D5.1 – KPIs plan for monitoring and assessment of the technologies at demo site levels.

WP5

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Executive Summary

The Envision project deals with the objective of harvesting solar heat throughout the whole building envelope by maintaining good aesthetics aspects. In order to provide a quantitative measurement of the performances achievable, an assessment methodology is required. This document provides detailed procedures for KPIs definition and data analysis that are harmonized for all the demonstrators of the Envision project. The methodology defined in this report is based on "energy signature method" as defined in the ISO EN 15603:2008 standard. This is a monitoring method, so monitoring plan for each demo cases and for each variables involved has been developed. The procedures described in this document are applicable for both stand alone and grid coupled solutions. Additionally these procedures could be used, as guide lines, by those could be interested in the measurement of Envision technology performances in other installations.

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Abbreviations and Acronyms

[ATO] – Antimony-doped Tin Oxide

[BIPV] – Building Integrated Photovoltaic

[CR] – Concentration Ratio

[DHN] – District Heating Network

[HVAC] – Heating Ventilation Air Conditioning

[IGU] – Insulated Glass Unit

[IESL] – Innovative Energy System Laboratory

[mGT] – micro Gas Turbine

[NIR] – Near Infrared Reflectance

[PVB] – PolyVinilButiral

[SEAC] – Solar Energy Application Centre

[SPM] – Smart Polygeneration Microgrid

[TRL] – Technology Readiness Level

[TSA] – Total Solar Absorbance

1 Introduction

The purpose of the D5.1 "KPIs plan for the monitoring and assessment of the technologies at demo sites levels" is to develop a methodology for the evaluation of the demonstrators through a quantitative measurement of the performances during the operation phase.
In section 2 the technical characteristics of the instrumentation and data collection methods have been introduced. The focus is on the sensors definition and its functioning parameters such as accuracy, range, measurement frequency and time sequential.
In the section 3 the KPIs have been introduced. ENVISION technologies effectiveness shall be evaluated under the four following main KPIs categories: technical, economic, environmental and social indicators. A KPIs overview is showed in the following table:

