D5.2 Energy Performance Guarantee planning & implementation guideline

WP5, T5.1

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Versions

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0.8	Irantzu URKOLA	TECNALIA	FINAL VERSION	2022/03/29

Abbreviations and acronyms

Acronym	Description
CDD	Cooling Degree Days
DHW	Domestic hot water
ECM	Energy conservation measures
EPBD	Energy performance of buildings directive
EPC	Energy Performance Contracting
ESCO	Energy Services COmpany
ESP	Energy Service Provider
EVO	Efficiency Valuation Organization
FEMP	Federal Energy Management Program (US)
GHG	GreenHouse effect Gases
HDD	Heating Degree Days
IEC	Integrated Energy-Contracting
IPMVP	International Performance Measurement and Verification Protocol
M&V	Measurement and verification
O&M	Operation and maintenance
PE	Primary Energy
PV	Photovoltaics
QA	Quality Assurance
QAI	Quality Assurance Instruments
QAP	Quality Assurance Plan
QAI	Quality Assurance Instruments
UMP	Uniform Methods Project (US)
WP	Work Package

Abstract of the HAPPENING project

Currently, **buildings are responsible for 40 % of the energy demand and 36% of the CO_2 emissions in Europe**. Decarbonisation of existing buildings plays a key role in order to reach the overall climate protection targets. However, current renovation rates lie in the order of 1%.

Heat pumps are a key technology in bringing renewable shares into heat supply of buildings; especially their combination with onsite renewable electricity production e.g., by PV allows to bring high renewable shares. Their current installation in existing multi-apartment buildings is however still marginal.

The proposed technological solution is based on decentralized heat pumps, in such a way that it results an easy-to-install solution for installers, low-intrusive for the occupants and easily adaptable to a large number of different building situations. This is flanked by developing near-zero planning, implementation and operation processes, in order to facilitate the work during the planning phase, ensure a high-quality installation and effective operation, and reduce the efforts and costs within the whole retrofitting project. The challenge of cost-competitiveness is addressed by developing new financial and business models. Bringing new players (such as financial experts) and financing models to the renovation market is expected to bring the needed paradigm change and boost investments in the residential retrofitting sector. Dissemination of measured performance and system characteristics from HAPPENING will be one of the key results of the project.

Through **3 demo sites (Spain, Italy and Austria)**, the project will demonstrate a highly versatile, scalable and replicable solution package for buildings energy system retrofitting allowing 70-75% of renewable energy fraction, 30-50% of PE and GHG savings, reduction of planning time by 50% and installation/operation time by 30% and payback time for ESCOs and investors of less than 8 years, compared to best available solution existing today.

1. Introduction

1.1 Objectives of the deliverable D5.2

The objective of the deliverable D5.2 is the development of energy performance guarantee planning and implementation guideline.

This task aims at facilitating the implementation of Energy Performance Contracting (EPC) schemes, where an executive party guarantees the energy performance of retrofitted building during the operational phase, reducing uncertainty and ensuring proper performance. In this task a guideline for energy performance guarantee in existing building practice will be developed that provides a practical method to calculate the risk and includes the relevant aspects of quality assurance.

This guideline will help developers to understand what an energy performance guarantee is and will guide them through the process of its implementation on their refurbishment project. The guideline will detail the necessary steps to introduce quality assurance and energy performance guarantee at the different stages of the building process.

The Energy Performance Guarantee planning, and implementation guideline will provide additional information to help ESCOs, professional investors and contractors with common issues and key concepts, such as selecting the appropriate measurement and verification (M&V) approach, developing robust baseline energy models, documenting an M&V Plan, and reporting results. It will provide detailed descriptions of energy models, uncertainty analysis and a reference M&V Plan.

1.2 Deliverable description

The deliverable D5.2 is structured in five main chapters:

- Generalities about M&V: a short explanation about generalities of M&V
- Energy modelling in buildings: a view on energy modelling of buildings
- IPMVP: an overview of what the International Performance Measurement and Verification Protocol or IPMVP is about
- Other M&V protocols: short definitions of other measurement and verification protocols
- M&V in the context of HAPPENING: an approach to M&V related to HAPPENING
- Conclusions
- Bibliography

1.3 Contribution of partners

The main partner involved in the energy performance guarantee planning and implementation guideline is ANESE, the Spanish Association of ESCOs. TECNOZENITH has contributed with the whole chapter 6.3, real data for the demo building in different aggregation time steps, description of their own M&V approach, as well as with revision work. TECNALIA has kindly contributed to chapters 6.4 and 6.5.

1.4 Relation with other activities in the project

The most direct relation of this information is in the deliverable 5.1, in which the M&V plan for HAPPENING system was defined.

The results obtained will be included in the Exploitation (WP6) and Dissemination (WP7) activities.

2. Generalities about M&V

2.1 Description

"Measurement and Verification" (M&V) is defined as "*the process of planning, measuring, collecting, and analysing data for the purpose of verifying and reporting energy savings within a facility resulting from the implementation of energy conservation measures (ECMs). Savings cannot be directly measured since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions.*" (Efficiency Valuation Organization, n.d.)

Main M&V activities consist of meter installation, calibration and maintenance, data gathering and screening, development of a computation method and acceptable estimates, computations with measured data, reporting, quality assurance and third-party verification of reports.

In WP5, the goal is to provide resources and tools to reduce the efforts, costs, and risks within the whole retrofitting process. Specifically, the deliverable D5.1 requires a generic M&V protocol and separate M&V protocols for each demo. The main objective of the M&V protocol is to reduce risk exposure and uncertainty to stakeholders, in a scenario where the driver for the implementation of the new system is to improve system performance / efficiency ***with respect to an existing installation***. The need to compare the new system to an existing system in terms of performance and efficiency, to be able to give acceptable proof of the achieved performance / efficiency improvements, dictates that the WP5 have a more "backward looking" approach, in the sense that it deals with the relationship between past and present events.

2.2 Purpose of M&V

M&V protocols may be used for a host of different purposes. An extensive and fairly detailed list can be found in (Efficiency Valuation Organization, n.d.).

In the context of the HAPPENING project, M&V techniques are mainly used for the following purposes:

- Increase energy savings: Accurate determination of energy savings helps facility owners and managers adjust ECM design or operations to improve savings, to achieve greater persistence of savings over time, and lower variations in savings.
- Document financial transactions: For some projects, the energy efficiency savings are the basis for performance-based financial payments and / or a guarantee in a performance contract.
- Enhance financing for efficiency projects: A good M&V Plan increases the transparency and credibility of reports and the projections for the outcome of efficiency investments.

2.3 M&V protocols

As was stated in the chapter 2.1, M&V protocols tackle with the challenge of determining a quantity that cannot be directly *measured*, i.e. energy saving. There are several internationally recognized M&V protocols, but all share some common principles:

- Accuracy
- Completeness
- Conservativeness
- Consistency
- Relevance
- Transparency

"*M&V is the process of quantifying the energy and cost savings resulting from improvements in energy-consuming systems. The effort required and rigor achieved should be commensurate with the project capital investment and savings risk. Energy and cost reductions are compared to a historical baseline, which may be adjusted to reflect changing operating conditions or utility rates.*" (US DOE FEMP, 2015)

"*M&V reports should be as accurate as can be justified based on the project value. M&V costs should normally be small relative to the monetary value of the savings being evaluated. M&V expenditures should also be consistent with the financial implications of over- or under-reporting of a project's performance. Accuracy trade-offs should be accompanied by increased conservativeness with increased use of estimates and judgements. In addition, accuracy can be influenced by the level of adjustment of energy quantities made to the reporting-period conditions or to some other set of conditions. Accuracy can also be affected by the duration of the baseline period and the reporting period.*" (Efficiency Valuation Organization, 2014)

The process followed by all the major M&V protocols is based on the same concept: since its purpose is to measure the "actual" energy savings (including water savings and related O&M savings) cannot be measured because they represent the absence of energy or water use and related expenditures post-implementation of a performance-based contract. Instead, savings are determined by comparing resource use before and after the installation of energy or water efficiency or conservation measures (ECMs) and making appropriate adjustments for changes in conditions.

The "before" case is called the baseline. The "after" case is referred to as the post-installation or performance period. Proper determination of savings includes adjusting for changes that affect energy use but that are unrelated to equipment performance. Such adjustments may account for changes in weather, occupancy, or other factors between the baseline and performance periods. The following Equation 2.1 shows the general equation used to calculate savings:

- Equation 2.1. General Equation Used to Calculate Savings:

Savings = (Baseline Energy – Post-Installation Energy) ± Adjustments

In the early days of the energy services industry, comparison of baseline and post-installation utility bills was the most common method of M&V. While this method proved adequate in the short term, it often led to difficulties in buildings and multi-building facilities with varying patterns of energy use. Utility bills are affected by construction and demolition at the site, as well as by changes in occupancy and occupant behaviour, mission, and plug loads. The need to track and account for such changes—i.e. the "Adjustments" in Equation 2.1—greatly increased informational requirements and ultimately the cost of performing M&V. This led to the development and use of M&V methods focused specifically on the installed conservation measures and the equipment they replaced.

