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Monitoring guidelines and specific measurement & validation plan for each demonstration site

BIPVBOOST

"Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation"

Start date: October 2018. Duration: 4 Years

Summary

This document provides a common set of monitoring guidelines and a specific measurement and validation plan for all BIPV project developments and each demo site. To that end an individual monitoring plan for each demo site and each BIPV technology development is defined base on the International Performance Measurement and Verification Protocol (IPMVP) and the previously performed pre-monitoring activities (T8.3). The monitoring plan comprises of monitoring objectives, performance checking procedures, testing tasks and required equipment.

Following the data protection document "Informed Consent Form_BIPVBOOST_v0.docx", the data presented in this deliverable shall be anonymized in case of use for publications, dissemination activities, etc., meaning that there is no need to show a connection between the building owners, building address and the information provided for these purposes.

Data provided for the development of this deliverable has been under authorization of each of the demo site owners or managers signing the conditions in the mentioned Informed Consent Form.

Acknowledgements

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Disclaimer

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This deliverable describes the measurement and validation plan for all the BIPVBOOST project developments and implementations. First the energy performance measuring and validation methodology is presented. This methodology is the common base line for all the developments and implementation. Second the measuring and validation plan for each demo site is presented. The variables that are going to be measured, the required instruments and its accuracy are specified.

1.2 Relation with other activities in the project

Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within the BIPVBOOST project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1 Relation between current deliverable and other activities in the project

TASK	Relation with current deliverable	Input
T7.1	D7.1. Use case definitions with optimization targets and constraints for tertiary and residential buildings.	Initial BEMS information as support for the monitoring plant
T7.1	D7.2. Architecture of the BIPVBOOST monitoring, control and energy management framework	Electric load distribution
T7.4	D7.4. Documentation of BEMS software for tertiary and residential buildings	Electric energy demand
T8.3	D8.2. Pre-audit of demonstration installations	Initial demo data as support for the monitoring plan
T8.6	D8.8. Post-intervention energy performance assessment from monitoring results	Initial consumption data as support for the study

1.3 Reference material

USDo, E. (2010). IPMVP: International performance measurement and verification protocol. *Concepts and Options for Determining Energy and Water Savings Efficiency Valuation Organization. US Department of Energy*.

Vilariño-García, J., & Menéndez-Milanés, H. F. (2016). Índices de comportamiento del sistema fotovoltaico conectado a la red eléctrica y teoría de errores. *Tecnología Química*, *36*(3), 321-349.

1.4 Nomenclature

Acronyms	Description
BIPV	Building Integrated Photovoltaics
BEMS	Building Energy Management System
DHW	Domestic Hot Water
HP	Heat Pumps
HVAC	Heat, Ventilation and Air Conditioning
PV	Photovoltaic
SoC	State of Charge
nZEBs	nearly Zero Energy Buildings
DC	Direct Current
AC	Alternative Current
KPI	Key Performance Indicators

Latin letters	Description	Units (SI)
Gi	Solar Irradiance	W/m^2
T	Temperature	K
Sw	Wind Speed	$m\cdot s^{-1}$
I	Electric current	A
V	Voltage	V
P	Power	kW
E	Energy	$kW\cdot h^{-1}$
Q	Mass Flow	$kg\cdot s^{-1}$
H	Humidity	%
C	Energy cost	€

Greek letters	Description	Units (SI)
Φ_Q	Heat flux	$Wm^{-2}\cdot h^{-1}$

Subscripts	Description
east	East direction
west	West direction
south	South direction
b	Balustrade
w	Walkable floor
vf	Ventilated facade
rr	Roof retrofitting
oc	Opaque cladding
pv	Photovoltaic field
BIPV	Building Integrated Photovoltaics
gr	Grid
st	Storage
in	influx
out	outflow
gas	Gas
amb	ambient
build	Inside the building
renewable	renewable
T	to
F	from

2 INTRODUCTION

The main objective of the BIPVBOOOST project is to bring down the cost of multifunctional building-integrated photovoltaic (BIPV) systems and demonstrate the contribution of the technology towards mass realization of nearly Zero Energy Buildings (nZEBs). The contribution of the BIPV technology to nZEBs is expected to be the reduction of the building required energy demand and increase the use of renewable energy at a competitive price.

To achieve this objective, the energy performance of the BIPVBOOST project developments and implementation in each demo site are going to be measured and verified to reliably determine its energy performance. In this context the energy performance is understood as the non-used energy (energy savings), the self-consumption ratio, the reduction in the energy bill and the performance ratio. This energy performance indicators are aligned with the Key performance indicators (KPIs) defined in the project (see deliverable 1.1), as follows;

- Energy savings: is the non-used energy due to the implementation of the BIPVBOOST developments. This is related with the BIPV competitiveness and will be useful to estimate the KPI_12 (Competitiveness)
- Self-consumption rate: is the percentage of the used energy that is produced by the BIPV systems (KPI 11)
- Energy bill savings due to BIPVBOOST developments. This is related with the BIPV Competitiveness and will be useful to estimate the KPI_12 (Competitiveness)
- Performance ratio: is the ratio of the actual and theoretically possible energy outputs, corresponding to KPI 5.

The BIPVBOOST project developments comprise BIPV components and a building energy management system (BEMS).

In general terms, the BIPV elements electricity (active effect), but also improve the building skin (passive effect). Both effects (passive and active) increase the energy performance of the building as follows: on one hand the active effect is associated to energy production that, in case of being used, can increases the use of renewable energy and reduce the energy bill due to the reduction of used grid electricity. On the other hand, the passive effect reduces the heating and cooling system consumed energy and in consequence it can also have a positive effect in the energy bill.

Regarding the BEMS, different energy management strategies are going to be implemented in the demo sites as described in D7.1 and resumed here after.

- Optimal use of thermal inertia of the building: This energy management strategy aims to reduce the energy consumption (energy saving) in heating/cooling of the building using its thermal inertia.
- Load shifting: The optimization algorithms will shift the load as function of PV electricity availability or energy price. By doing so, self-consumption can be maximized and energy consumption during peak hours can be reduced, and thus energy costs. This strategy allows to maximize PV self-consumption or to consume energy when it is cheaper.
- Battery storage management optimization: The energy stored in the battery is used to reduce electrical consumption from the grid at hours with the highest purchase tariff and the highest consumption peaks, to reduce the power capacity demanded from the grid.