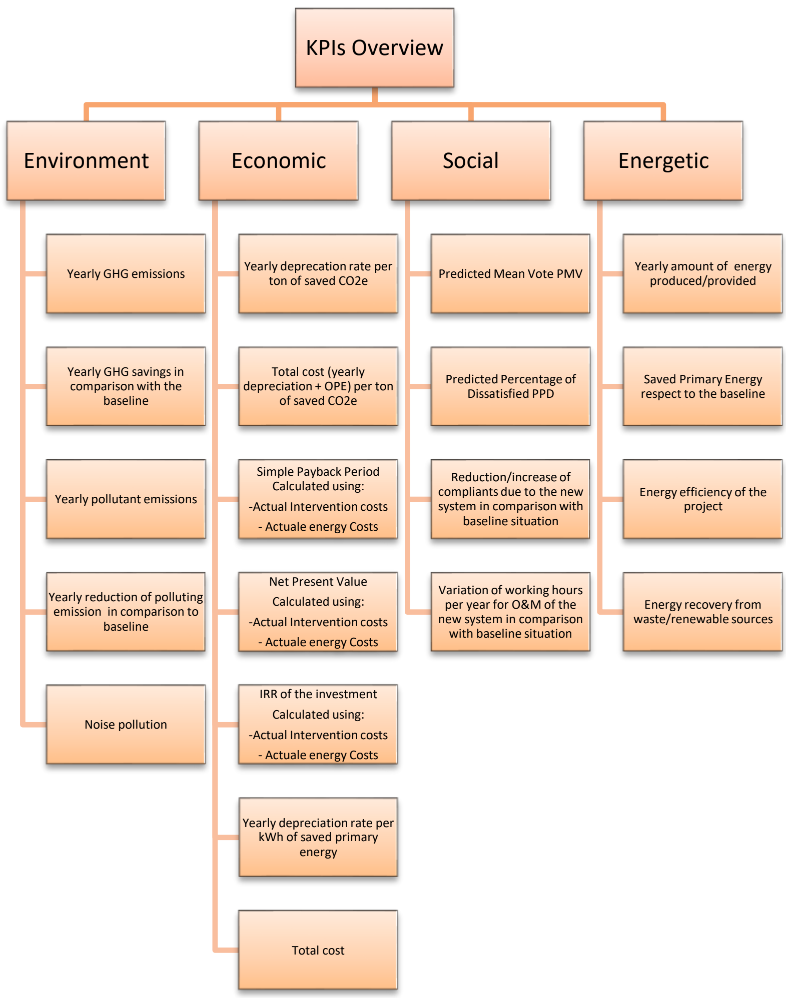


Table 1 – KPI's considered in the D5.1

For each KPIs, units of measurement and mathematic definition has been defined.

In the Envision project there are three demo site which are located in different climates and for which are foreseen different Envision technology installations. A brief description of each demonstrators is following reported:

- Savona Campus: it is one of the venues of the University of Genoa. The Campus includes classroom and office buildings, students' apartments, library, auditorium, canteen, laboratories, and sport facilities. One of the strength of this demonstrator is the presence of a “Smart Polygeneration Microgrid (SPM)” installed throughout the Campus connected to a DHN. This configuration will help to demonstrate how the Envision technologies can be integrated in a heating network. Additionally the SPM is connected to the National electrical grid, this can be a good opportunity to study how works the coupling between renewable energy on site and fluctuation of energy demand from national grid. Envision technology will be integrated into the “Smart Polygeneration Grid” in order to test and evaluate their performances and impact on the DH network management strategy.

- <u>Delft apartments</u>: is a three story apartment building present with 24 units. The apartment’s average surface is about 70 m^2. The construction of the building is a concrete skeleton, showing a visible grid on the façade. This architectural element was common in the fifties and sixties, when there was little energy consumption awareness. The main strength of this demonstrators is the possibility of studying the effect of Envision technologies both to the architectural aspect of the building and the influences on occupants in terms of comfort and social aspects.

  The building will be also connected to the electric grid, and a real energy production/consumption profile will be available before the renovation. The effects of the occupants will be also useful to evaluate plants management aspects.

- <u>Pilkington office</u> : located in Bischofshofen, Austria, this demonstrator aims to test as effectively as possible the functioning of the Pilkington Sunplus™ BIPV Technology. The current façade has been installed in 1992 and includes double glasses. The intervention consist in the substitution of the actual glass with about 70 m2 of new technology photovoltaic glasses.

These demo site and their installation layout are illustrated in section 4. Additionally a monitoring plan has been developed for each demo, and a complete sensors list, has been defined.
In chapter 5, an assessment methodology that allows to evaluate the efficiency of the Envision technologies regardless the different location and climatic conditions of the installation has been provided.

2 Monitoring protocols state of the art

According to the Ashrae Application 2011, protocols for residential building retrofit performance can answer specific questions associated with actual measured performance. For example, Ternes (1986) developed a single-family retrofit monitoring protocol, a data specification guideline that identifies important parameters to be measured. Both one-time and time sequential data parameters are covered, and parameters are defined carefully to ensure consistency and comparability between experiments. Discrepancies between predicted and actual performance, as measured by the energy bill, are common. This protocol improves on billing data methods in two ways: (1) internal temperature is monitored, which eliminates a major unknown variable in data interpretation; and (2) data are taken more frequently than monthly, which potentially shortens monitoring duration. Utility bill analysis generally requires a full season of pre- and post-retrofit data. The single-family retrofit protocol may require only a single season. Ternes (1986) identified both a minimum set of data, which must be collected in all field studies that use the protocol, and optional extensions to the minimum data set that can be used to study additional issues. Szydlowski and Diamond (1989) developed a similar method for multifamily buildings.