Baseline and performance period energy use can be determined by using the methods associated with several different M&V approaches classified by the types of measurements performed. The four options, originating in the IPMVP, are termed:

- Option A: Retrofit Isolation with Key Parameter Measurement
- Option B: Retrofit Isolation with All Parameter Measurement
- Option C: Whole Facility Measurement
- Option D: Calibrated Simulation

(These options are discussed in deep in the section 4 of this document)

The choice and use of a specific option are determined by the level of M&V rigor required to obtain the desired accuracy level in the savings determination and are dependent on the complexity of the project, the potential for changes in performance, each ECM's savings value, and the project's allocation of risk between the ESCO and the customer.

Two fundamental factors drive energy savings: ECM performance and use. The ECM performance describes the rate at which energy is used to accomplish a specific task; and the use describes how much of the task is required, such as the number of operating hours during which a piece of equipment operates. For example, in the simple case of lighting, performance is the power required to provide a specific amount of light, and use is the operating hours per year. For a chiller (which is a more complex system), performance is defined as the energy required to provide a specific amount of cooling (which varies with load), whereas use is defined by the cooling load profile and the total amount of cooling required. Both performance and use factors need to be known to determine savings, as shown in the Figure 2.1:

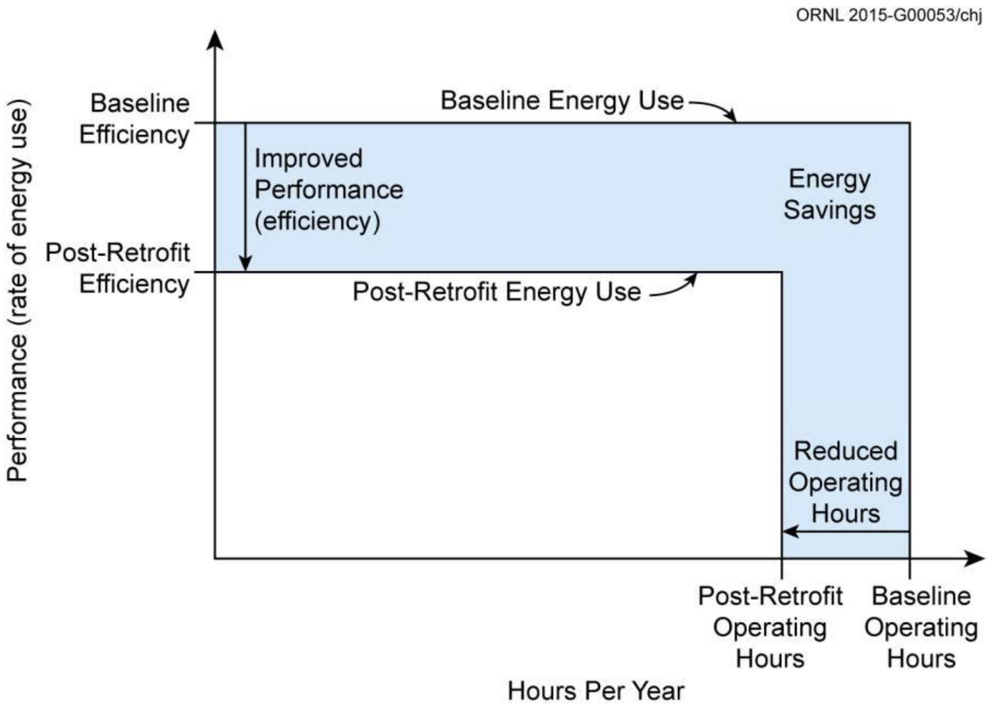

Figure 2.1: Energy Savings Depend on Performance and Use

In the Figure 2.1, the area of the large box represents the total energy used in the baseline case. Reduction in the rate of energy use (increase in performance) or reductions in use (decrease in operating hours) lead to reduced total energy use, which is represented by the smaller box. The difference between the two boxes—the shaded area—represents the energy savings.

M&V activities include site surveys, metering of energy and independent variables, engineering calculations, and reporting. How these activities are applied to determine energy savings depends on the characteristics of the ECMs being implemented and balancing accuracy in energy savings estimates with the cost of conducting M&V.

3. Energy modelling in buildings

The main challenge of M&V is to compare the energy consumption of two different versions of the same building when subjected to the same boundary conditions. As is evident, a strictly direct comparison is not possible since only one version of the building can exist at any given time. Energy modelling is the set of tools that enables this comparison, and it can have many forms and levels of complexity. It can be as simple as establishing a correlation between observed values of consumption and exterior temperature; or it can be as complex as solving systems of equations that describe the dynamic evolution of energy-related variables within the building, considering the building inertia and insulation, its usage patterns, the effects of wind, radiation and temperature, and even dynamically changing elements such as adaptive lighting, window blinds or shading.

3.1 Correlations

A correlation is "a relation existing between phenomena or things or between mathematical or statistical variables which tend to vary, be associated, or occur together in a way not expected on the basis of chance alone"[1], while a regression refers to "a functional relationship between two or more correlated variables that is often empirically determined from data and is used especially to predict values of one variable when given values of the others"[2].

From our daily experience, we know that the ambient temperature and the indoor temperature are correlated, unless the latter is acted upon by the action of artificial heating or cooling. It is also common sense that the energy consumption of such heating or cooling system is correlated to the intensity and duration of the effort it is required to make. So, transitively, one can assume a correlation between the outdoor ambient temperature and the energy consumption of the heating or cooling systems. More specifically, if we set a rigid target indoor temperature and assume the heating or cooling system to be able to maintain this temperature at all times, then we can expect the consumption of the system to be correlated to the value of the temperature difference between indoor and outdoor, and the time over which this difference exists. The definition of degree-days accounts precisely for the combination of these two factors.

Inertia also plays its own part on this, so an offset between the variation of the outdoor temperature and the corresponding variation of the system's energy consumption is to be expected. The effect of inertia, however, is in a large measure reversible, so it tends to cancel out when the exterior temperature variation changes sign. Overall, during the course of multiple days, the effects of inertia become negligible.

Up to this, only assumptions and educated guesses have been made, but if plotting a scatter chart of energy consumption in heating or cooling, with heating or cooling degree-days respectively, results in an elongated cloud of points around a straight axis, then probably the regression analysis will confirm a strong correlation between the two variables.

The most common spreadsheet programs include relatively complete analysis packs and regression functions, so instead of focusing on the statistical calculation, we will consider the practical aspects of selecting explanatory variables, aggregation intervals, and regression types.

[1] https://www.merriam-webster.com/dictionary/correlation

[2] https://www.merriam-webster.com/dictionary/regression

Correlation is usually made using the minimum squares method, and it can be single variable or multi variable. Single variable correlations are very easy to visualise graphically with a scatter plot.

3.1.1 Data aggregation interval

Correlation results depend on the time interval used for data aggregation. Usually larger intervals yield better results, at the expense of less detail. This can be due to the self-cancelling inertia effects, and to the random nature of small deviations from the "normal" consumption pattern. For instance, if a window is inadvertently left open for one hour during heating season, this can lead to a deviation of more than 100% in the consumption if hourly aggregation is being used for analysis. However, the same event has absolutely no relevance if yearly aggregation is used.

In the following example, two sets of data referring to heating degree-days and gas consumption from the same real installation[3] are shown. The first group of data is aggregated daily, and the second group is aggregated on a roughly monthly basis:

From	To	HDD/day	Nm3/day
02/11/2021	03/11/2021	12.1	28.329
03/11/2021	04/11/2021	11.5	26.029
04/11/2021	05/11/2021	11.3	29.483
05/11/2021	06/11/2021	11.9	32.324
06/11/2021	07/11/2021	12.5	31.147
07/11/2021	08/11/2021	12.3	28.974
08/11/2021	09/11/2021	12.1	33.448
09/11/2021	10/11/2021	11.5	26.881
10/11/2021	11/11/2021	9.3	27.789
11/11/2021	12/11/2021	8.0	24.913
12/11/2021	13/11/2021	10.3	26.412
13/11/2021	14/11/2021	11.3	27.271
14/11/2021	15/11/2021	11.9	30.564
15/11/2021	16/11/2021	10.4	31.589
16/11/2021	17/11/2021	11.5	28.889
17/11/2021	18/11/2021	13.0	29.926

Table 3.1: Daily aggregation of data

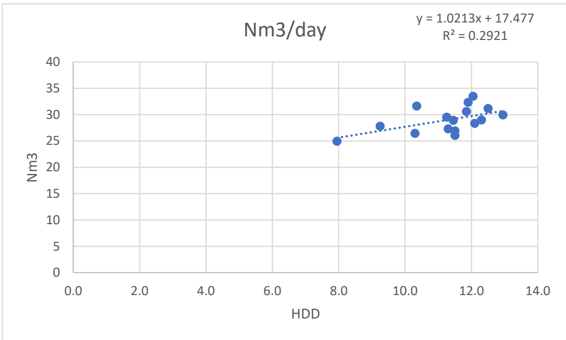

Figure 3.1: Daily aggregation of data

Both data sets have 16 pairs of values – 16 points on the scatter plot – and both refer to the same real building, so the main difference between them is just the aggregation period. We cannot say that both data have the same amount of information, since the first one has just over two weeks' worth of information, while the second has more than one year. Herein resides at least part of the explanation – more information, more chances for the cancelling out of sporadic, random events, better fit.