Typical Demo site developments and implementations

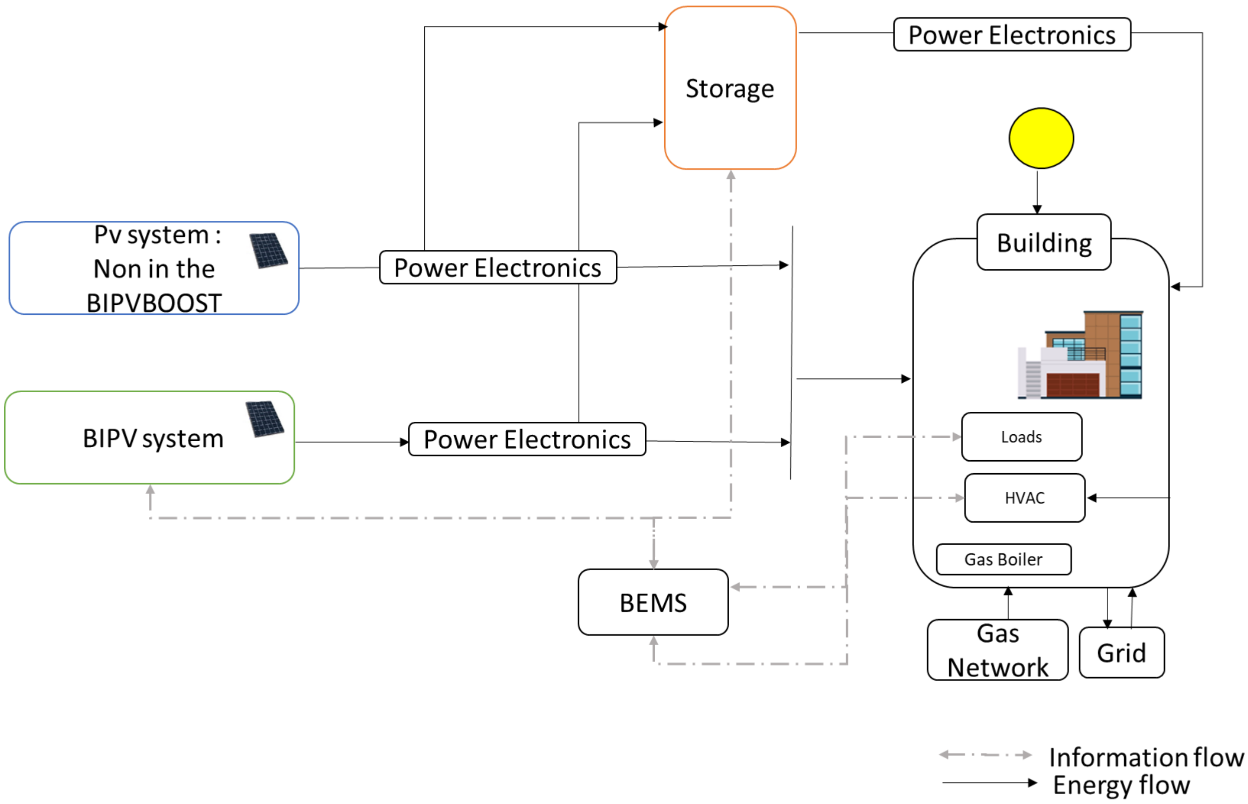

Figure 1. Schematic representation of the BIPVBOOST generic demo site. The developments and its implementation are represented together with all the relevant elements of the demos.

To sum up, Table 2 shows the energy performance indicators affected for each of the developments.

Table 2. Energy performance indicators affected by BIPVBOOST developments

	ENERGY PERFOMANCE INDICATORS			
Developments	**Energy savings**	**Self -consumption rate**	**Energy bill savings**	**Performance ratio**
BIPV				
passive effect	x		x	x
active effect		x	x	x
BEMS				
Thermal inertia	x		x	
BIPV use optimization		x	x	x
Battery storage management optimization		x	x	x

The energy performance of each development and implementation is going to be measured and validated at building and BIPV component level. At building level, the objective is to assess the impact of the whole BIPV solution implementation through energy performance and inner building comfort. At component level, the objective is to assess the performance of each BIPV technology development.

Next, the methodology to measure the energy performance is described and it is specified with more detailed definitions for each demo site.

3 MATERIALS AND METHODOLOGY

This section has been divided in two subsections. In the first subsection, the measurement variables that are required to evaluate the energy performance (Energy savings, self-consumption rate and Energy bill reduction) are identified both at building level and at component level. In the second subsection, the required instruments will be listed, and its requirements will be specified.

3.1 Identification of measuring variables

3.1.1 Building level

Energy savings:

As previously mentioned in the introduction (and shown in Table 2), two of the developments could have a positive impact on the building's energy savings: 1) the passive effect of the BIPV system, and 2) the BEMS strategy to optimize the use of thermal inertia of the building. Both developments impact directly in the reduction of heating and cooling requirements of the building. Considering the typical demo site shown in Figure 1, the developments implementations are expected to reduce the energy used by the HVAC system and the gas boiler. Thus, the affected measurement variables are the energy used by the HVAC system (E_{hvac}) and the energy used by the gas boiler that will be calculated from the measured gas flow ($E_{gas}(Q_{gas})$)

However, savings in cooling and heating consumption of the building cannot be directly measured, since they represent the absence of energy use. Instead, savings will be determined by comparing E_{hvac} and E_{gas} before and after the implementation of BIPV developments in each demo site, making appropriate adjustments for changes in conditions, following the recommendations of the IPMVP (Option C). The IPMVP is a guidance document of common practice in measuring, computing and reporting savings achieved in energy efficiency projects.

Figure 2 represents a hypothetic heating and cooling energy consumption of a demo site *before* (Pre-intervention) and *after* development implementation (Post-intervention).

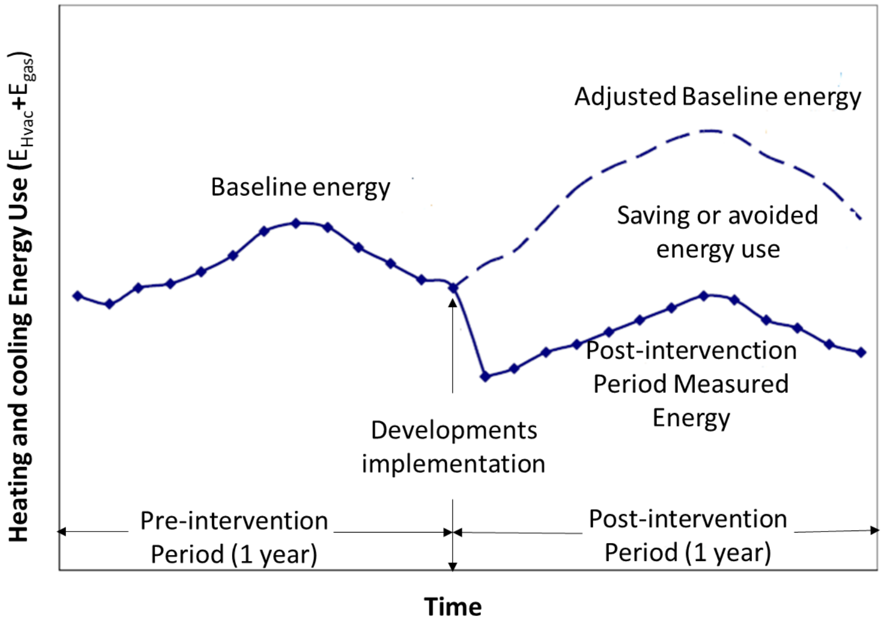

Figure 2. Example of the energy consumption, before and after the BIPV development implementation in a demo site.

To properly determine the impact of the BIPVBOOST developments and implementation, its energy effect must be separated from the energy effect of other variables, like the increase of the building use and weather conditions. The comparison of pre and post-intervention energy use or demand should be made on a consistent basis, using the following general equation:

$$\text{Energy Savings}_{\text{hvac +gas}} = (E_{\text{(hvac +gas) Pre-intervention}} - E_{\text{(hvac +gas) Post-intervention}}) \pm \text{Adjustments} \qquad \textbf{Eq 1.}$$

The "Adjustments" term in this general equation is used to re-state the use of the pre-intervention and post-intervention periods under a common set of conditions. The pre-intervention “baseline energy” use pattern before BIPV developments installation must be studied to determine the relationship between the energy use and the weather and building use of each demo site. This baseline relationship will be used to estimate the adjustments term of Eq. 1to estimate the energy consumption during the post intervention period if the BIPV developments were not installed (this is called the Adjusted-baseline energy (see Figure 2). The saving, or ‘Avoided energy use’ is the difference between the adjusted-baseline energy and the energy use measured during the post-intervention period.

The adjustment term shown in Eq. 1 should be obtained for any parameter that can affect to the cooling and heating system and is expected to change regularly during the post-intervention period, such as weather conditions or building use Therefore, meteorological data has to be measured (T_{amb}, G_i, S_w). Regarding the building exploitation the variables that can have an impact on the temperature of the building, e.g. variable Thermal loads, open windows, etc. These variables are not always easy to be measured and must be carefully controlled and monitored by the demo owners. Demo owners will be informed about how to control and monitor the building.