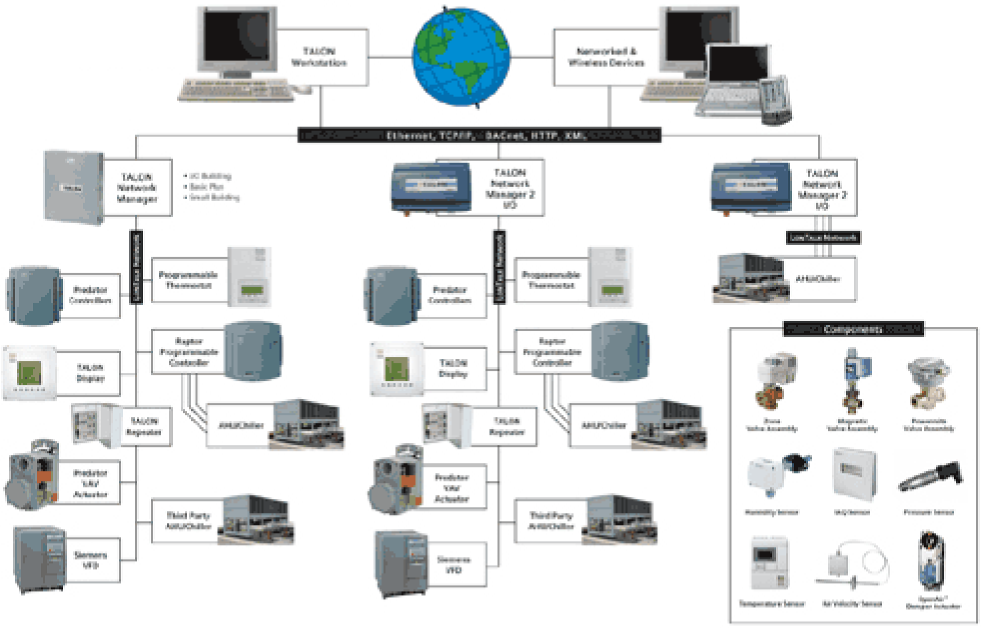


Figure 1 Monitoring general achitecture

Consequently, energy control strategies, require accurate measurements of the variables involved, in order to ensure that the system continues to perform in accordance with the design specifications. Thus, an adequate instrumentation constitutes the key for a high efficiency performance of the buildings. Advanced metering, control and environmental monitoring technologies have a significant role to play in data-driven energy efficiency measures. There is also an increase in energy-related building legislations and regulations around the world, including stringent energy efficiency requirements that motivate for increased level of metering, sub-metering and automated control. As an example, the European Energy Performance of Buildings Directive (EPBD) also requires EU members to encourage intelligent metering and active control systems in new or renovated buildings through building regulations[1].

[1] Ahmad, Muhammad Waseem, et al. "Building energy metering and environmental monitoring–A state-of-the-art review and directions for future research." *Energy and Buildings* 120 (2016): 85-102.

Building energy metering and environmental monitoring give information regarding how buildings are performing. Knowledge from analytics can also be used to improve the performance further. A comprehensive energy metering and environmental monitoring system can involve all stakeholders (building owners, energy managers), in order to take energy-efficiency measures. Energy metering can also help in identifying cost-cutting opportunities by detecting inefficiencies; benchmarking buildings internally and externally; improving load planning and energy usage; and managing demand to minimize exposure to system reliability and price volatility risks. Currently, the market offers several metering and sensor technologies with different sophistication and functionality. Choosing a correct metering and sensor solution for a building is a challenging and non-trivial task as it depends on different factors.

The state of the art in building monitoring, control and automation is focused on three different perspectives:

- Local loop controls;
- Energy management and control systems;
- The combination of local loop controls, energy management and control systems.

Local loop controls operate individual systems such as an air conditioning unit or a heat exchanger. These types of controls usually operate independently from one another and may or may not be connected to a central control system.

The energy monitoring and control systems (EMCS) denote a centralized, building-wide system that control energy-using equipment through a combination of global and independent strategies. An EMCS was originally a separate entity from the local loop controls. Today there is a trend towards a blending of the two types.