[3] Thanks to TECNOZENITH for the data referring to the HAPPENING demo site in Verzuolo, Italy.

From	To	HDD/month	Nm3/month
26/02/2016	25/03/2016	467.3	1155.461
26/03/2016	29/04/2016	371.3	665.265
30/04/2016	27/05/2016	230.0	321.128
28/05/2016	28/06/2016	120.1	251.100
29/06/2016	27/07/2016	19.2	190.076
28/07/2016	29/08/2016	24.0	264.105
30/08/2016	30/09/2016	101.3	211.084
01/10/2016	25/10/2016	284.6	432.172
26/10/2016	28/11/2016	510.6	1079.431
29/11/2016	28/12/2016	548.4	1116.445
29/12/2016	25/01/2017	613.4	1187.474
26/01/2017	24/02/2017	560.8	1185.473
25/02/2017	28/03/2017	423.9	1082.432
29/03/2017	26/04/2017	280.0	596.238
27/04/2017	31/05/2017	216.7	434.173
01/06/2017	28/06/2017	36.3	155.062

Table 3.2: Monthly aggregation of data

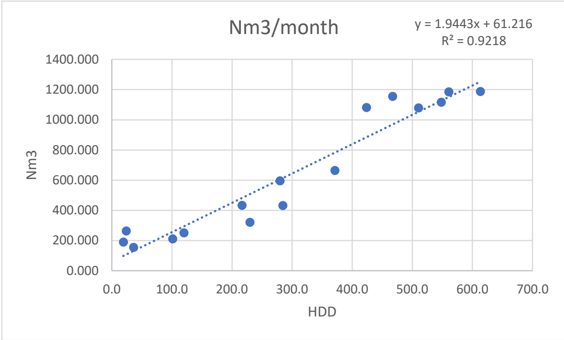

Figure 3.2: Monthly aggregation of data

Even though the data come from the same building, the correlation between monthly gas consumption and monthly degree-days is clearly much stronger than in a daily basis.

3.1.2 Selection of explanatory variables and regression models

Selecting the more appropriate explanatory variables is in equal parts a trial-and-error process and an exercise in practical common sense. Candidate explanatory variables should be selected based on whatever knowledge there is about the normal working of the installation, the laws of physics, and logic. The candidate explanatory variable must have known or easily accessible values on the same aggregation time interval as the response variable. The response variable is usually energy or a suitable proxy, such as Nm3 of gas consumed.

The first model to be tried is usually single-variable linear regression, unless there is a valid reason for supposing another kind of relationship between the variables. The correlation between the variables is then tested and if the R2 coefficient is under 75% then the candidate is discarded. A new candidate is tested until a suitable fit is found[4]. If a suitable explanatory variable isn't found, then pairs of variables are tested in multi-variate regression models[5]. If an appropriate fit still isn't found, then other functions can be tested – polynomic, exponential, logarithmic, etc.

[4] Tip: Changing the degree-days reference temperature often yields better results. Excel solver functions can be easily set-up to maximize the R2 coefficient by varying the degree-days reference temperature, provided that the degree-days calculation is performed locally. In any case, common sense must be exercised when changing the reference temperature, to avoid meaningless results.

[5] Tip: When lighting consumption is an important factor, the "hours of darkness" can correlate to electricity consumption. At times the values of illuminance are available from a suitable weather station close by, but if they're not, experience shows that irradiance values can also be used with some success.

3.2 Physical modelling of processes

By solving the equations that describe the physical behaviour of the relevant processes, it is possible to predict the energy consumption of a particular system given the actual demand, or even estimate the energy demand *and* consumption of a whole building given the usage parameters and environmental conditions.

Energy physical models can be quite simple or extremely complex. When increasing the model complexity, one trades-off the precise knowledge and total predictability of the simple model by the increased *potential* for precision of the complex model, at the expense of a much less obvious interpretation of the model behaviour. In fact, whole building simulations can become so complex that they sometimes produce unexpected results, especially when dynamic control systems are included in the simulation. Therefore, when M&V protocols have an option to use complex simulation models, they refer to “calibrated simulations”.

The increased complexity of the model, the interaction between causes with opposing effects, the sheer volume of input and output data these models handle makes it impossible to judge the quality of the “fit” between the model and the reality without recourse to the comparison between the real verified energy consumptions and those predicted by the simulation, when the simulation is “fed” with the actual conditions. The deviations between the simulated and real consumption are assessed, and if they are not deemed good enough then the simulation parameters are corrected, and the simulation is re-run. This back-and-forth process, which goes on until a good enough fit is achieved, is what is called *model calibration*.

3.2.1 Simple models

In this case, we narrow down the scope of the analysis and simplify the processes as much as possible, to end up with linear equations, such as the one that relates boiler thermal energy with fuel consumption through the concept of boiler efficiency.

These equations are often accurate enough to correctly estimate what the energy consumption of one system would have been, given the real demands placed upon said system.

Consider, for example, the case where a domestic DHW natural gas fuelled boiler is replaced by an electric heat pump. During the baseline, period the boiler efficiency was measured. During the reporting period the DHW demand is measured, as well as the heat pump electric consumption. To determine the energy saving, there is the need to estimate what the boiler consumption would have been, given the measured demand. This can be easily achieved by dividing the reporting period DHW energy demand by the Baseline period measured boiler efficiency.

3.2.2 Complex models

According to the US Department of Energy (DOE) office of Energy Efficiency & Renewable Energy (EERE), “*Whole-Building Energy Modelling (BEM) is a versatile, multipurpose tool that is used in new building and retrofit design, code compliance, green certification, qualification for tax credits and utility incentives, and real-time building control.*” (US DOE - EERE, 2022)

As was previously mentioned, this versatility comes at a price: these models are complicated and setting up simulations is a time-consuming process. Based on the authors' previous experience on the subject, complemented whenever possible with bibliographic references, a set of tips aimed at making the calibration process easier, and models more robust and predictable will be put forth at the end of this chapter. Before that, though, a quick explanation of the basics of simulation is needed in order to clearly state some key concepts:

- The first step and arguably the most critical one is to develop a physical model of the building. This involves knowing all the materials and geometries, building orientation, windows' locations and their compositions, shading elements – both in the building façade and external, such as other buildings, trees, or orography.
- The next step is to define internal loads, occupancy, air renovation, electric lighting, other energy consuming equipment, etc. For each of these concepts, a usage pattern has to be defined.
- Depending on the software and on the detail level of the simulation, infiltration can either be calculated or it can be defined to behave according to a set pattern.
- Then, the building systems are defined, the systems that will be responsible for acting on the interior conditions of the building with the aim of maintaining a given set of conditions (set-points).
- The weather conditions have to be specified. Typically, a file with values for each of the 8,760 hours of the year is used, and the hourly values are then interpolated according to the simulation timestep. Some programs require you to provide the weather file, while others have built-in libraries, so that you just choose the project location, and the correct weather file is automatically selected or downloaded from the internet.
- The last step is to execute the simulation. Depending on how the systems have been defined, this can have up to three steps: a couple of dimensioning runs for winter and summer peak loads and the yearly simulation itself. Shading is usually updated at much larger intervals than the simulation timestep[6], for the sake of computing efficiency.

In order to be able to calibrate the simulation model, a fairly good understanding of the relationship between the components of "internal loads" is needed. There are some important points to follow:

- Actual weather conditions must be taken into consideration. Synthetic climatic years will generally not provide sufficient accuracy.
- We will start with the assumption that the physical and geometric descriptions of the building are accurate, unless we manage to prove that they are not.
- We will run the simulation and compare the results with the real measured values, and we will repeat the simulation after carefully adjusting some parameters:
    - The "loads" in the simulation results should be looked for, specifically sensible heating and cooling loads and latent cooling loads.
    - Increasing occupancy increases both sensible and latent cooling loads (or reduces heating load)
    - Increasing equipment loads increases sensible cooling load only (or reduces heating load)

[6] The simulation timestep can be typically a few minutes – 10 is very usual – while the shading calculations are performed in intervals of 20 days approximately.

- Increasing fresh outside air fraction acts on loads *depending on the external temperature* (!!!) but also depending on mechanical ventilation usage pattern.
- Increasing outside air infiltration acts on loads *depending on the external temperature* (!!!). Depending on how the infiltration is defined, it can follow a pattern, or it can be calculated.
- Increasing DHW usage increases gas or electricity consumption without any particular effect on internal loads.
- Lighting has a non-negligible effect on heating and cooling loads.