The measurement period (Pre-intervention period and the Post-intervention period) has been defined as *one year* to adequately characterize the load pattern in a normal annual cycle (i.e. seasons, weekday/weekend, etc). That way, all the operating modes of each demo site, from the maximum energy use to the minimum energy use, are included.

Finally, it must be pointed out that the internal comfort of the building must be guaranteed and should not be jeopardized against the energy savings. The internal temperature of the building will be measured to identify any deviation in the internal comfort. Moreover, the temperature setpoint are expected to be constant or at least monitored during the pre and post intervention period.

Self-consumption rate

The percentage of renewable energy ($\%E_{renewable}$) consumed by a typical demo site (as the one shown in Figure 1), is defined as the percentage of total energy consumed in the building (E_{Total}) that has been generated by the BIPV (E_{BIPV}) field and consumed in the building, not sent to the grid (E_{T_grid}), as is represented in Eq. 2.

$$\text{Self consumption rate} = \frac{(E_{BIPV} - E_{T\_grid})}{E_{F\_grid} + (E_{BIPV} - E_{T_{grid}})} \times 100$$ **Eq 2.**

The lower term of the division represents the total energy (E_{Total}) consumed in the building, defined as the energy consumed from the grid (E_{F_grid}) plus the energy generated by the BIPV systems (E_{BIPV}) that is consumed by the building ($E_{Total} = E_{F\_grid} + (E_{BIPV} - E_{T_{grid}})$). The upper term of the division represents the total renewable energy (within this project) consumed by the building ($E_{BIPV} - E_{T\_grid}$).

From Eq 2 it can be determined that to obtain the $\%E_{renewable}$ it is necessary to measure: E_{BIPV}, E_{s_grid} and E_{F_grid}.

Energy bill savings:

The energy cost (C) can be estimated as the product of the measured energy consumed from the grid (E_{F_grid}) and the energy price (obtained from the energy market). However, economic savings could not be directly measured, because expenses are not included. Instead, savings will be determined by comparing the energy costs before ($C_{Pre-intervention\_Period\ Use}$) and after ($C_{Post-intervention\_Period\ Use}$) the implementation of BIPVBOOST project developments in each demo site, making appropriate adjustments for changes in conditions as done for energy savings (as defined in the IPMVP). Thus Eq 1 applied to economic savings can be written as:

Energy bill Savings = ($C_{Pre-intervention\_Period\ Use} - C_{Post-intervention\_Period\ Use}$)± Adjustments **Eq 3.**

The energy saving must be representative of the BIPV developments performance and not due to changes in weather conditions or building exploitation. Therefore, the adjustment term should be obtained to take into account the effect of the weather conditions in the heating and cooling system energy consumption and the building exploitation in the energy consumption. On one hand the energy consumption by the heating and cooling system ($E_{\text{hvac+gas}}$) will be adjusted based on measured meteorological data (T_{amb}, G_i, S_w). On the other hand, the building exploitation will be adjusted from the energy consumed from the loads (E_{loads}), like production lines, computers and others.

Therefore, to correctly determine the energy bill savings, the energy price must be known and the following variables should be measured:

- T_{amb}, G_i, S_w , $E_{\text{hvac+gas}}$, E_{loads}, E_{F_grid}

Performance ratio:

The BIPV field of the demo sites have been sized to demonstrate the BIPVBOOST developments performance but it is not necessary the optimal size. In a real case the size of the BIPVs could be greater to optimize the whole building performance.

The performance ratio between the demo sites and the optimal size will be studied (in terms of energy savings, self-consumption rate and energy bill reduction) considering the performance of the building with the optimal size BIPV field. For that purpose, the optimal size of the BIPV field will be estimated from the obtained results and simulations.

3.1.2 Component level

The retrofitting of the building with the BIPV and BEMS components is expected to optimise the energy performance of the affected systems, which can be referred to the entire building or only an isolated component like a heating and cooling system. Following the option C of IPMVP, savings due to the BIPV and BEMS components of each demo site are determined by field measurements of the energy performance of the effected system. Measurement frequency can range from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.
When measuring the energy performance of an effected system is not possible or could not be desegregated from other effects, a key parameter that represents its performance will be measured.

BIPV developments

In certain cases, the BIPV passive effect is expected to reduce the heating and cooling requirements of the building which is translated into energy savings. The energy savings associated with the BIPV can be measured using the same methodology as described at building level based on the IPMVP (Option C) and described in Eq 1; Comparing the heating and cooling system energy consumption ($E_{hvac+gas}$)during pre-intervention and post-intervention period and adjusted to the same boundary conditions.

However, during the post intervention period, the BEMS also affects the cooling and heating system and it will be difficult to desegregate the effect of BIPV and BEMS. This could be addressed by switching off the BEMS during certain periods. The frequency and the duration of the BEMS switching off periods it must be decided with the demo owners prior to post intervention period.

In case will not be possible to switch off the BEMS, BIPV (passive effect) performance will be evaluated by measuring the key parameters that allow estimation of the energy savings. These key parameters are the difference between temperature inside ($T_{building}$) and outside (T_{amb}) the building and heat flux (Φ_{Q}) across the skin of the building, BIPV temperature (T_m), and solar irradiance in the module plane. The measured variables to assess the passive effect performance will be: $T_{building}$, T_{amb}, T_m, G_i, Φ_{Q}, and $E_{hvac+gas}$.

On the other hand, the active effects of BIPV on energy performance are characterized by measuring the produced energy (E_{BIPV}), as a function of temperature of the module (T_m), Solar irradiance on the module plane (G_i), i and wind speed (S_w). The measured variables will be: T_m, G_i , S_w, E_{BIPV}. These results will be used to estimate the performance ratio of the BIPV field.

BEMS

The optimal use of thermal inertia of the building by the BEMS will be evaluate following the Eq 1 and measured by the energy used ($E_{hvac+gas}$) by the effected system (the heating and cooling system). However, as mentioned before, the BEMS effect in the heating and cooling system could not be desegregated from the passive effects of BIPV in the same system. Therefore, the BEMS must be switched off during certain periods. This is not the case in the demo sites which have no passive BIPV effects, since the only active element in the heating and cooling system is the BEMS.

The BIPV use optimization and battery storage management strategies of the BEMS aim to reduce the energy costs, and increase the percentage of renewable energy used. The economic saving will be estimated applying Eq. 3 to the effected systems. The effected systems are the grid, the batteries, and the shifted loads. The measuring variables are; energy consumption from the grid ($E_{f_{grid}}$), energy consumption of the shifted loads(E_{loads}), and batteries energy influx(E_{st_in}), and outflow(E_{st_out}). Finally, to calculate the energy bill savings, the energy price variation must be considered.

The percentage of renewable energy is estimated as described in Eq. 2. However, this value can be associated with BIPV and BEMS. In order to evaluate the effects of the BEMS on the percentage of renewable energy, it is compared to the percentage of renewable energy with and without BEMS, as described in Eq 4. This requires switching off the BEMS during certain periods.

$$\Delta\%E_{renewable\_BMS} = (\%E_{renewable\_{BIPV+BMS}} - \%E_{renewable\_BIPV}) \pm \text{Adjustments}$$ **Eq 4.**

Summary of the measuring variables

Figure 2 shows the measuring variables in a typical demo site and Table 2 lists them in more detail. The pre-intervention measuring variables are inside the blue boxes and the post-intervention measuring variables inside red box.