Seven main sensors categories for building monitoring can be distinguished:

- Temperature sensors;
- Relative Humidity sensors;
- Air quality sensors;
- Occupancy sensors;
- Energy consumption sensors;
- Inlet air velocity;
- Pressure sensors.

The sensing and metering considered are commercially available electronic devices that measure and record data for further analysis and not only individual the sensing components. The variables to be measured/monitored are listed below and a brief description has also been reported:

- Air temperature sensors: The air temperature sensors are based on mechanical and electrical operative principles. Mechanical devices are in general cheap and reliable. However, usually they are used only for direct control purposes and/or visualization rather than for metering and monitoring. The most common example is the domestic room thermostat, where the output is the temperature-dependent physical displacement of a bimetal to operate directly a switch. Electrical devices, instead, are mainly based on thermoelectric and electrical resistance principles. Thermocouples are the most common example of thermoelectric devices and are commonly used because of their low cost, simplicity, robustness, temperature range and size. They provide the measurement thanks to the production of an electromotive force in a circuit of two different conductors experiencing a thermal gradient. Resistance temperature devices (RTD), instead, use the dependency between temperature and electrical resistivity of a conductor. The materials employed are usually copper, gold, nickel, platinum and few other semiconductors. Examples of RTDs used in the building sector are platinum resistance thermometer (PRT) and thermistor. In summary, thermocouples are cheaper and can measure a wide range of temperatures, but have lower accuracy than PRTs. PRTs have higher stability and accuracy, but longer response time and higher cost. Thermistors are the most accurate and sensitive: they have shorter response time as compared to RTDs but nearly have same response time when compared with thermocouples.

- Humidity sensors: For the monitoring of relative air humidity, capacitive and resistive sensors can be employed. Capacitive sensors consist of a film of polymer or metal oxide, situated between two conductive electrodes. The incremental change in the dielectric constant of the sensor is nearly directly proportional to the relative humidity of the surrounding environment. Resistive sensors usually consist of noble metal electrodes deposited on a substrate by photoresist techniques or wire-wound electrodes on a plastic or glass cylinder. Resistive humidity sensors measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt or treated substrate. Thermal conductivity sensors (also known as absolute humidity sensors) are mostly used to measure absolute humidity even at high temperatures or in polluted environments by means of a system that employs two thermistors in a bridge connection.
- IAQ sensors: IAQ control systems aims at fulfill the air temperature, the air humidity and the pollutants concentrations (e.g. CO and CO_2). CO_2 sensors are divided into two categories: the first type uses chemical methods, with high accuracy, but low stability and durability due to heterogeneous gases poisoning effects; the second uses a non-dispersive infrared (NDIR) method based on the physical principle of gas-absorption at a particular wavelength. NDIR-based sensors have higher energy consumption. However, they are the most applied, for their durability, reliability and accuracy. CO_2 concentration can also be used to estimate the occupancy. Thanks to this information, it will implement a more efficient control of the HVAC system. CO detection in building, instead, is achieved by using the physical principle of gas-adsorption on semi-conductors. Their operation relies on the establishment of adsorption equilibrium between the molecules of the measured gas and the grains of semiconductor, resulting in a change of electrical conductivity of the sensor's material. Metal oxide sensors have high sensitivity, but they also require an electric heater, causing high electric consumptions. Their high-energy consumptions and short life have led to the recent development of new gas sensors based on electrochemical methods. Due to their very low power consumptions, quick response time, high sensitivity and longer life, electrochemical gas sensors have been increasingly used for CO detection.
- Occupancy sensors: Occupancy sensors detect the presence of occupants, through motion sensing techniques in a given range of space.
- Energy consumption sensors: Electricity meters operate by continuously sensing the instantaneous values of current and voltage to provide a measurement of energy used. The oldest and most common type of electricity meter is the electromechanical watt-hour meter (a 2-phase inductive motor). Although electromechanical meters represent the majority of the currently installed meters in both residential and commercial buildings, the future of the utility industry is represented by electronic (solid-state/digital) advanced meters, which do not require moving parts and are capable of storing and managing data. The most conventional current and voltage sensor circuits are typically current and voltage transformers. Due to their higher accuracy, data storage and communication capability and the consequent possibility to manage energy and power data, electronic meters are gradually replacing the old electromechanical models.
- Air velocity sensors: The most common sensors used to measure the air velocity are the kata thermometers. Their work is based on an alcohol thermometer with a large bulb that is heated and exposed to the environment. Although these thermometers provide average practical values of air velocity, they are inadequate for significant fluctuations and cannot be used for recording and computer analysis purposes. An alternative to the kata thermometers are hot wire anemometers. These devices measure the cooling capacity of air moving across a 'hot' wire and relate this to the air velocity using the value of air temperature within the environment. Compared to kata thermometer, hot wire anemometers mea-sure fluctuations in the air temperature and measurements can be easily recorded for later analysis. They are, however, directional in response and can be inaccurate in low air velocities due to the natural convection of the hot wire. An improvement of the hot wire