- Exercise caution whenever the intermediate results suggest that a change in the different usage patterns[7] is beneficial. As a rule of thumb always make the patterns *general*, i.e. valid throughout the year or season. Tweaking the patterns is sometimes the quickest way to get a simulation to yield the results that are wanted, but if the patterns are too specific the simulation will have to be re-calibrated every time a different period is considered.
- With the knowledge of the abovementioned relationships and a good dose of common sense[8], it will generally be possible to make the simulation yield values that approximate the reality with a sufficient degree of precision.

[7] What we here call patterns are sometimes called *schedules* or *profiles* in simulation software.

[8] It is a frequent beginner mistake to blindly change numbers focusing only on the simulation results – to later find out, for example, that the occupation levels or ventilation rates that result are unrealistic, or even straight impossible.

4. IPMVP

The International Performance Measurement and Verification Protocol (IPMVP) was first published in 1996 (under the name NEMVP – North American Energy Measurement and Verification Protocol) and has since gone through several revisions. It has been selected as a basis for the HAPPENING M&V due to it being the most widely adopted international M&V standard. (Morell, 2021).

4.1 IPMVP Framework

According to Efficiency Valuation Organization (Efficiency Valuation Organization, 2014), "*savings represent the absence of energy / water consumption or demand, so Energy, water or demand savings cannot be directly measured. Instead, savings are determined by comparing measured consumption or demand before and after implementation of a program, making suitable adjustments for changes in conditions*". The comparison of before and after energy consumption or demand should be done on a consistent basis, using the following general M&V equation:

Savings = (Baseline Period Energy – Reporting Period Energy) ± Adjustments

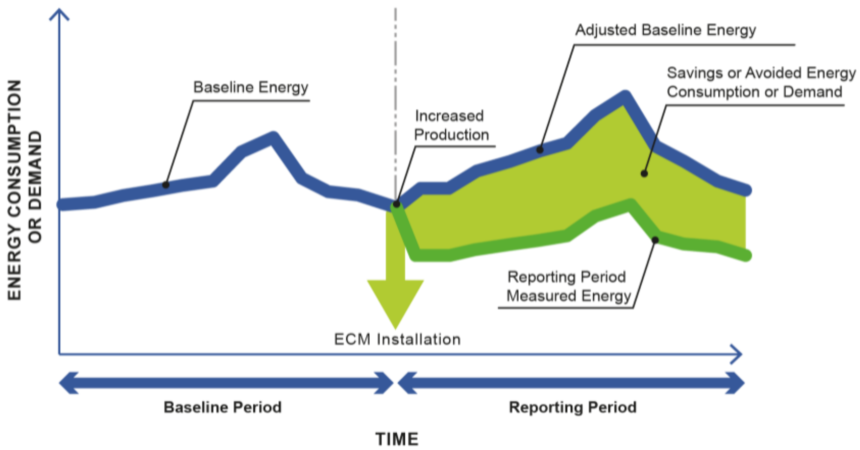

Figure 4.1: IPMVP Framework (Efficiency Valuation Organization, 2014)

4.2 IPMVP Options

To actually determine and quantify the savings, in accordance with EVO (Efficiency Valuation Organization, 2014), there are four IPMVP options (A, B, C, D) pertaining to the needs of the M&V analysis and reporting:

IPMVP options	Description
A **Retrofit Isolation, Key Parameter Measurement**	Savings are determined by partial field measurements of the energy use of the system(s) to which an ECM gas applied. Some, but not all, parameters may be stipulated.
B **Retrofit Isolation, All Parameter Measurement**	Savings are determined by field measurement of the energy use of the systems to which the ECM was applied.
C **Whole Facility**	Savings are determined by measuring energy use at the utility meter level. Bills may be corrected for weather.
D **Calibrated Simulation**	Savings are determined using building simulation. This option is rarely used and is used primarily when there is no pre-retrofit utility data available.

Table 4.1: IPMVP options (Efficiency Valuation Organization, 2014)

4.3 Benefits of using IPMVP

The use of IPMVP brings the following benefits, according to EVO (Efficiency Valuation Organization, 2014):

- "Substantiation of payments for performance. Where financial payments are based on demonstrated energy or water savings, adherence to IPMVP ensures that savings follow good practice. An IPMVP-adherent savings report allows a customer, an energy user, or a utility, to readily accept reported performance. Energy service companies (ESCOs), whose invoices are supported by IPMVP-adherent savings reports, usually receive prompt payments.
- Lower transaction costs in an energy performance contract. Specification of IPMVP as the basis for designing a project's M&V plan can simplify the negotiations for an energy performance contract.
- International credibility for energy savings reports, thereby increasing the value to a buyer of the associated energy savings.
- Enhanced rating under programs to encourage or label sustainably designed and / or operated facilities.
- Help national and industry organizations promote and achieve resource efficiency and environmental objectives. The IPMVP is widely adopted by national and regional government agencies and by industry organizations to help manage their programs and enhance the credibility of their reported results."

5. Other M&V protocols of interest

5.1 ASHRAE Guideline 14

“ASHRAE Guideline 14, Measurement of Energy, Demand and Water Savings, is a reference for calculating energy and demand savings associated with performance contracts using measurements. In addition, it sets forth instrumentation and data management guidelines and describes methods for accounting for uncertainty associated with models and measurements. Guideline 14 does not discuss other issues related to performance contracting.

The ASHRAE guideline specifies three engineering approaches to M&V. Compliance with each approach requires that the overall uncertainty of the savings estimates be below prescribed thresholds. The three approaches presented are closely related to and support the options provided in IPMVP, except that Guideline 14 has no parallel approach to IPMVP / FEMP Option A.” (US DOE FEMP, 2015)

5.2 DOE Uniform Methods Project

“Under the Uniform Methods Project (UMP), DOE[9] is developing a set of protocols for determining savings from energy efficiency measures and programs. The protocols provide a straightforward method for evaluating gross energy savings for residential, commercial, and industrial measures commonly offered in ratepayer-funded programs in the United States. The measure protocols are based on a particular International Performance Verification and Measurement Protocol (IPMVP) option but include additional procedures necessary to aggregate savings from individual projects in order to evaluate program-wide impacts.” (US DOE FEMP, 2015)

5.3 Federal Energy Management Program (FEMP) – Measurement and Verification for Performance-Based Contracts

“The FEMP M&V Guideline contains specific procedures for applying concepts originating in the IPMVP. The Guideline represents a specific application of the IPMVP. It outlines procedures for determining M&V approaches, evaluating M&V plans and reports, and establishing the basis of payment for energy savings during the contract. These procedures are intended to be fully compatible and consistent with the IPMVP.” (US DOE FEMP, 2015)

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[9] DOE = Department of Energy of United States.

"For commercial measures, the FEMP guideline and the UMP are complementary. However, since one of the objectives of M&V in a performance-based project is to ensure long-term equipment performance, the FEMP guideline includes additional recommendations for annual inspection and measurements, where appropriate." (US DOE FEMP, 2015)

5.4 Ad-Hoc Proprietary Protocols

"For the retrofit of houses, we usually work with condominiums with a centralized heating system; we ask for the past invoices with energy consumption so that we create a baseline for the annual energy consumption referring to the annual degree days. In every condominium, we install an energy meter on the distribution to heating terminals that measures the instantaneous power and calculates the total energy provided to the system, recording periodically this last data we have the energy consumption and so we can compare the actual savings with the expected energy savings. Then yearly we provide to the condominium a report with the energy consumption data over the heating period of the year. It is a simple procedure, but it fits our purposes."[10]

[10] Thanks to TECNOZENITH for this contribution.

6. M&V in the context of HAPPENING

6.1 IPMVP M&V options for HAPPENING

As stated before, there are four options in the IPMVP:

- Option A: Retrofit Isolation with Key Parameter Measurement
- Option B: Retrofit Isolation with All Parameter Measurement
- Option C: Whole Facility Measurement
- Option D: Calibrated Simulation

In the HAPPENING project, option B and C are considered, depending on the initial or previous system (centralised or individual) available in the building to be refurbished. And in addition, option D is proposed for the HAPPENING system implemented in new buildings or for the refurbishment of building with no data available for establishing a baseline.

6.1.1 Option B

This M&V option may be used when the building being retrofitted has no central services, such as heating, cooling or DHW, and instead relies on individual equipment installed within each dwelling. It may prove more practical and cost-effective to measure the efficiencies of each equipment on a dwelling-by-dwelling basis, than to attempt to establish correlations between energy invoice data and independent variables, especially so when the number of dwellings is high.

6.1.2 Option C

This M&V option should be used whenever it is not possible or practical to implement Option B, or when the building has central services that can be treated as a “single client” (e.g. single owner for the whole building). In many cases of buildings with central services implementing an M&V plan based on the IPMVP option B will prove challenging, since HAPPENING will replace purely central services with a hybrid central / distributed model, which will make hard work of establishing comparable baseline and reporting period measurement boundaries. In this case, it is preferrable to choose option C and make sure the measurement boundaries physically coincide with the different owners’ properties.