Typical Demo site developments and implementations

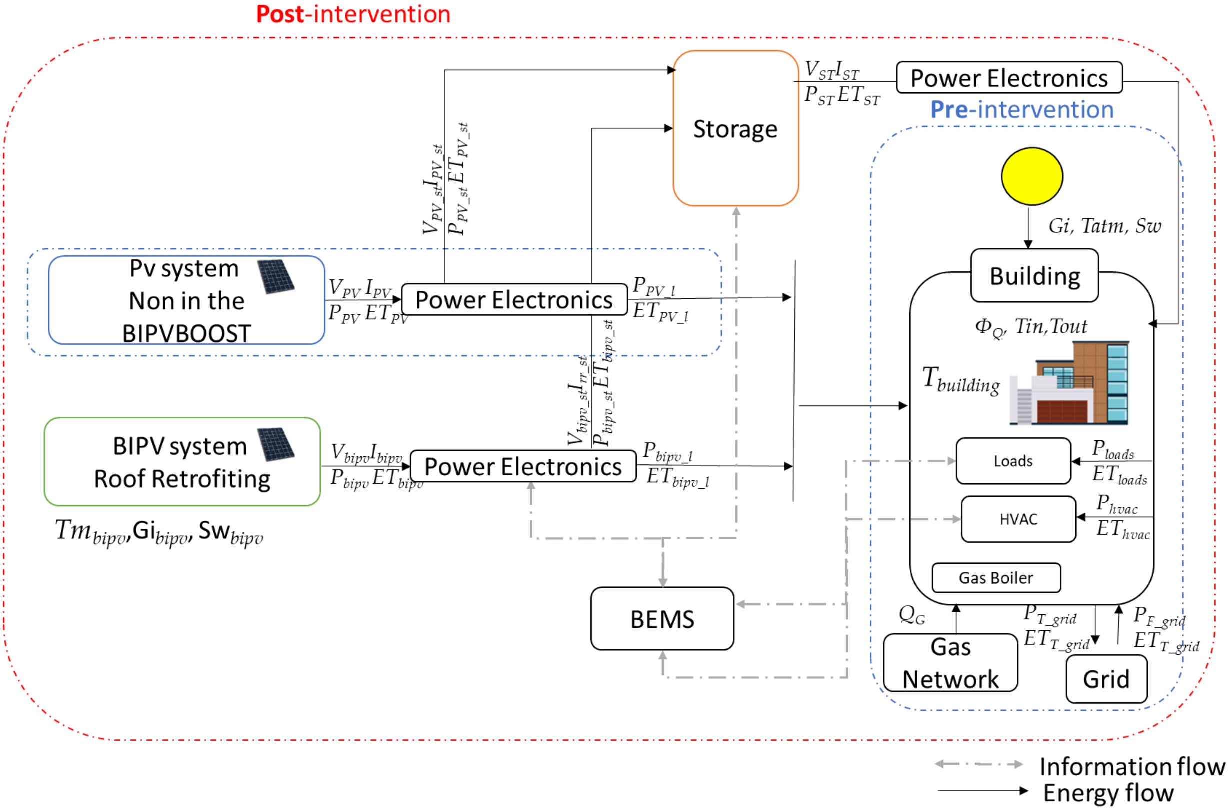

Figure 3. Main measuring variables of a typical demo site

3.2 Instrument specifications.

Solar irradiance: The solar irradiance that reaches the BIPV field and the building will be measured. The irradiance in the BIPV field will be measured in the same plane as the cells using calibrated reference devices. The reference modules or cells used must be calibrated and maintained in accordance with IEC 60904-2 or IEC 60904-6. The location of these sensors must be representative of the irradiance conditions of the BIPV field. The irradiance that reaches the building will be measured in a horizontal surface with a pyranometer.

In both cases, the accuracy of the solar irradiance sensors, including the signal conditioning, will be more than 5% of the sensors reading.

Ambient Temperature: The temperature of the environment will be measured with appropriate temperature sensors placed in the shade. The accuracy of these temperature sensors, including the signal conditioning, has to be better than 1K.

Module temperature: The temperature of the BIPV module will be measured in a module that is representative for BIPV field conditions. The measurements will be carried out with temperature sensors placed at the back of one or more modules. The accuracy of these sensors, including signal conditioning, will be higher than 1K.

DC electric Current and Voltage: The voltage and current parameters can be AC or DC The accuracy of the current and voltage sensors, including the signal conditioning, has to be higher than 1% of the reading.

DC electric Power: The power of DC can be calculated in real time as a product of the voltage and current or measured directly with a Power sensor. To calculate DC power, a voltage measurement and current can be used; the product of average voltage and current values cannot be used. The power A.C will be measured using a power sensor that considers the power factor and harmonic distortion. The accuracy of the power sensors, including signal conditioning, has to be higher than 2% of the reading. A power integrating sensor (for example a kWh meter) can be used to reduce sampling errors.

Wind speed: The wind speed will be measured in a place that is representative of the BIPV wind conditions. The accuracy of wind sensors has to be higher than $0.5 m.s^{-1}$ for wind speed less than or equal to $5 m.s^{-1}$ and higher than 10% for wind speed over $5 m.s^{-1}$

Measurement range: The measurement range will be defined for each variable base on typical values in the case of solar irradiance, temperatures and wind speed. In the case of electric current, voltage or power, the range is defined for each specific case, based on data collected in DB 8.1. When no collected data are available, the range is estimated from design values.

Mass flow rate: The gas consumption will be measured by means of mass flow rate. The measurement error has to be lower than 0.5%. The measurement principle will be defined later.

Heat flux: The heat flux across the building skin will be measured with heat flux sensors. It must be installed in a place where it is not affected by external heat sources and the measurement accuracy must be better than 5%.

4 Demo Sites measured variables information

Next, the variables that must be measured in each demo sites are presented, as well as the information about the measuring procedure and instrumentation.

