non-) Routine Adjustment must be defined and calculated that serves as the basis for the IPMVP measurement and verification.

3.3. FLEX MODEL CREATION MODULES

Flex Model Creation Modules are optional[7] modules that contain the functionality to determine relevant flex-characterization parameters of the building and selected flexibility assets. This can be done for the baseline building as well as for the building with applied measures. This module can be used if one wants to use building and context specific parameters instead of experience-based rule-of-thumb parameters, to more accurately determine relevant flex-related parameter values.

In the AmBIENCe proof-of-concept platform, only a Flex Model Creation module that creates a building dynamic thermal model represented by an RC Grey-Box model (see Figure 5) is provided. Such an RC Grey-Box model is an electrical equivalence model in which heat losses are represented by resistance (R) values, and heat thermal storage capacities (e.g. in walls, floors or furniture) are represented by capacitance (C) values. Temperatures are represented by voltages (V) and heat flows/transfers are represented by current (I) values. With such an electrical equivalence model, one can model the building's thermal losses and inertia, and the corresponding thermal flexibility in relation to thermal comfort boundaries. Multiple model complexities and topologies are possible, depending on the available measurements and the building's characteristics. The provided RC Grey-Box Model Creation module selects the most appropriate model topology and complexity from a set of templates, and determines the related R and C parameter values.

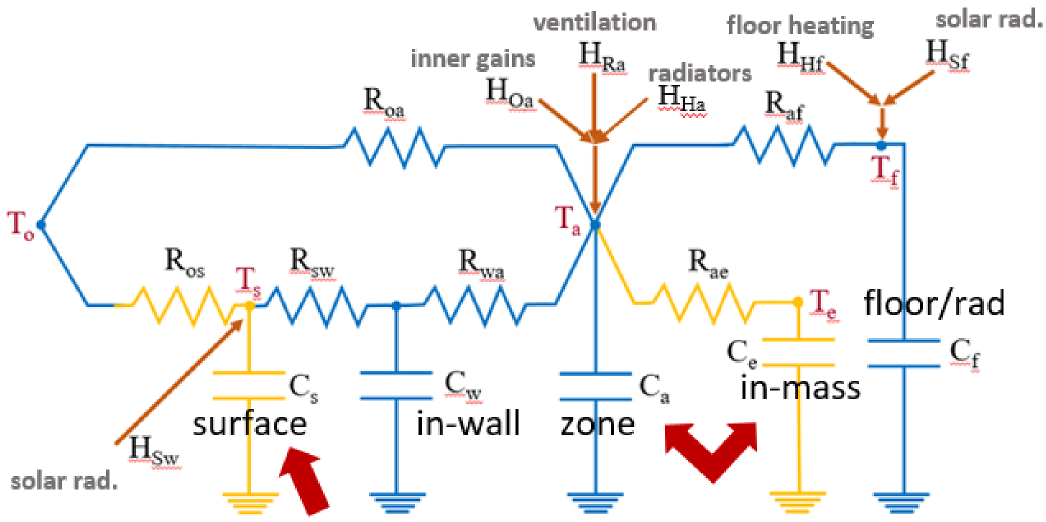


FIGURE 5 – EXAMPLE OF AN RC GREY-BOX MODEL TEMPLATE THAT CHARACTERIZES A BUILDING'S DYNAMIC THERMAL BEHAVIOUR.

[7] Instead of using this module to determine the relevant flex related parameters and feed these back to the Configuration Form, a knowledgeable user may estimate and manually enter these parameters directly in the Configuration Form.

This RC Grey-Box Model Creation module relies on the availability of sufficient measurement data at sufficiently high time resolution (e.g. 15 minutes), and applies data analytics and Machine Learning to select the most appropriate model template along with the best matching R and C values. When such data is not available, one could generate such data from a (simplified) White-Box model of the building, if available. If also this is not available, the RC Grey-Box Model Creation module cannot be used, and one must resort to expert knowledge to estimate proper R and C values based on a number of relevant building parameters and visual inspection.