6.1.3 Option D (only for new buildings or when total lack data of previous situation)

Producing a good calibrated simulation is quite a complex and time-consuming task, so it is advisable to only use this option when it is the only practical choice left. In the case of new buildings or in the case of no data for the baseline period, the simulation model can be developed at the project stage as part of the ECM definition, and it can then be calibrated during the commissioning phase.

Once the model's results are sufficiently close to the real observed behaviour of the building, the model is said to be calibrated. A new model is then derived from the calibrated model, implementing the industry-standard energy systems instead of the ECMs and keeping all other factors constant. The results of this model will be the corrected baseline against which the real energy consumption of the building can be compared to determine energy savings due to the ECMs.

6.2 Uncertainty analysis of the M&V for HAPPENING

6.2.1 Risk factors and mitigation strategies for the M&V for HAPPENING

The main source of information for this chapter comes from the study by Taminiau et al. (Taminiau, Byrne, Sanchez Carretero, Shin, & Xu, 2021). In the cited study, the authors deliver a deep analysis of the main risk factors and risk mitigation strategies implemented in the ESCO market.

According to this study, risk has been identified as a critical barrier surrounding operational performance uncertainty. It is commonly referred to as the energy saving "credibility gap" or "performance gap", whereby project clients express concern about ESCOs not being able to meet the guaranteed energy savings, thus causing problems to third-party financing. Likewise, the uncertainty of payments based on energy savings is seen as a key market and financial barrier. Paradoxically, evaluations of performance contracts find many instances of over-performance, in some cases by as much as 50% more than the savings guaranteed by the ESCOs.

While it is undoubtedly true that there are inherent risks accompanying energy performance contracts, clear risk allocation is of paramount importance to avoid disputes. Contractual agreements between the parties are a very important risk mitigation option. In this aspect, shared-savings and guaranteed-savings contracts are the two most widely used options:

a) In shared-savings contracts, the ESCO is allowed to take a share of the savings above an agreed-upon target level. Typically, in this model, the ESCO provides project financing.

b) In guaranteed-savings contracts, the ESCO guarantees a level of performance sufficient to pay back installation and financing costs, if the proposed ECMs are implemented, monitored, and verified according to protocol guidelines. If the project performance is inferior to the guarantee, the ESCO compensates the client for the difference. In this model, the ESCO does not benefit from savings that are above the guarantee. This is currently the most popular option in the ESCO market nowadays.

Still according to (Taminiau, Byrne, Sanchez Carretero, Shin, & Xu, 2021), under the energy savings guarantee contract the ESCOs are faced with the choice between lowering the guarantee level in order to lower overall risk of disputes and of having to compensate the client, and to raise the guarantee level in order to be competitive and win the project bidding. Although there is no general rule to determine the "optimal" value of the guarantee, it is suggested that typically the guarantee is set to a conservative value below the expected performance, according to individual risk-tolerances that vary from one ESCO to another, and even from one ECM to another within the same ESCO.

A range of factors can cause energy savings uncertainty, including monitoring and verification risk, financing risk, and technology risk (Table 6.1). These factors complicate risk assessment, limiting the usefulness of conventional risk screening tools such as simple payback.

The next Table 6.1 shows some examples of relevant risks causing uncertainty in the M&V:

Category	Manifestation	Causes	EPC contract design
Financial	Payment default	Insufficient savings	Guaranteed savings
Technology	Equipment fault	Poor maintenance	Diagnostics
Operational	Unexpected use	Baseline changes	IPMVP
Monitoring and verification	Modelling errors	Incorrect assumptions	IPMVP
Economic	Fuel cost increases	Price volatility	Price escalator

Table 6.1: Examples of relevant risks (Taminiau, Byrne, Sanchez Carretero, Shin, & Xu, 2021)

An ESCO implementing the HAPPENING solution would be advised to use a guaranteed savings contract, paying close attention to the previous risk matrix when defining the duties and the responsibilities of each of the stakeholders, before, during and after the implementation of the system.

Before the implementation, it is important to make very clear how each estimate was calculated, and who was the party responsible for the supplying the input data for these estimates.

It is also important to clarify exactly who has what role during implementation and commissioning of the system.

After the implementation of the system, it is important to clearly define the maintenance duties and to set standards for defining “normal” system operation. And last but certainly not least, it is crucial to allocate beforehand the recurring responsibilities for the collection of all the necessary data, including the data that’s needed for determining whether non-routine adjustments are needed.

Regarding data, during the reporting period, it would be very important to secure online access to the HAPPENING monitoring system, allowing for the early detection and correction of abnormalities. If online access would not be possible, then a periodic verification of working conditions should be carried out. This is an important risk mitigation measure, both from the final user as from the ESCO point of view.

As for the determination of the guarantee, this should be done according to the technical guidance provided by the HAPPENING partners and corrected according to the specific risk-tolerance of the ESCO in question.

6.2.2 Quality assurance in the M&V for HAPPENING

Quality assurance can be defined as "part of *quality management* focused on providing confidence that *quality requirements* will be fulfilled" or "all the planned and systematic activities implemented within the quality system that can be demonstrated to provide confidence that a product or service will fulfil requirements for quality." (ASQ Quality Press, n.d.)

According to the Office of Environment, Health, Safety and Security (Office of Environment, Health, Safety & Security, n.d.), “Quality Assurance ensures mission achievement, consistency, and the effectiveness of products and services to meet the project’s missions and goals. The management system should be tailored to individual missions and goals for each project based on the graded approach. The graded approach should be used to develop a Quality Assurance management system that incorporates the applicable requirements aligned with the scope of work, and the level of assurance needed for the intended use of the products and services.”

In general, continued performing can be ensured through monitoring and optimization in the use phase. It can be done informally, or within a performance guarantee or service contract:

1. Collect data on parameters like energy use, costs, user comfort and health
2. Verify whether performance objectives and specifications are being met
3. Analyse the causes of performance gaps and apply appropriate interventions
4. Optimize the performance of the building services as one entity

All these activities complete the quality assurance. (H2020 AZEB - Affordable Zero Energy Buildings, 2020)

If energy upgrade or EPC projects are worth more than $500,000, energy users should appoint an independent expert to undertake Quality Assurance (QA) to make that the M&V services provided by the ESCO are robust and adhere to IPMVP key principles. The cost of QA is likely to be well under the value provided by the QA service, and failure to undertake this QA is usually a false economy. (8020Green, n.d.)

According to this guideline, we will recommend all HAPPENING instances to appoint an independent expert to undertake Quality Assurance, whenever the total budget (HAPPENING + all other actuations included in the same is project) a tall order, for example exceeding $500,000.

Quality Assurance Instruments (QAI)

Quality Assurance Instruments have some similarity to the “operational verification” approach in IPMVP. QAIs shall verify the functionality and quality of ECMs, but not necessarily their exact quantitative outcome over an entire project cycle. In several cases, the simplified M&V approaches proposed are combinations of savings calculations to determine savings cash flows backed up by QAIs. (Bleyl, Sattler, & Bareit, 2014)

In other words, the concept of QAIs is to provide the functionality and quality of a particular saving measure. Their function is to verify that a specific saving measure has been implemented correctly and that it is performing according to specifications. On the other hand, QAIs cannot determine the exact quantitative outcome of an ECM, which is often subject to a number of external and dynamic parameters, like the utilization of the facility or climate conditions, which may change over the course of the project cycle.

In the case of M&V approaches, savings calculations are typically used to determine savings cash flows and to back these up with QAIs as a “safeguarding mechanism”. Individual QAIs will be designed for each ECM.

The concept of QAIs to support the quality of the measures is also applied in the “Integrated Energy-Contracting” (IEC) business model, as illustrated in the next Figure 6.1:

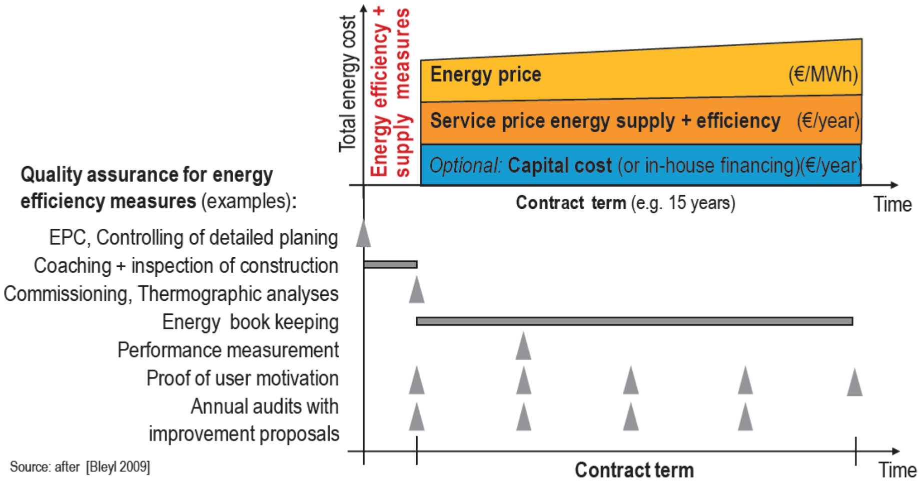

Figure 6.1: IEC business model and sample QAIs to back up saving measure quality.