anemometer is the low-speed hot sphere anemometer. It consists of two sphere/sensors: an electrically heated sensor that registers the air velocity and a cold sensor that measures the air temperature to allow for the correction of the heated sensor temperature. With respect to the hot wire anemometer, the hot sphere sensor is omnidirectional and, therefore, it is the most practical device that can be used for the measurement of indoor air velocity. Air flow can be also measured by using more advanced (and thus expensive) sensors with directional sensitivity, like ultrasonic and laser Doppler anemometers. The former consists of 2, 4 or 6 prongs (about 100 mm apart) that emit a sonic signal in 1, 2 or 3 directions respectively. The velocity of the air in one direction influences the time of flight of pulsed sound waves between the corresponded prongs. As a consequence, pulsing two ultrasonic signals in opposite direction between each set of prongs and comparing the time of flights of the out signal and the back signal, it is possible to calculate easily the air velocity. In the latter, the velocity measurement is measured by focusing a laser beam onto the measuring point and recording the frequency shift of the light scattered by moving particles. These instruments are mostly used to room air velocity measurement both in laboratories and in field applications, their high cost, size and sensitiveness have limited their commercial development.

- Pressure sensors: Pressure sensors play a key role in making HVAC systems more efficient by measuring air flow and pressure throughout the system for effective air distribution. By measuring pressure of individual rooms and monitoring the air flow to each room, the HVAC system can optimize a building's cooling, heating and air flow and reduce energy consumption. All Sensors employs a microelectromechanical system (MEMS) piezoresistive technology housed in a durable, printed circuit mountable packages. Monitoring the pressure drop across filters is another essential approach to reducing energy costs and preventing unnecessary load on air moving equipment. In addition, in order to being permanently installed in a control system, some pressure sensors may be used by HVAC service technicians for maintenance or trouble shooting. Fan energy increases as the cube of the air leakage, so detecting air leakage for new HVAC installation or during routine maintenance can save the building owner money. These sensors are used for acquiring the differential pressure of air or nonaggressive gases in ventilation, air conditioning, and heating plants. The differential pressure sensors are used to measure over- or under pressure in air ducts in relation to ambient pressure as well as to monitor filters and to control fans and acquire pressure differentials between different rooms[2].

2.1 Technical characteristics of the instrumentation to be used

To guarantee continuity of in-process measurement capabilities, all monitoring and measurement equipment used for product and process verification must be regularly controlled and calibrated against nationally/internationally approved standards at specified intervals or prior to use. The timing depends on many factors, including the instrument type and timing of use.

In line with the ISO 9001 requirements, the basis of calibration must be traceable back to an approved laboratory. The calibration record of each instrument should contain:

- identification number;
- manufacturer and model;
- frequency of calibration;
- reference standards used;
- validation certificates and calibration findings;
- detail of actions be taken in case of unsatisfactory results.