3.4. ECONOMIC AND FINANCIAL CALCULATIONS MODULE

The Economic and Financial Calculations Module (E&FCM), which is an integral part of the ABEPeM-platform, intends to be a decision-making tool to support specific stakeholders in answering the question whether an investment in selected energy efficiency measures (e.g. HVAC retrofit, relighting, building envelope, on-site renewable energy production, ...) combined with DR flexibility (active control) makes sense from a financial and economic point of view. This would obviously be the case when, for a given project period (usually the lifetime of the asset), the future savings and possible income obtained from the implementation of the EEM and the DR flexibility would be equal to or exceed the initial investment outlay and the additional operating expenses. Thus, this is the module that users (ESCOs and beneficiaries) will use to perform a financial evaluation or build the financial case of the envisaged project. In order to do so, they can take into consideration the KPI shown in the KPI table of the module. The KPI are grouped in Investment, Energy, Financial and Other KPI.

The E&FCM includes the relevant cash flows, discounted to reflect the time value of money, resulting from the investment in the selected energy efficiency measures and the application of active control (DR flexibility) over the analysed or observed period (usually the lifetime of the asset). It shows both the cash flows related to benefits and cost reductions such as energy savings, savings from active control, maintenance savings, additional income (when applicable) and residual building value and cash flows related to relevant expenses such as initial capital expenditures, maintenance, repairs, operating expenses, capital replacements, energy service fees and decommissioning.

In order to provide the additional value of DR Flexibility the E&FCM builds on two different cash flow tables:

- the first one showing the relevant project cash flows after implementation of the EEM only and
- the second one showing the cash flows after the implementation of DR Flexibility (active control measures), thus in addition to the first EEM only scenario.

These two cash flow tables feature all relevant information, on a year-on-year basis, grouped in the following cash flow groups:

- Operating income (e.g. rent, additional income),
- Operating expenses (e.g. rent, rent charges, energy expenses and savings,
- DR Flexibility savings, maintenance expenses and other relevant expenses),
- Initial Outlay (e.g. capital expenditures) and
- One-off Income (e.g. subsidies and residual value of the asset).

Both cash flow tables also include separate financing cash flows to show the effect of the financing cash flows from ESCO (Shared Savings Agreements, First-In First-Out agreements, …) or third-party financing when applicable.

The data in the cash flow tables is being obtained from different input tables and auxiliary tables within the E&FCM. The input tables, including all necessary input variables to run the auxiliary tables and the cash flow tables, are being either fed manually by the user of the E&FCM or by other ABEPeM modules (e.g.

Configuration Form).

The following Figure 6 shows the high-level architecture and building blocks of the E&FCM. It is implemented as an Excel workbook consisting of 12 tabs structured in four groups as described in the following sections.