As can be seen in the Figure 6.1, one-time QAIs can be supplemented by periodic or continuous QAIs. The function of the latter is to maintain performance levels throughout the project cycle.

A prominent issue is to design individual and practicable QAIs. The selection of QAIs as well as their exact design will depend on the specific requirements of the project scope and the parties involved. QAIs can be specified internally by a facility manager, by an ESP[11] client or by an ESP (as part of the competition of solutions during the procurement process or the detailed project design). A number of possible QAIs are described in the following section.

QAIs performed by facility owners (examples)

The study of (Bleyl, Sattler, & Bareit, 2014) captures the possible QAIs for individual energy-efficiency measures (which can be provided by the client or by third parties on behalf of the client), as follows:

1. (Functional) specifications to communicate and document energy-related objectives and requirements (e.g., quality standards, maximum energy indicators, request of renewable energy sources with proof of origin etc.).
2. Support of detailed planning by the ESCO or by an (independent) energy consultant.
3. Third-party construction supervision by the ESCO or by an (independent) energy consultant.
4. Commissioning ("acceptance") after the construction phase, in order to verify compliance with functional specifications, involving proof of function, etc.
5. Energy book-keeping – comparison of target and actual values - is directly provided by the HAPPENING control and monitoring system, so it is important to secure online access to these data.
6. Survey by an (independent) energy consultant (2nd opinion report).[12]
7. Building certification (like EPBD or Green Building; could also be provided by the ESP).[12]

[11] The cited study by (Bleyl, Sattler, & Bareit, 2014) mentions ESPs, but in this context all that is said as applicable to ESPs is also applicable to the ESCO model.

[12] This step is not mandatorily applicable to HAPPENING under the ESCO - EPC model

IPMVP takes a somewhat comparable approach and calls it "verification of the potential to achieve savings". After the "reporting" period "operational verification" is recommended to "support energy savings persistence". Nevertheless, operational verification is formally not considered a part of the M&V process but "it reduces the risk of adverse shifts in performance associated with ECMs that can fail, fade or be bypassed".

Pre-implementation report

The following aspects should be included to specify how quality assurance is to be performed (Clean Energy Ministerial, 2014):

- **Metering Specifications**
  - How and where metering will be done
  - Duration of metering
  - Metering intervals
  - Accuracy requirements (including calibration of meters)
  - Metering schedule (time frames)
- **Sampling Requirements**

  This should include all aspects related to sampling (sample sizes used (where appropriate), the representativeness of the sample, the sampling interval, etc.).
- **Energy Accounting**

  Deals with calculation methodologies, accuracy and confidence levels of energy performance impacts reported on and would include the interactive effects which have an influence on the projects and its results.
- **Checks and Balances**

  Specify what methods will be used to ensure that the data capturing process and the results of the Preinstallation report are reliable.

Post-implementation report

In the case of post-implementation, quality assurance shall be performed by specifying the following (Clean Energy Ministerial, 2014):

- **Metering Specifications**
  - How metering will be done
  - Duration of metering
  - Metering intervals
  - Accuracy requirements (including calibration of meters)
  - Metering schedule (time frames)
- **Sampling Requirements**

  This should include all aspects related to sampling (sample sizes used (where appropriate), the representativeness of the sample, the sampling interval, etc.) and the ultimate impact thereof on the precision and confidence levels of the energy performance impacts being reported.

- **Checks and Balances**

  Specify what methods will be used to ensure that the data capturing process and the results of the Post installation report are reliable.

Under the HAPPENING model provided, the ESCO is granted online access to the HAPPENING monitoring and control system, all these previous topics are already suitably defined and all that the ESCO must do is make sure to follow closely the evolution of the energy behaviour of the system and to act immediately upon detecting significative deviations – for example by issuing a corrective maintenance request.

6.3 Commissioning procedure in HAPPENING

The commissioning procedure of a project is a series of activities aiming to correct management with the results of reducing the risks of errors and delays and ensuring the quality and the correct functioning of the construction. In literature, it is stated that "*commissioning brings a holistic perspective to design, construction, and operation that integrates and enhances traditionally separate functions. It does so through a meticulous forensic review […] to identify suboptimal situations or malfunctions and the associated opportunities for energy savings*" (Mills).

Commissioning is usually applied to new projects that can imply a new construction or the retrofit of an already existing building. In this last case, the literature shows commissioning to be a highly effective way to reduce energy consumption. In case the commissioning is applied to the operations of an already existing project, it is called retro-commissioning. In principle, the HAPPENING solution is thought as a commissioning.

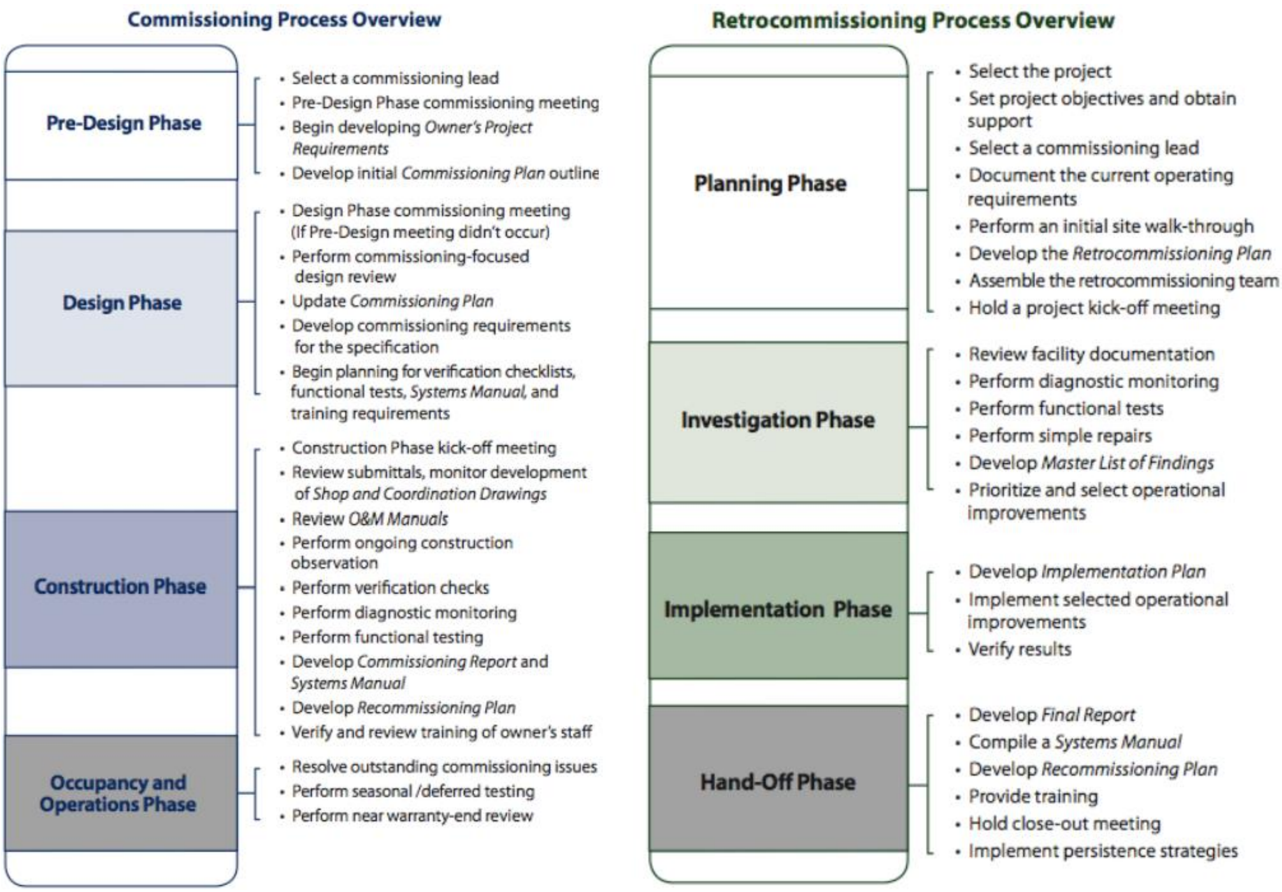

Figure 6.2: Commissioning procedures steps for commissioning Vs. retro-commissioning (Mills)

It is important to notice that every site is different and has a unique plan to achieve the desired outcome, but it is possible to identify an overall process that is similar for each case. In general, it can be stated that commissioning is more beneficial to more complex systems where a holistic view is needed (Coyner & Kramer, 2017).