4.1 Demo site 1: ISFOC office building - Puertollano, Spain

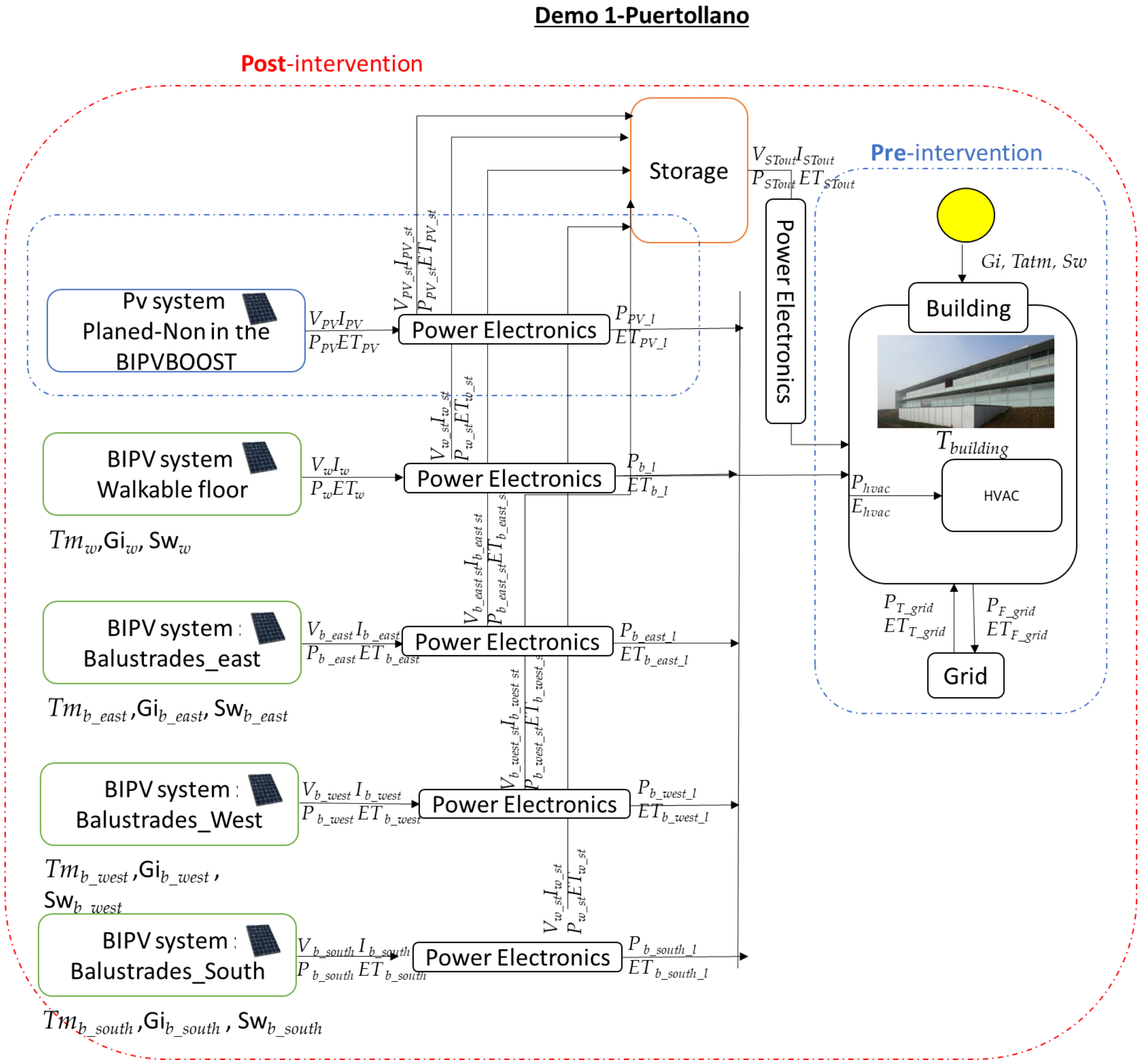

Figure 4. Main measuring variables of Puertollano demo site

Table 3. Puertollano demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	instrument	Range	Units	Time Resolution	Accuracy
BIPV components					
Balustrades east					
Meteorological					
Gi_{east_1}	Reference cell	0-1200	w/m2	<1min	5% of the reading
Gi_{west_1}	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{b_east}	Thermocouple type T	0-100	ºC	<1min	1K
DC					
I_{b_east}	Amperimeter		A	<1min	1% of the reading
V_{b_east}	Voltimeter		V	<1min	1% of the reading
P_{b_east}	Power meter	1,2	kW	<1min	2% of the reading
ET_{b_east}	Energy meter		kW/h	<1min	
AC					
$P_{b\_east\_I}$	Power meter	1,2	kW	<1min	2% of the reading
$ET_{b\_east\_I}$	Energy meter		kW/h	<1min	
Balustrades West					
Meteorological					5% of the reading
Gi_{east_2}	Reference cell	0-1200	w/m2	<1min	5% of the reading
Gi_{west_2}	Reference cell	0-1200	w/m2	<1min	1K
Tm_{b_west}	Thermocouple type T		ºC	<1min	
DC					1% of the reading
I_{b_west}	Amperimeter		A	<1min	1% of the reading
V_{b_west}	Voltimeter		V	<1min	2% of the reading
P_{b_west}	Power meter	1,2	kW	<1min	
ET_{b_west}	Energy meter		kW/h	<1min	
AC					2% of the reading
$P_{b\_west\_I}$	Power meter	1,2	kW	<1min	
$ET_{b\_west\_I}$	Energy meter		kW/h	<1min	
Balustrades South					
Meteorological					5% of the reading
$Gi_{\_south}$	Reference cell	0-1200	w/m2	<1min	5% of the reading
$Gi_{\_north}$	Reference cell	0-1200	w/m2	<1min	1K
Tm_{b_south}	Thermocouple type T		ºC	<1min	
DC					1% of the reading
I_{b_south}	Amperimeter		A	<1min	1% of the reading
V_{b_south}	Voltimeter		V	<1min	2% of the reading
P_{b_south}	Power meter	6,4	kW	<1min	
ET_{b_south}	Energy meter		kW/h	<1min	
AC					2% of the reading
$P_{b\_south\_I}$	Power meter	6,4	kW	<1min	

$ET_{b\_south\_I}$	Energy meter		kW/h	<1min	
Walkable Floor					
Meteorological					5% of the reading
Gi_w	Reference cell	0-1200	w/m2	<1min	1K
Tm_w	Thermocouple type T	0-100	ºC	<1min	
DC					1% of the reading
I_w	Amperimeter		A	<1min	1% of the reading
V_w	Voltimeter		V	<1min	2% of the reading
P_w	Power meter	14	kW	<1min	
ET_w	Energy meter		kW/h	<1min	
AC					2% of the reading
P_{w_I}	Power meter	14	kW	<1min	
ET_{w_I}	Energy meter		kW/h	<1min	
Storage					
Input					1% of the reading
$I_{b\_east\_st}$	Amperimeter		A	<1min	1% of the reading
$V_{b\_east\_st}$	Voltimeter		V	<1min	2% of the reading
$P_{b\_east\_st}$	Power meter	1,2	kW	<1min	1% of the reading
$ET_{b\_east\_st}$	Energy meter		kW/h	<1min	
$I_{b\_west\_st}$	Amperimeter		A	<1min	1% of the reading
$V_{b\_west\_st}$	Voltimeter		V	<1min	2% of the reading
$P_{b\_west\_st}$	Power meter	1,2	kW	<1min	1% of the reading
$ET_{b\_west\_st}$	Energy meter		kW/h	<1min	
$I_{b\_south\_st}$	Amperimeter		A	<1min	1% of the reading
$V_{b\_south\_st}$	Voltimeter		V	<1min	2% of the reading
$P_{b\_south\_st}$	Power meter	6,4	kW	<1min	1% of the reading
$ET_{b\_south\_st}$	Energy meter		kW/h	<1min	
I_{w_st}	Amperimeter		A	<1min	1% of the reading
V_{w_st}	Voltimeter		V	<1min	2% of the reading
P_{w_st}	Power meter	14	kW	<1min	1% of the reading
ET_{w_st}	Energy meter		kW/h	<1min	
I_{pv_st}	Amperimeter		A	<1min	1% of the reading
V_{pv_st}	Voltimeter		V	<1min	2% of the reading
P_{pv_st}	Power meter	89	kW	<1min	
ET_{pv_st}	Energy meter		kW/h	<1min	
Output					1% of the reading
I_{st_out}	Amperimeter		A	<1min	1% of the reading
V_{st_out}	Voltimeter		V	<1min	2% of the reading
P_{st_out}	Power meter		kW	<1min	
ET_{st_out}	Energy meter		kW/h	<1min	
Building					5% of the reading
Gi	Pyranometer	0-1200	w/m2	<1min	1K
T_{amb}	Thermocouple type T	0-50	ºC	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading

S_w	Ultrasonic anemometer	0-100	m/s	<1min	
HVAC					1% of the reading
I_{hvac}	Amperimeter		A	<1min	1% of the reading
V_{hvac}	Voltimeter		V	<1min	2% of the reading
P_{hvac}	Power meter		kW	<1min	
ET_{hvac}	Energy meter		kW/h	<1min	
Existing PV field					
DC					1% of the reading
I_{pv}	Amperimeter		A	<1min	1% of the reading
V_{pv}	Voltimeter		V	<1min	2% of the reading
P_{pv}	Power meter	89	kW	<1min	
ET_{pv}	Energy meter		kW/h	<1min	
AC					
P_{pv_I}	Power meter	89	kW	<1min	
Et_{pv_I}	Energy meter		kW/h	<1min	
Grid					
P_{gr}	Power meter		kW	<1min	
ET_{pv_I}	Energy meter		kW/h	<1min	