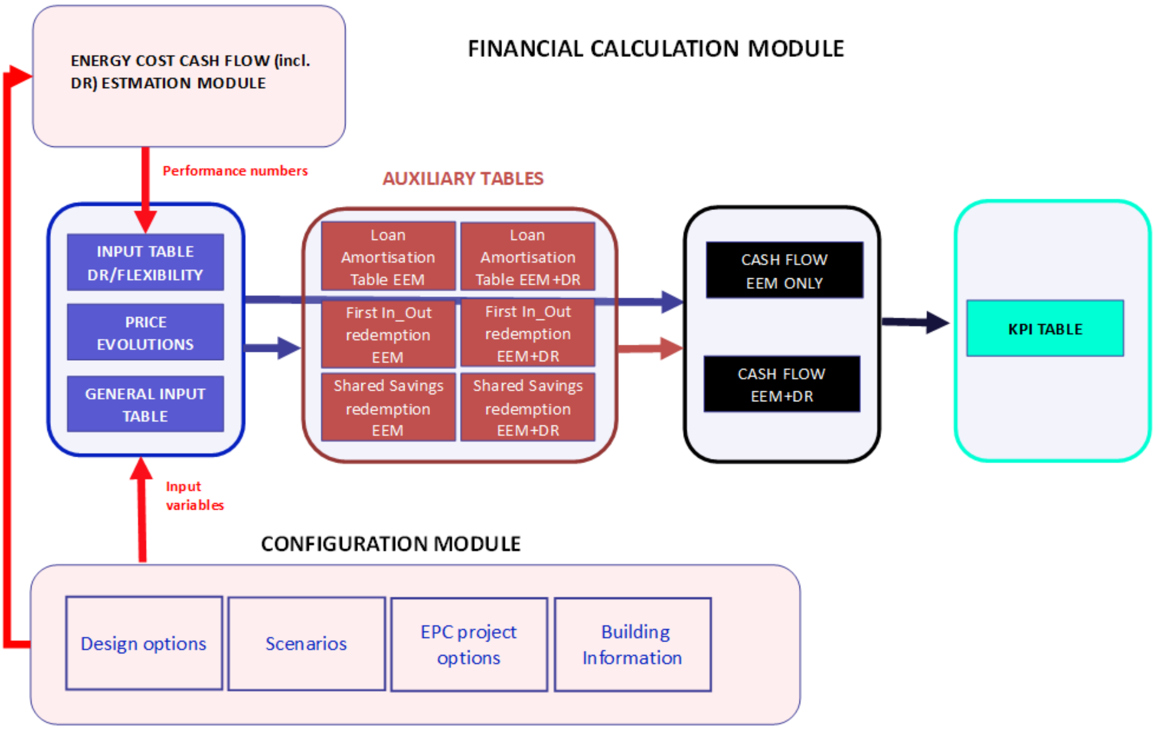


FIGURE 6 – THE BUILDING BLOCKS OF THE E&CFM.

3.4.1. INPUT TABLES

The information that is needed to perform the different calculations in the auxiliary tables, the cash flow tabs and the KPI table is obtained from the input tables. The tool includes 3 different input tables:

- General input table,
- Price evolutions,
- Input Table DR/ flexibility.

The General Input table consists of 7 sections:

1. Project details: This section includes general information on the project, the Financial tool user, the **beneficiary** for whom the KPIs are calculated (Owner-Occupier, Owner-Lessor,” …) which determines what kind of information is provided in the Cash Flow tables and KPI table, and information on the **analysed period** and **contract duration (less than or equal to analysed period)**.

2. Project General Parameters: Information on the **discount rate** applied to calculate the present value of the future cash flows.
3. Asset General Details: This section provides information on the current sales price per m^2 of the asset when asset valuation is being performed based on market value evolution.
4. Rent, Rent charges and Other Income details (except DR related Income). These input variables refer to the case when **rent** cash flows are applicable. They provide information on the rent and rent charges before any measures, after EEM only, and after EEM + DR.
5. Operating expenses: Depending on the AEPC Beneficiary this section provides information on typical operating expenses such as **maintenance**, **insurance**, **property taxes** and other expenses (**property/facilities management, …**). The information for these types of expenses needs to be provided for the following three situations: before any measures, after EEM only and after EEM + DR. Besides, it can include DR service fees if applicable (separately for implicit DR and explicit DR).
6. Investment details: This section defines the **investment** amounts required to implement the Energy Efficiency project. The investment amounts need to be provided separately for the EEM only, for the required investment for DR and, when applicable, for any other one-off capital expenditure. This section also provides the information related to possible grants and subsidies. The investment values are being fed from the Configuration Module of ABEPeM.
7. Financing details: In this section the platform users can define whether the investments related to the Energy Efficiency projects are being financed based on own financial resources (**own funding**) of the project owner or if financing is being provided by the ESCO or any other Third-Party financier (e.g. financial institution). In the case of lending, also the **loan amount**, the **interest rate** applicable and the **loan term** must be specified.

The Price evolutions table provides the input information for different general indexations or price escalations of future expenses such as operating expenses (e.g. maintenance, ...), energy prices, DR/Flexibility savings, rent income and property taxes and other levies. It also includes the possibility to simulate the market value evolution of the asset (the building, the dwelling, …) if no EEM are implemented and if EEM are implemented thus providing the asset value change (normally increase) at sales or disposal of the asset (based on the market value evolution assumptions).