According to ASHRAE, commissioning is "*the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent... Commissioning begins with planning and includes design, construction, start-up, acceptance, and training, and can be applied throughout the life of the building*." (Kubba, 2010)

The commissioning starts before the construction phase of the project, usually during the **design phase**. At first, it is important to understand the requirements of the owners that are the basis on which the whole project is built; the requirements might change over the project lifespan, and they will be used as a benchmark to evaluate the success of the work. Subsequently, these requirements will be translated into criteria that the project needs to fulfil. In the context of HAPPENING, the owner of the building typically has economical requirements regarding the initial investment and the O&M cost over the lifespan of the system; moreover the requirements also point to the internal comfort to be achieved and there can be constraints about spacing and noise of the machinery. Last, the owner might require interconnecting with other systems that produce hot water, like solar panels, or optimize the usage of the electricity produced by photovoltaic panels installed on the building.

A commissioning plan is developed aiming to identify processes and procedures necessary for a successful commissioning project; this plan will be continuously updated during the project to reflect changes that may arise during the life of the project. At this stage clear methods are established to share information between parts involved in the project and the schedule of the activities are agreed identifying the construction milestones over the timespan of the project construction. The issue log is expected to be prepared that will contain descriptions of every problem that arises during the project.

A system manual is created to inform about the system's operation and maintenance. This manual can expand the traditional information with measures obtained during the commissioning process that will improve the understanding of the system. In the case of HAPPENING manuals are available in the deliverable 5.4, however these can be expanded including peculiarities of the project.

During the **construction phase**, it is necessary to verify that the selected materials and systems comply with the expected quality, then the installation must comply with the state-of-the-art, so that the owner's requirements will be achieved. It is important to check the compliance with the schedule of the project and to have continuous communication. The documentation of both the schedule of the project and the continuous communication helps to make the process clearer.

The owner's requirements are still subject to possible changes, possibly leading to updating the design / construction of the project aiming to comply with the new requirements. When the owner requires these changes the commissioning team should evaluate how these would affect the overall project.

Several **tests** should be conducted during the construction phase for every equipment installation to check the correct functioning of the various parts of the project, every test should have a standard procedure and minimum performance to be achieved that will be documented by the inspecting staff.

Testing will be done over single components to verify the correct functioning under a wide range of circumstances: for every heat pump (standard and micro) should be checked the correct functioning under different loads; all the circulation pumps valves and general hydraulic components should work correctly, last also the electronic components that control the systems needs to be verified to communicate as expected. Systems are also tested under various conditions to check responses in case of normal operation and case of faults or emergencies: now the conditioning system should be able to work correctly together and the supervision system should be able to verify the status of every indicator monitored and to correctly manage the electronic devices. Intersystem verification controls the interactions between the various systems checking that there are no conflicts and that the operations are optimized (e.g., in case there is the presence of solar panels that produce hot water their usage should be maximized since it is a free energy source). Last the owner's requirements must be verified testing the correct operations of the project. In case an issue arises during the tests it has to be reported in the issues log, it is necessary to understand the nature of the issue: how long will it take to be resolved and how much it affects the correct functioning of the project. When the issue arises, the test must be stopped, and the issue fixed then it can be repeated the test. In case the problem cannot be resolved in an acceptable time the test can be run immediately and then again once the issues are resolved. All the results need to be recorded and signed by the technicians who performed the observations.

Finally, a **report** should be written in which the equipment installed, and the work carried out is detailed indicating compliance with the owner's requirements; all the lessons and evaluations that emerged could improve the report.

When the construction phase is completed, the **operation phase** starts. The commissioning is mainly involved at the beginning of this phase. Firstly, the performance of the project is tested when it is occupied verifying t that the system is able to reach the desired temperature set point and the other comfort requirements. During these tests, it can be useful to compare with a benchmark of similar systems, the HAPPENING demo sites will provide data for future installation, a significantly worse performance is a sign that the project is not working correctly, and it should be revised. Trend data are helpful in analysing anomalies to verify that the components and systems work, with adequate performance; thanks to this it is easier to evaluate issues when systems do not comply with expected performance, and eventually, the timing when faults occur helps to better identify their causes.

For the HAPPENING system the main **values monitored** are the energy performance of the system by measuring the primary energy consumed to guarantee the setpoint ambient temperature, and the evolution of the ambient temperature, this allows to verify the comfort of the occupant and eventually situations of overconsumption. It is also especially useful to monitor the temperature in the various pipes that shows if the systems are functioning correctly (e.g., the outlet temperature of the central heat pump should be higher than the inlet temperature during the heating season); to evaluate the performance of a circulation pump it can be measured the water flow in the pipes. In case of high consumption, the efficiency of single components should also be monitored since malfunctioning can affect the overall consumption of the system. Inhabitants can provide useful feedback on the capacity of the system to meet the comfort requirements.

Finally, the **commissioning report** will also be updated including the operation phase. It is possible to apply a continuous commissioning process, in this situation the commissioning process report will be delivered at the end of the construction and then for the operation phase will be created periodical reports; continuous commissioning main goal is to maintain the owner’s requirements over the life of the facility through the correct operations of the system. (ASHRAE GUIDELINE) (Wanga, et al., 2013)

6.4 Documenting M&V plan in HAPPENING

Although IPMVP does not currently include a formal certification of M&V plans, it does provide guidelines to develop IPMVP adherent M&V plans.

An IPMVP adherent M&V plan is one that conforms to all the 14 points listed below (Efficiency Valuation Organization, 2016):

1. Facility and Project Overview

M&V Plan should provide an overall description of the facility and the proposed project along with the list of all the additional measures that are included as part of the project, as well as the HAPPENING system itself, with a detailed description of all heat-pumps (both standard and micro), and all the terminal units. The description should also cover ancillary equipment such as pumps, tanks, and distribution manifolds This section should also include references to any energy audit reports or other analysis that was used to scope the project, if any.

2. ECM Intent

This section of the M&V Plan should provide a clear understanding of each measure’s scope and intent. At a minimum, this section should include, for the HAPPENING system:

- Type and number of the primary heat pumps.
- Type and number of the terminal units.

- The HAPPENING system works by improving overall efficiency and reducing distribution losses. A brief explanation should be included.
- Estimation of the expected primary energy saving.

For the additional ECMs, included in the project:

- A measure description
- How the measure saves energy or other resources (e.g., improves efficiency, reduces utility demand, etc.)
- Affected equipment inventory
- Expected savings

3. Selected IPMVP Option and Measurement Boundary

As a general rule of thumb, for those refurbishment cases where a centralized system was not previously available, IPMVP option B is recommended, whereas for those cases that did have centralized services, it is option C that's favoured. In both cases the measurement boundary comprises two disjoint domains: the central equipment and the terminal units. In the case of new builds or when there isn't enough data to characterise the baseline, then option D should be considered.

4. Baseline: Period, Usage and Conditions

This section of the M&V Plan documents the facilities or system's baseline utility demand and consumption along with corresponding influencing parameters, within each measurement boundary.

The baseline description must be well-documented. The baseline data may come from many sources such as short-term metering or spot measurements or from other sources such as manufacturer specification sheets. The extent of the needed information is determined by the selected M&V Option, measurement boundary chosen or the scope of the savings determination.

Baseline documentation should include the following information:

- Identification of the Baseline Period

  For typical HAPPENING usage, one full, continuous year is the most appropriate baseline period

- Baseline Utility Consumption and Demand Data

  Except if there are other more convenient sources of reliable data, utility billing data should be used in option C. Option B should rely on instantaneous measurements of the heating and DHW production equipment efficiencies.

  Option D can rely on the HAPPENING monitoring instrumentation, but appropriate care must be taken to double check that this instrumentation is fit for the purpose of calibrating the simulation.

- Utility Influencing Variable Data

  Almost for sure, in the scope of the HAPPENING implementations, one of these variables will be Heating Degree Days (HDD). Another strong candidate is Cooling Degree Days (CDD). Dry bulb temperature could also potentially be used, as well as illuminance or irradiance data. These and / or any other independent variables will need to be gathered in the appropriate time aggregation intervals.

- Operating Conditions

  Define the prevailing operating conditions corresponding to the dependent and independent variables (e.g., Baseline Utility Consumption and Demand Data, Utility Influencing Variable Data) during the Identification of the Baseline Period. These prevailing conditions (i.e., also known as static factors) are assumed to remain constant but may change and have to be addressed as part of non-routine adjustments if needed. Examples of static conditions may include, but not be limited to the following:

  - Occupancy type, occupancy density and climatization running times.
  - Operating conditions (e.g., set points, lighting levels, ventilation levels) for each baseline period and season.
  - Significant equipment problems or outages during the baseline period.
  - Baseline adjustments may be made, for example, on systems that are not providing adequate heating. System changes may include equipment efficiency, capacity, operating sequence, or any other element of the measure that results in changes in energy use.
  - Identify planned changes to conditions that affect the baseline (may include variations in occupancy levels, temperature set-points, lighting levels, etc.)

5. Reporting Period

The reporting period is a selected interval for evaluating and quantifying the post-installation performance of the measure. The M&V Plan shall identify the reporting periods for which the measure or a project is being evaluated. This may be for a short period of time right after the installation of the measure to ensure that the measure is performing as intended or it could be a longer time at periodic intervals such as a year, multiple years, or other time periods.