4.2 Demo Site 2: MASS building - Aretxabaleta, Spain

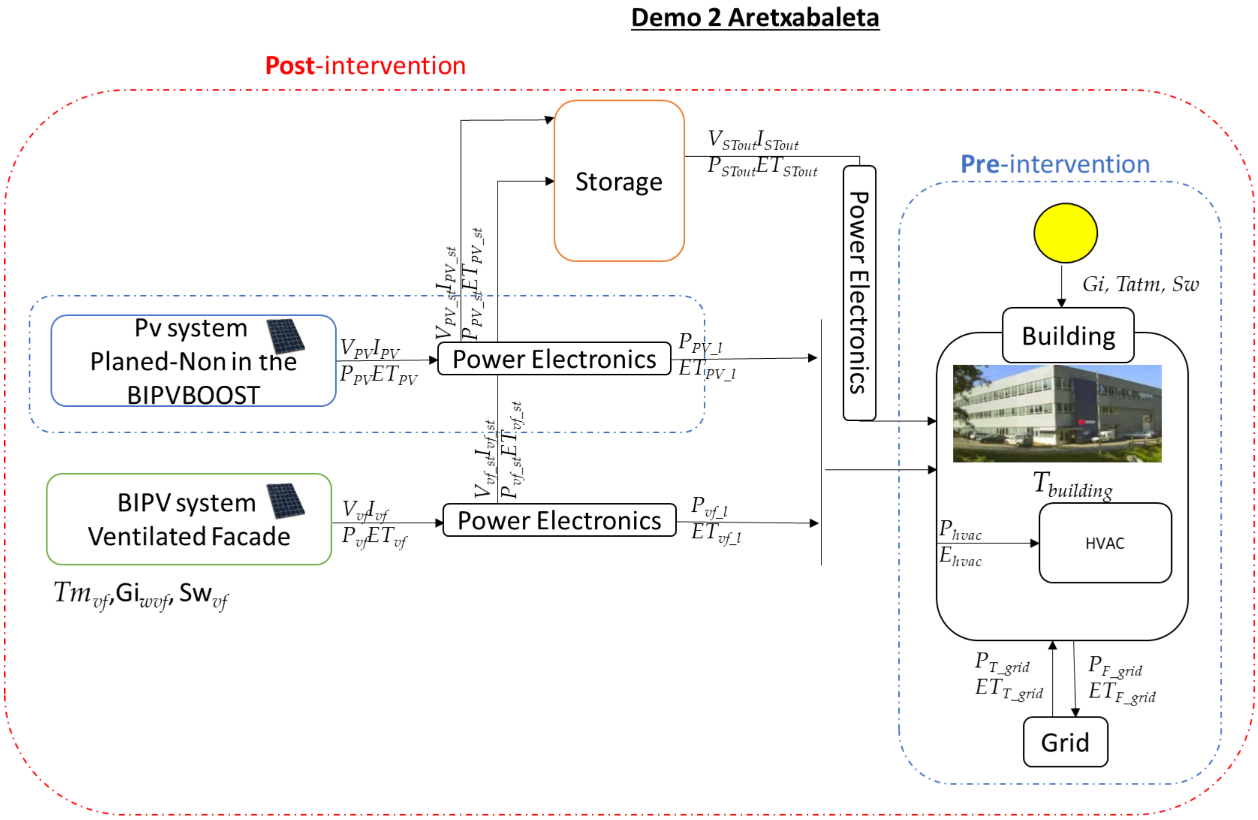

Figure 5. Main measuring variables of Aretxabaleta demo site

Table 4. Aretxabaleta demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	instrument	Range	Units	Time Resolution	Accuracy
BIPV components					
Ventilated facade					
Meteorological					
Gi_{vf}	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{vf}	Thermocouple type T	0-100	ºC	<1min	1K
DC					
I_{vf}	Amperimeter		A	<1min	1% of the reading
V_{vf}	Voltimeter		V	<1min	1% of the reading
P_{vf}	Power meter	24	kW	<1min	2% of the reading
ET_{vf}	Energy meter		kW/h	<1min	
AC					
P_{vf_I}	Power meter	24	kW	<1min	2% of the reading
ET_{vf_I}	Energy meter		kW/h	<1min	
Storage					
Imput					
I_{vf_st}	Amperimeter		A	<1min	1% of the reading

V_{vf_st}	Voltimeter		V	<1min	1% of the reading
P_{vf_st}	Power meter	24	kW	<1min	2% of the reading
ET_{vf_st}	Energy meter		kW/h	<1min	
I_{pv_st}	Amperimeter		A	<1min	1% of the reading
V_{pv_st}	Voltimeter		V	<1min	1% of the reading
P_{pv_st}	Power meter	100	kW	<1min	2% of the reading
ET_{pv_st}	Energy meter		kW/h	<1min	
Output					
I_{st_out}	Amperimeter		A	<1min	1% of the reading
V_{st_out}	Voltimeter		V	<1min	1% of the reading
P_{st_out}	Power meter		kW	<1min	2% of the reading
ET_{st_out}	Energy meter		kW/h	<1min	
Building					
Gi	Pyranometer	0-1200	w/m2	<1min	5% of the reading
T_{amb}	Thermocouple type T	0-50	ºC	<1min	1K
S_w	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
HVAC					
I_{hvac}	Amperimeter		A	<1min	1% of the reading
V_{hvac}	Voltimeter		V	<1min	1% of the reading
P_{hvac}	Power meter		kW	<1min	2% of the reading
ET_{hvac}	Energy meter		kW/h	<1min	
Existing PV field					
DC					
I_{pv}	Amperimeter		A	<1min	1% of the reading
V_{pv}	Voltimeter		V	<1min	1% of the reading
P_{pv}	Power meter	100	kW	<1min	2% of the reading
ET_{pv}	Energy meter		kW/h	<1min	
AC					
P_{pv_l}	Power meter	89	kW	<1min	2% of the reading
ET_{pv_l}	Energy meter		kW/h	<1min	
Grid					
P_{gr}	Power meter		kW	<1min	2% of the reading
ET_{gr}	Energy meter		kW/h	<1min	