The Input table DR/flexibility is being fed by the Energy Cost Cash Flow Estimation Module (see section 3.1) of ABEPeM. It provides, on a year-on-year basis and in kWh and Euro, the Reference/Baseline energy consumption information, the consumption after EEM only and the energy consumption after also valorising DR Flexibility (EEM + DR). The provided information by the Energy Cost Cash Flow Estimation Module allows to calculate, again in kWh and Euro, the savings after Energy Efficiency Measures and the savings after addition of DR Flexibility. It also allows to derive the monetary value of the DR Flexibility only and is the basis for the calculation of the DR Flexibility service fees to be paid, if any. The data calculated in this tab is being fed into the two cash flow tables.

3.4.2. AUXILIARY TABLES

The auxiliary tables calculate the financing cash flows depending on the financing option chosen in the General Input table (No third-party financing, third party financing based on lending or ESCO financing) and ESCO payment models (Shared Savings, First In, First Out).

- The Loan Amortisation tables (for EEM and for EEM + DR) calculate the financing cash flows related to the loans provided by a third-party financier or by the ESCO, i.e. the reimbursement of the investment. They provide information on total yearly reimbursements of the loan, i.e. the investment, including interest amounts and principal amounts.
- The First In_Out Redemption tables (for EEM and for EEM + DR) calculate the financing cash flows related to this selected ESCO payment model (First In or First Out) where the obtained energy savings are being fully used (or partially used in the case of the First In option) to remunerate the ESCO for its services including investment reimbursements. This means that for each year, the investment reimbursement to the ESCO, i.e. the principal payment (the reimbursement of the investment) plus the interest payment, equals the used energy cost savings minus the maintenance fee to the ESCO.
- The Shared Savings Redemption tables (for EEM and for EEM + DR) calculate the financing cash flows related to this selected ESCO payment model (Shared Savings) where the obtained energy savings are shared between the ESCO and the project owner, and the ESCO's share is being used to remunerate the ESCO for its services, including reimbursements. This means that for every year, the loan reimbursement to the ESCO, i.e. the principal payment (reimbursement of the investment) plus the interest payment, equals the ESCO share of the energy cost savings minus the maintenance fees to the ESCO.

3.4.3. CASH FLOW TABLES

The E&FCM features two cash flow tables: one for EEM only and one for EEM + DR. These cash flow tables include all yearly cash flows (income, expenses and capital expenditures) relevant to the business case over an analysis or life-cycle period of maximum 40 years. The two cash flow tables have, in principle, the same structure, though the cash flow values will obviously be different when DR valorisation is considered in the EEM + DR case. Besides, additional cash flows (cash flow drivers) related to Explicit DR incentives and (Explicit) DR service fees will be included in this EEM + DR case.

The cash flow tables calculate the Net Present Value (NPV) of all yearly cash flows, i.e. the income, the expenses and the capital expenditures cash flows to reflect the time value of money. The information required to calculate the cash flows in the cash flow tables is being obtained from the input tables and the auxiliary tables. The cash flow tables incorporate four major sections:

1. The **Auxiliary Calculations** section calculates parameters related to the analysis period, EPC-contract period, general indexations or price escalations and asset market evolution. This table is being fed by the General Input table and the Price evolutions table.

2. The **Cash Flow before Measures** section calculates all relevant cash flows for the Building-As-Is, without any measures. These cash flows are clustered into the following cash flow groups:
    - Operating Income: Current Rent Income and Current Rent Charges (for the Owner-Lessor if applicable)
    - Operating Expenses:
        - Current Rent Expense and Current Rent Charges (for the Lessee/Tenant if applicable);
        - Current Energy expenses (for the Lessee/Tenant and Owner-occupier);
        - Other operating expenses such as maintenance, insurance, Facilities/Property Management expenses, Property taxes (Owner-Occupier and Owner-Lessor).
    - One-off income: Sales or residual value of the asset

    This section further calculates the total yearly cash flows, the NPV of those yearly cash flows and finally the sum of those discounted cash flows.

3. The **Cash Flow after Measures** section has basically the same structure and performs the same calculations as described for the previous section. But obviously (all) cash flow values will be different because of the measures. And additional cash flows (cash flow drivers) will be introduced related to the related investment, the ESCO involvement, and (implicit and explicit) DR service fees and income (incentives). These as well depend on the business case beneficiary (Owner-Occupier, Owner-Lessor, Lessee/Tenant) and the measures (EEM or EEM + DR).