The instrumentation used must be adjusted or re-adjusted, as necessary, only in accordance with manufacturer's instructions, safe guarding to preclude unauthorized adjustments. All the devices and sensors

[2] https://www.allsensors.com/applications/hvac-pressure-sensor-applications

must be protected from damage or deterioration during handling, maintenance or storage and the monitoring and measurement activities must be conducted by qualified personnel.

Typically It is important to establish the type and format of the final results calculated from data before selecting data points. Failure to plan these data products first may lead to failure to answer

critical questions.

Failure to anticipate the typically large amounts of data collected can lead to major difficulties. The computer and personnel resources needed to verify, retrieve, analyze, and archive data can be estimated based on experience with previous projects. It is also important to check and validate the quality and reasonableness of data before use. Failure to use some type of quality control typically results in data errors and invalid results. Many projects require long-term commitment of personnel and resources. Project success depends on long-term, daily attention to detail and on staff continuity.

For most projects, the collected data must be analyzed and put into reports. Because the objective of the project is to translate these data into information and ultimately into knowledge and action, the importance of this step cannot be overemphasized. Clear, convenient, and informative formats should be devised in the planning stages and adhered to throughout the project. Close attention must be paid to resource allocation to ensure that adequate resources are dedicated to verification, management, and analysis of data and to ongoing maintenance of monitoring equipment. As a quality control procedure and to make data analysis more manageable, these activities should be ongoing. Data analysis should be carefully defined before the project begins.

The following steps can facilitate smooth project implementation and data management:

- Calibrate sensors before installation. Spot-check calibration on site. During long-term monitoring projects, recalibrate sensors periodically. Appropriate procedures and standards should be used in all calibration procedures [see ASHRAE *Guideline* 14 and IPMVP (2007)].
- Track sensor performance regularly. Quick detection of sensor failure or calibration problems is essential. Ideally, this should be an automated or a daily task. The value of data is high because they may be difficult or impossible to reconstruct.
- Generate and review data on a timely, periodic basis. Problems that often occur in developing final data products include missing data from failed sensors, data points not installed because of planning oversights, and anomalous data for which there are no explanatory records. If data products are specified as part of general project planning and produced periodically, production problems can be identified and resolved as they occur. Automating the process of checking data reliability and accuracy can be invaluable in keeping the project on track and in preventing sensor failure and data loss.

Guidelines on how and when these checks should be carried out are normally provided by the companies which manufacture and sell the instruments.

Following table shows the instrumentation installation, accuracy, and measurement frequency and expected ranges for all time-sequential parameters:

	Data Parameter	Accuracy	Range	Stored value per Recording Period	Time - sequential
Basic Parameters	Heating/cooling equipment energy consumption	3%		Total consumption	15 s
	Indoor temperature	0,5K	10 to 35°C	Average Temperature	1 h
	House gas or oil consumption	3%		Total consumption	15 s
	House electricity consumption	3%		Total consumption	15 s

	Wood heating use	0,5K	10 to 450°C	Average surface temperature or total use time	
	Domestic hot water	3%		Total consumption	15 s
	Optional Data Parameter Sets				
Occupant behavior	Additional Indoor temperature	0,5 K	10 to 35°C	Average Temperature	1 h
Occupant behavior	Heating thermostat set point	0,5 K	10 to 35°C	Average setpoint	
Occupant behavior	Cooling thermostat set point	0,5 K	10 to 35°C	Average setpoint	
Occupant behavior	Indoor humidity	5%	10 to 95%	Average humidity	1 h
Microclimate	Outdoor temperature	0,5K	-40 to 50 K	Average Temperature	1 h
Microclimate	Solar radiation	30 W/m2	0 to 1100 W/m2	Total horizontal radiation	1 min
Microclimate	Outdoor humidity	5%	10 to 95%	Average humidity	1 h
Microclimate	Wind speed	0,2 m/s	0 to 10 m/s	Average speed	1 min
Microclimate	Wind direction	5°	0 to 360°	Average direction	1 min

Table 2 – Time-sequential Parameters for residential retrofit monitoring

2.1.1 Sensors characterization

In this section, the fundamental characteristics of sensing systems are presented. Their importance are highlighted and their influence on the operation of sensing systems is described.