4.3 Demo Site 3: RESIDENTIAL SINGLE-DWELLING BUILDING (BELGIUM)

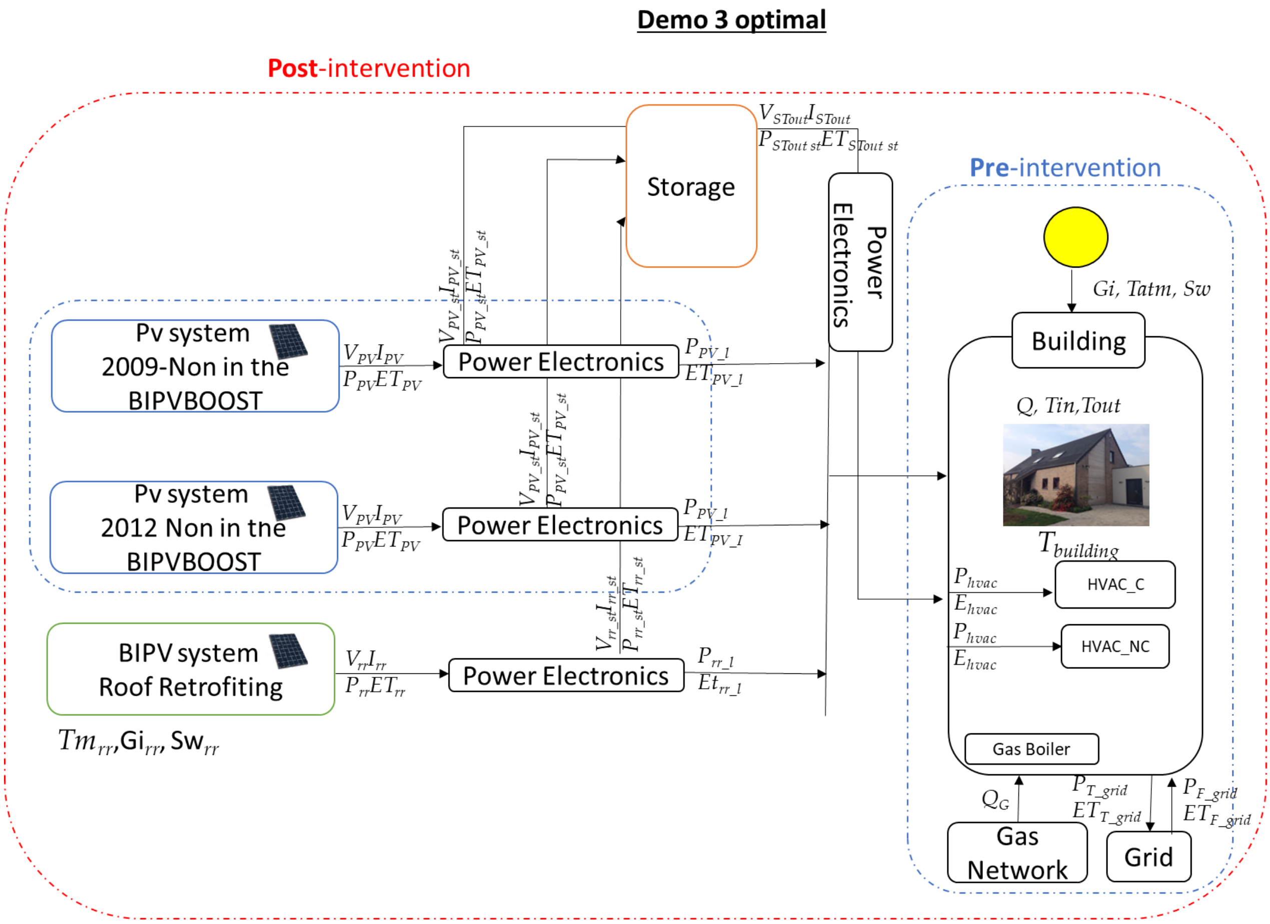

Figure 6. Main measuring variables of Optimal demo site

Table 5. Optimal demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	instrument	Range	Units	Time Resolution	Accuracy
BIPV components					
Roof retrofitting					
Meteorological					
Gi_{rr}	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{rr}	Thermocouple type T	0-100	ºC	<1min	1K
DC					
I_{rr}	Amperimeter		A	<1min	1% of the reading
V_{rr}	Voltimeter		V	<1min	1% of the reading
P_{rr}	Power meter	15	kW	<1min	2% of the reading
ET_{rr}	Energy meter		kW/h	<1min	
AC					
P_{rr_I}	Power meter	15	kW	<1min	2% of the reading
ET_{rr_I}	Energy meter		kW/h	<1min	
Passive key parameter					
Q	Heat flux meter	200	W/m²	<1min	1% of the reading
T_{in}	Thermocouple type T	0-50	ºC	<1min	1K

T_{out}	Thermocouple type T	0-50	ºC	<1min	1K
Storage					
Input					
I_{rr_st}	Amperimeter		A	<1min	1% of the reading
V_{rr_st}	Voltimeter		V	<1min	1% of the reading
P_{rr_st}	Power meter		kW	<1min	2% of the reading
ET_{rr_st}	Energy meter		kW/h	<1min	
I_{pv09_st}	Amperimeter		A	<1min	1% of the reading
V_{pv09_st}	Voltimeter		V	<1min	1% of the reading
P_{pv09_st}	Power meter		kW	<1min	2% of the reading
ET_{pv09_st}	Energy meter		kW/h	<1min	
I_{pv12_st}	Amperimeter		A	<1min	1% of the reading
V_{pv12_st}	Voltimeter		V	<1min	1% of the reading
P_{pv12_st}	Power meter		kW	<1min	2% of the reading
ET_{pv12_st}	Energy meter		kW/h	<1min	
Output					
I_{st_out}	Amperimeter		A	<1min	1% of the reading
V_{st_out}	Voltimeter		V	<1min	1% of the reading
P_{st_out}	Power meter		kW	<1min	2% of the reading
ET_{st_out}	Energy meter		kW/h	<1min	
Building					
Gi	Pyranometer	0-1200	w/m2	<1min	5% of the reading
T_{amb}	Thermocouple type T	0-50	ºC	<1min	1K
S_w	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
HVAC					
I_{hvac_c}	Amperimeter		A	<1min	1% of the reading
V_{hvac_c}	Voltimeter		V	<1min	1% of the reading
P_{hvac_c}	Power meter		kW	<1min	2% of the reading
ET_{hvac_c}	Energy meter		kW/h	<1min	
I_{hvac_nc}	Amperimeter		A	<1min	1% of the reading
V_{hvac_nc}	Voltimeter		V	<1min	1% of the reading
P_{hvac_nc}	Power meter		kW	<1min	2% of the reading
ET_{hvac_nc}	Energy meter		kW/h	<1min	
Q_{gas}	Gas flow meter		kg/s	<1min	
Existing PV field 2009					
DC					
I_{pv09}	Amperimeter		A	<1min	1% of the reading
V_{pv09}	Voltimeter		V	<1min	1% of the reading
P_{pv09}	Power meter	3,4	kW	<1min	2% of the reading
ET_{pv09}	Energy meter		kW/h	<1min	
AC					
P_{pv09_I}	Power meter	3,4	kW	<1min	2% of the reading
ET_{pv09_I}	Energy meter		kW/h	<1min	
Existing PV field 2012					
DC					
I_{pv12}	Amperimeter		A	<1min	1% of the reading
V_{pv12}	Voltimeter		V	<1min	1% of the reading
P_{pv12}	Power meter	1,35	kW	<1min	2% of the reading

ET_{pv12}	Energy meter		kW/h	<1min	
AC					
P_{pv12_I}	Power meter	1,35	kW	<1min	2% of the reading
ET_{pv12_I}	Energy meter		kW/h	<1min	
Grid					
P_{gr}	Power meter		kW	<1min	2% of the reading
ET_{grid}	Energy meter		kW/h	<1min	