    Specific additional cash flows (cash flow drivers) for EEM are:
    - Operating Expenses: Maintenance payments to ESCO,
    - Initial Outlay: Investment and other initial outlays,
    - One-off income: Subsidies or grants.

    Additional cash flows (cash flow drivers) on top of that for EEM + DR are Operating Expenses, i.e. Savings from Implicit DR and Income from Explicit DR and their respective service fees to enabling DR service providers (aggregators, …).

    This section further calculates for both cases (EEM and EEM + DR) the difference between the cash flows before the measures and the cash flows after the measures, thus providing Total Net Cash Flows (versus Business-as-usual) and NPV of the yearly Net Cash Flows. These cash flow data allow for calculating the NPV of the Total Cash Flows, the Internal Rate of Return (IRR) and the Discounted Payback period of the financial business case.

4. The **Financing Cash Flows** section is only relevant in case financing by a Third-Party financier (e.g. financial institution or investor) or by the ESCO is being envisaged. This section shows condensed Project Cash flows and Financing Cash Flows. The Financing Cash Flows are being divided in Incoming Financing Cash flows (Equity Contributions and Third Party or ESCO contributions to financing) and Outgoing Financing Cash Flows (reimbursements of loans/investment and interests), ultimately providing the cash flows to the Equity Holders. When relevant Equity NPV, Equity IRR and Equity Discounted Payback is calculated.

3.4.4. KPI TABLES

The KPI table shows financial Key Performance Indicators calculated by the E&FCM for both the EEM and the EEM + DR cases:

- Total Cost of Ownership: before measures, after EEM measures, after EEM + DR measures;
- Net Present Value: after EEM measures, after EEM + DR measures;
- Internal Rate of Return: after EEM measures, after EEM + DR measures;
- Discounted payback period: after EEM measures, after EEM + DR measures.

Besides, it gives for the selected design option and scenario an overview of the project's key numbers related to:

- Investments:
  - Initial investment amount,
  - Other initial outlay,
  - Subsidies (-),
  - Total investment.
- Energy consumption and cost:
  - Adjusted Baseline energy consumption kWh/year;
  - Adjusted Baseline energy consumption €/year;
  - Average Yearly energy consumption savings kWh for EEM and EEM + DR;
  - Average Yearly energy cost savings € (non-indexed) for EEM and EEM + DR;
  - Yearly energy consumption and energy cost savings (in %) for EEM and EEM + DR.

3.5. SCENARIO CREATION MODULE

Realistic scenarios of future evolutions must be created in order to realistically predict and compare performance KPIs for the design options that are considered. Scenarios can be provided by the ESCO, or by the beneficiary, or by both. The scenarios feed the simulation in the Energy Cost Cashflow Calculation module, and serve as the basis for the scenario-based forecasts that feed the MPC optimization in the Energy Cost Cashflow Calculation module.

Typically, scenarios are needed for factors that influence energy performance, like weather conditions and user usage patterns, and evolutions of energy prices and financial parameters. They can be created from historical data or from synthetic data (using expert knowledge and/or tools) or a combination of both. Some examples as applied in our proof-of-concept platform:

- Weather condition scenarios – for a given location – are produced from historical data to generate statistically relevant profiles. Possibly, some specific sub-scenarios, like a mild winter, may be generated as well.
- Energy price scenarios are produced from expert insights and knowledge, e.g. related to expected rate evolutions related to energy mix and taxation evolutions and changing regulation, or publicly available scenario information.
- User usage scenarios are preferably produced from historical data, if available. Examples are non-controllable load, sanitary hot water usage or EV usage. Specific knowledge – e.g. about changing family composition or intended purchase and installation of additional loads – may be used to adapt scenarios to make them better fit the future profile. If no historical data is available, publicly available databases that contain specific profiles, or profile generation tools can be used to create such usage related scenarios.