Essential to any data acquisition, sensors constitute one of the main parts of the technologies for indoor and environmental comfort. Air conditioning equipment needs a control system to regulate the operation of a heating and/or cooling component. Usually a sensing device is used to compare the actual state (e.g. temperature) with a target state. Then the control system draws a conclusion on the action that has to be taken.

A sensor is a device that produces a measurable signal in response to a stimulus. It is employed to monitor and quantify changes in the specific physical quantity (measurand). Each component system (heating, ventilation and air conditioning) comprising the overall HVAC system uses: pressure sensors, temperature sensors, occupancy sensors, IAQ sensors, air velocity sensors.

The characteristics of a sensor are classified as static, or dynamic.

Static characteristics are those that can be measured when the steady state conditions have been reached, during the monitoring. They are related to issues such as how a sensor's output change in response to an input change, how selective the sensor is, how external or internal interferences can affect its response, and how stable the operation of a sensing system can be. Dynamic characteristics are related to the sensing system's transient properties. In the case of the methodology described in this task, only the static characteristics will be considered. The most important static characteristics include: accuracy, precision, repeatability, error, resolution and selectivity. Their definitions are reported below[3]:

[3] http://research.cs.tamu.edu/prism/lectures/iss/iss_l2.pdf

- *Accuracy* represents the correctness of its output in comparison to the actual value of a measurand. In order to assess the accuracy of a sensor, either the measurement should be benchmarked against a standard measurand or the output should be compared with a measurement system with a known accuracy;

- *Resolution* is the smallest incremental change in the measurand that will result in a detectable increment in the output signal, that means the number of decimal digits signed by the sensor. Resolution is strongly limited by any noise in the signal;

- *Repeatability* is the sensor's ability to produce the same response for successive measurements of the same input, when all operating and environmental conditions remain constant;

- *Linearity:* the closeness of the calibration curve to a specified straight line shows the linearity of a sensor. Its degree of resemblance to a straight line describes how linear a system is;

- *Error* is the difference between the true value of the quantity being measured and the actual value obtained from the sensor:

- *Precision* represents the capacity of a sensing system to give the same reading when repetitively measuring the same measured under the same conditions. The precision is a statistical parameter and can be assessed by the standard deviation (or variance) of a set of readings of the system for similar inputs;

- *Selectivity* is the sensor's ability to measure a single component in the presence of others.

Some of the mentioned characteristics are generally reported in the datasheet of each sensor. Below the main properties of the sensors used in ENVISION applications are presented.

2.2 Data collection methods

Almost every type of transducer and sensor is available with the necessary interface system to make it computer compatible. The transducer itself begins to lose its identity when integrated into a

system with features such as linearization, offset correction, self calibration, and so forth. This has eliminated concern about the details of signal conditioning and amplification of basic transducer outputs, although engineering judgment is still required to review all data for validity, accuracy, and acceptability before making decisions based on the results. There are three different ways to record the data as follows:

- Direct output devices;
- Digital recording;
- Data-Logging devices.
- Direct output devices : direct output devices can be either multipurpose or specifically designed for a given sensor. Traditional chart recorders still provide a visual indication and a hard-copy record of the data, but their output is now rarely used to process data. Simple indicators and readouts are used mostly to monitor the output of a sensor visually, and have usually been replaced by modern digital indicators. A system specifically configured to meet a particular measurement need can quickly become obsolete if it has inadequate flexibility. Memory size, recording speed, and signal processing capability are major considerations in determining the correct recording system. Thermal,

mechanical, electromagnetic interference, portability, and meteorological factors also influence the selection.