4.4 DEMO SITE 4: RESIDENTIAL MULTI_FAMILLY DWELLING (ITALY)

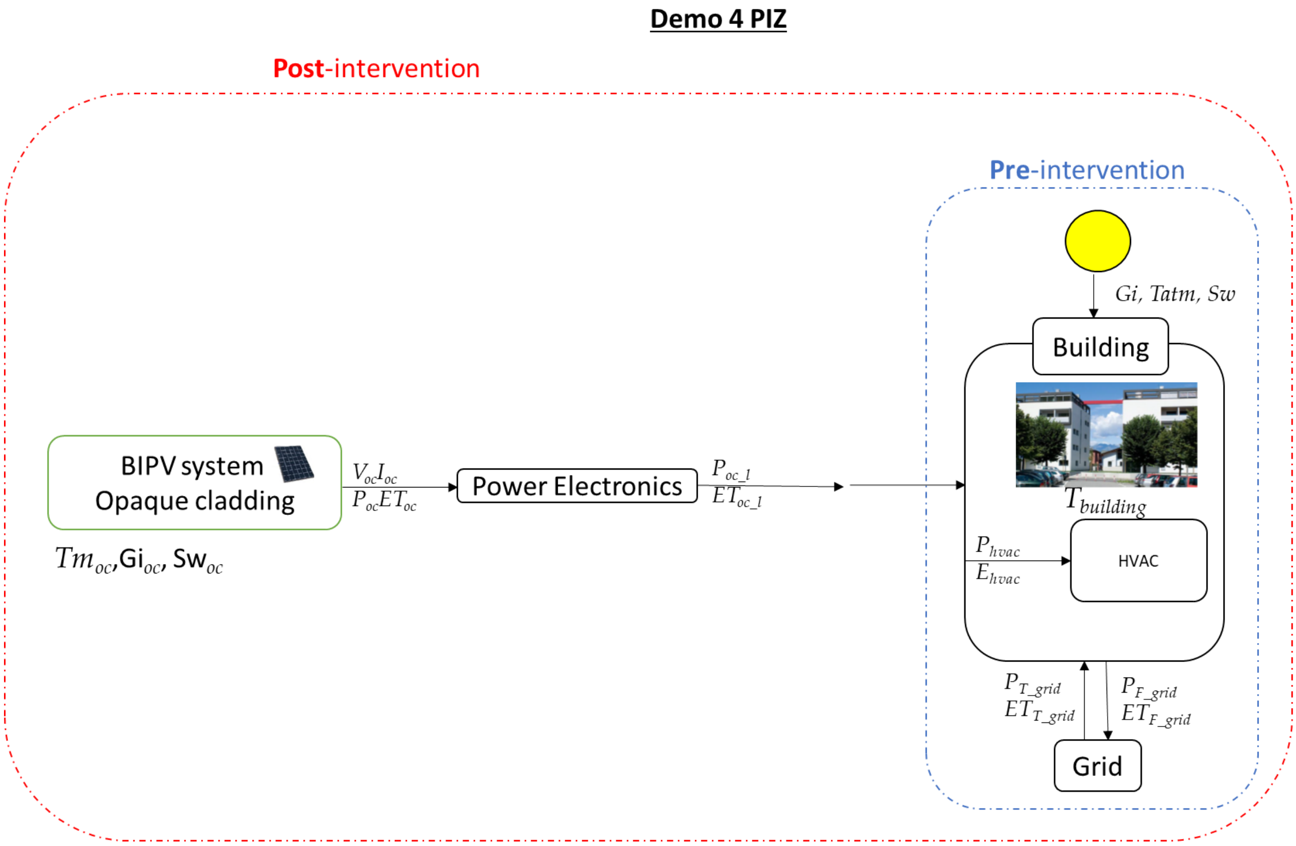

Figure 7. Main measuring variables of the Piz demo site

Table 6. Piz demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	**instrument**	**Range**	**Units**	**Time Resolution**	**Accuracy**
BIPV components					
Opaque cladding					
Meteorological					
$G_{\_east\text{-}west}$	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm	Thermocouple type T	0-100	ºC	<1min	1K
DC					
$I_{\_DC}$	Amperimeter		A	<1min	1% of the reading
$V_{\_DC}$	Voltimeter		V	<1min	1% of the reading
$P_{\_DC}$	Power meter	10	kW	<1min	2% of the reading
$ET_{\_DC}$	Energy meter		kW/h	<1min	
AC					
$P_{\_AC}$	Power meter	10	kW	<1min	2% of the reading
$ET_{\_AC}$	Energy meter		kW/h	<1min	
Building					
Meteorological					
$G_{\_iHorizontal}$	Pyranometer	0-1200	w/m2	<1min	5% of the reading
T_{amb}	Thermocouple type T	0-50	ºC	<1min	1K
Sw	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
Grid					
P_{gr}	Power meter		kW	<1min	2% of the reading

5 MONITORING OF DEMO SITES, DATA COLLECTION AND ANALYSIS

Each demo site will be monitored with the instrumentation defined in section 3.2 measuring the variables defined in Section 4. The instruments must be calibrated and installed on site by the partners responsible for this specific task. The installation needs to be properly conducted with an emphasis on the verification of communication between equipment and the correct data acquisition for all the devices installed on site.
Equipment installation has to be conducted by qualified professionals and the necessary authorizations, especially for electricity and fluids monitoring.

The building owner and the local stakeholders (housekeeper, tenants, building manager, maintenance responsible…) should also be involved in the installation process when necessary.
As mentioned in Section 3, 2 reporting periods will be required (Pre intervention and post intervention), thus the monitoring equipment will be installed in two different phases:

- Before the pre-intervention period.
- Between pre-intervention period and post intervention period.

All the data will be collected by a local data logger connected by LAN to a router. All the data will be automatically sent to a general server where the data will be stored via data service software.
Data will be stored in daily files (*.csv or *.txt) that will be uploaded and actualized every 15 minutes. The structure of the data contained in the file or data format will be defined. It will include at least a variable tag, value, description and a timestamp for each value.

The data will be available for all the authorized users via a web-datalogger installed in the server. Figure 8 shows a schematic representation of the BIPVBOOST data collecting architecture.

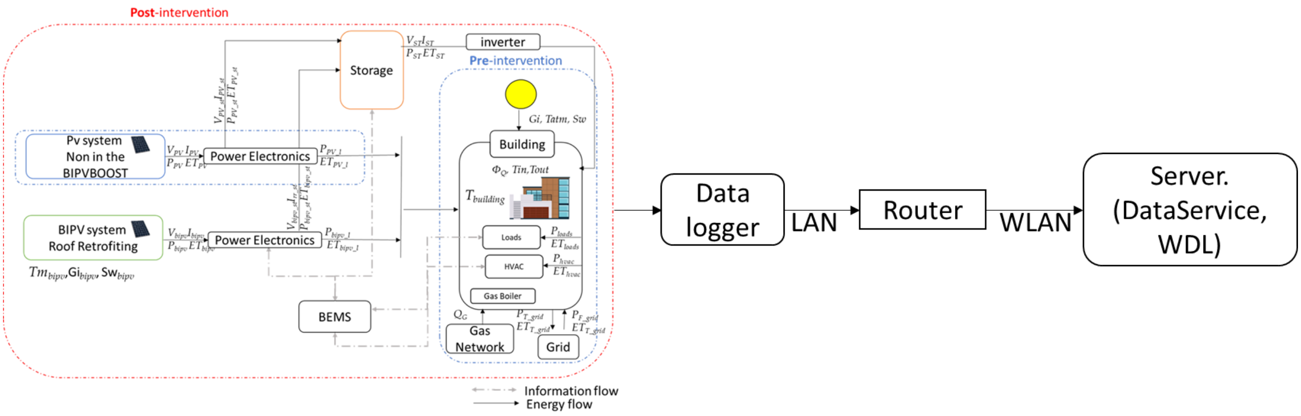

Figure 8. Data collection architecture.

Regarding the analysis of the collected data will be periodically a reported to;

- Detect anomalies in the BIPV or BEMS solutions functioning or in the building behaviour,
- Understand real performances in different climatic seasons and operation conditions,
- Detect problems in data collection or measurement devices functioning,
- Get intermediary results that could be used to improve the systems themselves.

The reporting will be shared with the partners periodically. The frequency of reporting will be defined later with the demo owners.

6 CONCLUSIONS

The monitoring guidelines for BIPVBOOST demo sites have been described. These guidelines define how the KPIs can be evaluated at the demo-sites. Moreover, the measuring variables and instrumentations requirements have been defined for each specific demo site.

However, at this moment the demo sites implementation is not totally defined, and some minor variations can be expected. This deliverable will be updated with higher level of definition when all the demo sites implementations are completed.