Scenarios must be supplied as a time-series, with a parametrizable time horizon, and a parametrizable time resolution. Following scenarios are currently used in our project:

- Weather conditions: temperature and solar irradiation;
- Energy prices: distinguishing between offtake price, injection price (and local PV generation price) to account for no-net-metering conditions; including dynamic prices; including capacity tariff parameters;
- Non-controllable load/consumption;
- Flex related user behaviour/usage patterns: sanitary hot water tapping, EV usage, comfort setpoints and flexibility.

Performance guarantees are given in relation to an agreed scenario. To compare the realized performance against the performance guarantee, a re-calibration of the former is done to account for the difference between the scenario and the actual conditions that occurred, as proposed by the IPMVP. Therefore, an effective yet simple (Non-) Routine Adjustment factor must be defined for each of the scenarios, that captures its impact on the energy performance.

The degree-days concept is an example of a Routine Adjustment factor for heat demand performance in relation to weather condition scenarios.

For the AEPC concept, that focusses on the financial performance including the valorisation of Demand Response by actively controlling flexibility, (Non-) Routine Adjustment factors are required that capture essential characteristics of energy price profiles. One factor will be related to the average energy price. Besides (or combined with) that, an adjustment factor will be needed that captures the dynamics of the energy prices. Both the spread between high and low, as well as the distribution of higher than average and lower than average prices is important. Besides, it must be decided whether this factor should be calculated for a complete reporting period (e.g. a full year) or for shorter periods. E.g. as heating flex is only available in winter, the price dynamics in winter can be expected to be far more relevant than the price dynamics in summer. For the definition of a suitable adjustment factor that captures the dynamics of energy prices and the relation to DR valorization, we will work with external experts and stakeholders, as well as with EVO, the founding fathers of the IPMVP methodology.

3.6. SCENARIO-BASED FORECAST CREATION MODULE

The scenario-based forecast creation module is fed by the scenarios, and perturbates the scenario in a stochastic manner to create forecasts that are used by the Model Predictive Control (optimization), whereas the scenario itself is fed to the Digital Twin simulation. This way, it allows to model and analyse the impact of non-perfect forecasts and therefore (one aspect of) the non-all knowingness on the predicted performance. This not only avoids overly-optimistic performance results, but as well makes it possible to analyse the impact of a good versus a bad forecaster on the result of the optimization during the operational phase.

The current module assumes a Gaussian error distribution (see Figure 7), characterized by a mean absolute error (parameter 1) and an error variance (parameter 2). These two parameters can be set to create a forecast as a perturbed scenario, which is then used in the MPC optimization in the Energy Cost Cash-flow Quantification.

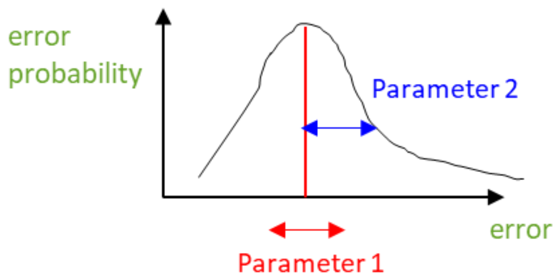


FIGURE 7 – A GAUSSIAN ERROR DISTRIBUTION IS ASSUMED FOR THE FORECAST ERRORS.

4. CONCLUSION

In the scope of the AmBIENCe project, a Proof-of-Concept version of the ABEPEM platform has been developed. Its main purpose is to be used during the pilots, and to get feedback from the Advisory Board members and relevant stakeholders.

Some future improvements have been identified already that will increase its applicability by ESCOs in a commercial setting:

- Typically, multiple scenarios and design options must be analysed and compared not only with the (adjusted) baseline performance (i.e. before measures), but also with each other: e.g. to compare a deep renovation versus a mild renovation with electrification and DR. Besides, the specific impact of the smart control of individual assets could be analysed by selectively activating or de-activating their smart control. This means that multiple quantifications must be done, for different design options and/or scenarios. E.g. explore PV sizes between 4 kilowatt peak (kWp) and 20 kWp in steps of 2 kWp. To facilitate and further automate this process, support for multiple parameter values or ranges could be added to automatically quantify the performance for each of them, and collect this information in a single overview to facilitate the comparative analysis. In this case, the quantification (adjusted) baseline performance must only be done once.
- Specific information from the Configuration Form must be copied over to specific module inputs and input formats. Some of these are based on JSON. Therefore, the creation of these specific module inputs from the Configuration Form could be automated. As a next step, the excel Configuration Form could be replaced by a webform that can be filled in remotely.
- More sophisticated asset and flex models could be introduced: e.g. multi-zone building models or seasonal building models.