In HAPPENING, the baseline period and the reporting period should both be one year each, but, in cases where the baseline period and reporting period are not of the same length, it is important to explain how the time frames are normalized so the baseline and reporting period energy consumption and demand are compared evenly and reliably.

In a performance contract, the performance period refers to the duration of the project guarantee and is made up of numerous reporting periods. Normally the contractor is required to report on the performance of the project and the ECMs on a regular basis for the entire duration of the performance period.

6. Basis for Adjustment

The operating conditions that affect energy consumption may differ between the baseline and reporting periods. It is important to make adjustments to account for these changes in operating conditions.

If the M&V guidelines set forth in the HAPPENING project are followed, the M&V Plan provides details outlining how the baseline and/or reporting period energy consumption and demand will be adjusted to allow for valid comparison and saving calculation. Depending on the IPMVP option, it is suggested that the basis for adjustments be made by:

- Option B: Projecting reporting period energy consumption and demand to baseline operating conditions.
- Option C: Projecting the baseline energy consumption and demand to reporting period conditions.
- Option D: Projecting the baseline energy consumption and demand to reporting period conditions.

The other possible option results in normalized savings being calculated instead of avoided energy:

- Projecting both the baseline and reporting period energy consumption and demand to standard conditions (e.g., Typical Meteorological Year, TMY).

7. Calculation Methodology and Analysis Procedure

The HAPPENING M&V Plan specifies data analysis procedures, model descriptions and assumptions that are used to calculate savings for each of the reporting periods.

For each model used, it identifies and defines all independent variables, dependent variables, and other model-related terms. Report all coefficients, constants, statistical metrics (CV{RMSE}, MBE, R2, t-statistic, etc.) or other model elements or terms.

8. Energy Prices

The HAPPENING M&V Plan also specifies the utility prices, or tariffs that will be used to calculate the cost savings associated with the measure or project, and how the monetary value of savings will be adjusted if utility prices change during the life of a measure or a project. The plan clearly defines and reports any assumed or stipulated values It is suggested that fixed utility prices be agreed upon by all parts, for the sole purpose of cost saving calculations. This simplifies the calculations, although it may be problematic in scenarios with very large price oscillations.

9. Meter Specifications

Within the HAPPENING project, a full specification of the control and monitoring system has been developed, so correct metering specifications will be embedded in the system from the start.

For non-utility meters, the M&V Plan should specify:

- Meter - type, make, model and characteristics
- Meter specifications including accuracy and precision
- Meter reading and witnessing protocol
- Meter commissioning procedure
- Calibration procedure/process
- Method of dealing with lost data and data transfer

10. Monitoring Responsibilities

The plan assigns responsibilities for collecting, analysing, archiving, and reporting the data. Management of M&V data is assigned to the party that is qualified to efficiently and effectively access, manage, and provide data sets. Typically, an ESCO should be capable of this, but it can also be agreed that the property do it, or the maintainer, or any other appropriate stakeholder. Monitored data that must be managed includes:

- Energy data
- Independent variables
- Static factors within the measurement boundary
- Periodic inspection findings

11. Expected Accuracy

The HAPPENING M&V Plan includes the expected accuracy associated with the measurement, data capture, sampling, and data analysis. This assessment includes qualitative and any feasible quantitative measures related to the level of uncertainty in the measurements and describes adjustments to be used in the planned savings report.

12. Budget

The M&V Plan should include the budget and the resources required for saving determination, costs for both the initial setup and ongoing tasks for evaluating, documenting, and reporting the performance for each of the reporting periods.

13. Report Format

The HAPPENING M&V plan proposes a format for the periodic report.

14. Quality Assurance

The M&V Plan should also include quality-assurance procedures and processes that will be used for the baseline and post-retrofit M&V data collection, calculations, saving reports and any interim steps in preparing reports. Quality assurance should include inspections at regular frequencies to ensure that the measure and equipment continues to be operated per the contract.

Additionally, for IPMVP Option D, the following requirements must also be met (Efficiency Valuation Organization, 2016):

1. Software Identification

The M&V Plan should report the name and the version number of the simulation software that is used to calculate savings.

2. Input/Output Data

The plan should provide copies of the input files, output files, and weather files, or weather file identification, used for the simulation, including any post-processing or presentation development methods and calculations.

3. Measured Data

The M&V Plan should describe the process of obtaining any measured data including which input parameters were measured and which input parameters were estimated. The actual measured data should also be reported, and raw data should be archived and made available as needed. This may include interval data or utility-provided bills.

4. Calibration

The plan should report the energy and operating data used for calibration including the calibration requirements (e.g., CV{RMSE}, MBE, etc.) and the accuracy with which the simulation results match the calibration energy data. Data should be provided at a minimum of one-month (i.e., billing period) intervals, and more resolution is preferred.

5. Future Changes

The M&V Plan should provide a description of the method for making relevant non-routine adjustments. Non-routine adjustments may require revising the model and recalculating baseline and post-installation energy use and savings.

6.5 Reporting results

Correctly reporting the results of a M&V plan is as important as every other process included in the M&V plan, since incorrect reporting could defeat one of the main purposes of M&V, which is to boost stakeholders' confidence in energy efficiency projects' results. When using IPMVP (Efficiency Valuation Organization, 2016), a report should include at least:

- The background of the project
- Description of the implemented measures
- M&V Option chosen for the project
- Start and end dates of the reporting period
- M&V activities conducted during the reporting period, including:
  - Start and end time for the measurement period
  - Energy use data
  - Data for independent static variables
  - Description of inspection activities conducted
  - Verified saving calculations and methodology
  - Detailed description of data analysis and methodology
  - Updated list of assumptions and source of data used in the calculations
  - Details of any baseline or saving adjustments including both routine and non-routine adjustments to account for changes
  - Details of utility costs used to calculate the reported savings
  - Clear presentation of verified energy, cost savings and comparison to the proposed savings
- List of new installed equipment
- List of project team members – especially if there are changes regarding parties responsible for specific M&V plan items
- Performance measurements
- Expected savings for the first year
- Savings uncertainty

The "*Measurement and Verification Operational Guide*" (Office of Environment and Heritage, 2012) printed by the Australian Office of Environment and Heritage offers some practical tips for M&V reporting, which should be observed when planning and preparing the periodic reports:

- Consider the audience of the report. Use appropriate language and provide background details to put findings into context.
- Use the details within your M&V plan to shape your report, including goals, expected outcomes and measures

for success

- Use both words and diagrams to demonstrate the savings
- Add pictures that demonstrate the ECM in-situ and the process for conducting measurements
- Describe step-by-step the data analysis and savings calculations. Add equations with explanations if they are unfamiliar to the audience.
- Report savings figures using an appropriate number of significant digits
- Note that 'actual' savings can only be stated for the post-retrofit measurement period. Any extrapolation beyond this is considered an estimate.
- Acknowledge key stakeholders and project champions.

7. Conclusions

This deliverable tries to detail in as much of a practical fashion as possible the steps needed to arrive at a successful Energy Performance Guarantee that is beneficial for both the client and the ESCO.

M&V protocols tackle the challenge of determining a quantity that cannot be directly measured: energy saving. Instead, savings are determined by comparing measured use before and after implementation of a project, the HAPPENING solution in this case, making appropriate adjustments for changes in conditions. Energy modelling is the set of tools that enables this comparison, and it can have many forms and levels of complexity. It can be as simple as establishing a correlation between observed values of consumption and exterior temperature; or it can involve the time-consuming process of calibrating a simulation.

There are several internationally recognized M&V protocols, and while almost all of these can be traced back to IPMVP in one way or another, they aren't mandatory. A simple-yet-effective protocol might be all it takes – it all depends on the trust relationship between ESCO and client.

Most "standard" M&V protocols include some form of options that allow them to fit to different projects with very different sizes. In the framework of the HAPPENING project, the IPMVP protocol has been selected as a reference, and all options except *option A* have been identified as valid alternatives, depending on the characteristics of the building and the data availability. In many cases of buildings with central services, implementing an M&V plan based on the IPMVP option B will prove challenging, since HAPPENING will replace purely central services with a hybrid central / distributed model, which will make hard work of establishing comparable baseline and reporting period measurement boundaries. In this case it is preferrable to choose option C. Option D is quite a complex and time-consuming task, but it is a good option in the case of new buildings or in the case of no data for the baseline period.

While it is undoubtedly true that there are inherent risks accompanying energy performance contracts, clear risk allocation is of paramount importance to avoid disputes. Contractual agreements between the parties are a very important risk mitigation option. In this aspect shared-savings and guaranteed-savings contracts are the two most widely used options.

Quality Assurance ensures mission achievement, consistency, and effectiveness in meeting the project's missions and goals.

Commissioning integrates traditionally separate functions through a meticulous review to identify suboptimal situations, or malfunctions, and the associated opportunities for energy savings.

All the above-mentioned topics should be clearly defined in an IPMVP compliant *M&V plan*, together with other details that will all contribute to the success of the replicability of the HAPPENING project in the long run.

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