In work package 5, a strategy will be developed to make this platform available for interested ESCOs and stakeholders.

5. ANNEXES

5.1. ANNEX 1 – EXAMPLE ENERGY COST CASH-FLOW QUANTIFICATION COMPARING MULTIPLE DESIGN OPTIONS FOR A GIVEN SCENARIO.

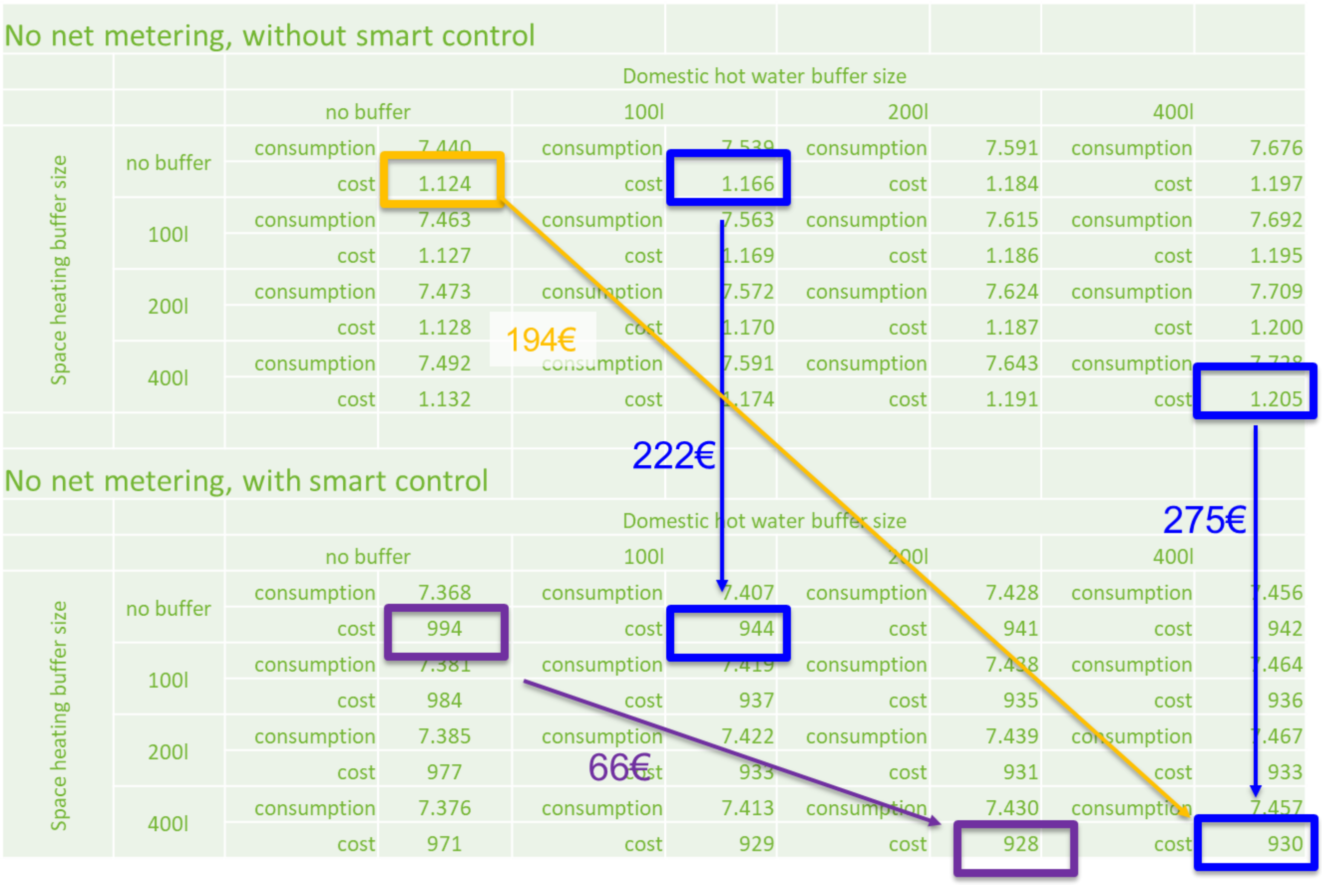
Belgian Free-standing Single Family Building

- Dimensions:
    - 2 floors;
    - 84 m2 (ground floor);
    - 412 m3.
- Characteristics before measures (baseline):
    - Roof: 105 m2 (no insulation);
    - Outer walls: 176 m2 (brick 9cm, cavity 3cm, limestone 14cm, plaster 1 cm);
    - Windows (12): 45 m2 total (single glass).
- Baseline energy consumption and cost:
    - Gas: Space Heating and DHW: 1.079 m3 (11,870 kWh_thermal);
    - Electricity: 3.605 kWh_electric;
    - Total energy cost: 1.595€.
- Scenario:
    - tariff structure change (stopping net metering):
        - Consumption: 0.25€/kWh,
        - Feed-in: 0.05€/kWh;
    - Exogeneous parameters: 2018 conditions;
    - User usage profiles: measured profiles.

- Design options:
    - Envelop measures:
        - Roof: 105 m2 (rockwool 12 cm, 0.04 W/mK);
        - Outer walls: 176 m2 (3 cm cavity filled with PUR 0.025 W/mK);
        - Windows (12): 45 m2 total (double glazing).
    - Infrastructure measures:
        - Electrify heating and DHW: switching to a Heat pump (Coefficient Of Performance (COP) space heating 3.5, COP DHW 1.5);

- Add PV (6 kWp);
- Space heating buffer (various sizes);
- DHW tank (various sizes).
- Active control measures: minimize for energy cost.

An example Energy Cost Quantification and analysis of the impact of Active Control and thermal buffer dimensions is depicted below:



No net metering, without smart control

Space heating buffer size		Domestic hot water buffer size: no buffer		100l		200l		400l	
no buffer		consumption	7.440	consumption	7.539	consumption	7.591	consumption	7.676
		cost	1.124	cost	1.166	cost	1.184	cost	1.197
100l		consumption	7.463	consumption	7.563	consumption	7.615	consumption	7.692
		cost	1.127	cost	1.169	cost	1.186	cost	1.195
200l		consumption	7.473	consumption	7.572	consumption	7.624	consumption	7.709
		cost	1.128	cost	1.170	cost	1.187	cost	1.200
400l		consumption	7.492	consumption	7.591	consumption	7.643	consumption	7.728
		cost	1.132	cost	1.174	cost	1.191	cost	1.205

No net metering, with smart control

Space heating buffer size		Domestic hot water buffer size: no buffer		100l		200l		400l	
no buffer		consumption	7.368	consumption	7.407	consumption	7.428	consumption	7.456
		cost	994	cost	944	cost	941	cost	942
100l		consumption	7.381	consumption	7.419	consumption	7.438	consumption	7.464
		cost	984	cost	937	cost	935	cost	936
200l		consumption	7.385	consumption	7.422	consumption	7.439	consumption	7.467
		cost	977	cost	933	cost	931	cost	933
400l		consumption	7.376	consumption	7.413	consumption	7.430	consumption	7.457
		cost	971	cost	929	cost	928	cost	930

ABBREVIATIONS AND ACRONYMS

ABEPeM	Active Building Energy Performance Modelling
AEPC	Active Building Energy Performance Contracting
BEMS	Building Energy Management System
C	Capacitance
COP	Coefficient Of Performance
DHW	Domestic hot water
DR	Demand Response
EPC	Energy Performance Contracting
EEM	Energy Efficiency Measures
E&FCM	Economic and Financial Calculations Module
ESCO	Energy Service Company
EV	Electric Vehicle
HP	Heat pump
IPMVP	International Performance Measurement and Verification Protocol
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
kWh	Kilowatt hour
kWp	kilowatt peak
MPC	Model Predictive Control
NPV	Net Present Value
PV	Photovoltaic
R	Resistance
V	Voltage