- Digital recording: a digital data acquisition system must contain an interface, which is a system involving one or several analog-to-digital converters, and, in the case of multichannel inputs, circuitry for multiplexing. The interface may also provide excitation for transducers, calibration, and conversion of units. The digital data are arranged into one or several standard digital bus formats. Many data acquisition systems are designed to acquire data rapidly and store large records of data for later recording and analysis. Once the input signals have been digitized, the digital data are essentially immune to noise and can be transmitted over great distances.
- Data- Logging devices:Data loggers digitally store electrical signals (analog or digital)to an internal memory storage component. The signal from connected sensors is typically stored to memory at timed intervals ranging from MHz to hourly sampling. Some data loggers store data based on an event (e.g., button push, contact closure). Many data loggers can perform linearization, scaling, or other signal conditioning and allow logged readings to be either instantaneous or averaged values. Most data loggers have built-in clocks that record the time and date together with transducer signal information. Data loggers range from single-channel input to 256 or more channels. Some are general-purpose devices that accept a multitude of analog and/or digital inputs, whereas others are more specialized to a specific measurement (e.g., a portable anemometer with built-in data-logging capability) or application (e.g., a temperature, relative humidity, CO2, and CO monitor with data logging for IAQ applications). Stored data are generally downloaded using a serial interface with a temporary direct connection to a personal computer. Some data loggers allow downloading directly to a printer, or to an external hard drive or tape drive that can later be connected to a PC. Measurement generally consists of a sequence of operations or steps. Virtually every step introduces a conceivable source of uncertainty, the effect of which must be assessed.

3 KPIs definition

3.1 Variables involved in the measurement/monitoring and used for the KPI definition

The minimal data set, common to all demonstrators, of measured parameters necessary to evaluate the KPIs and the performances of the ENVISION technologies are shown in the following table.

Recommended measured parameters					
Parameter		Unit	Sensor / Meter	Timesteps	Notes and remarks
Consumptions	Total consumption of fuels	[kWh]	Fuel Meter	h	e.g. gas, oil, biomass
	Total consumption of district heat/cold	[kWh]	Thermal Meter	h	
	Total consumption of electricity	[kWh]	Electric Meter	h	
	Total consumption of water	[m^3]	Water meter	h	
Weather data	Outdoor air temperature	[°C]	Weather station	h	Data from weather provider could be permitted
	Outdoor rel. humidity	[%]	Weather station	h	
	Global irradiation	[W/m^2]	Weather station	h	
Indoor conditions	Indoor temperature	[°C]	Temperature probe	h	
	Indoor relative humidity	[%]	Hygrometer	h	
Data System	Temperatures of main water circuits	[°C]	Temperature probe	h	
	Supply air temperature of main AHUs, if present	[°C]	Temperature probe	h	only if supply air is thermo-dynamically treated
	Supply air relative humidity of main AHUs, if present	[%]	Hygrometer	h	only if supply air is humidified / dehumidified

Table 3 – Minimal measured parameters required

Timesteps:

- **Monthly/weekly data**: typically used for consumptions;
- **Daily data**: provide much richer information as different day types can be distinguished (workday/weekend/holiday);
- **Hourly data**: typically used for indoor supply air temperature, humidity, solar radiation etc..

In order to calculate a correct building performance, weather data as outdoor temperature, outdoor relative humidity and irradiation must be measured. For each demo site, weather data could be directly measured with the installation of a weather station or could be deduced from suitable weather provider.

3.2 KPIs classification

In order to evaluate the different impacts of the ENVISION demonstration projects on track, a set of key performance indicators (KPIs) have been set-up.

Since the ENVISION project aims to bring to the market affordable technologies, monitoring the performance of the different demonstrators is essential in evaluating the transfer and replication potential in different European regions. Hence, relevant economic, energetic, environmental and social performance indicators (KPIs) will be identified at two different levels:

- Generic KPIs, aimed at identifying common aspects covering all the demonstrators involved in the ENVISION project;
- Specific KPIs, taking into account peculiar features of each demonstrator included in the framework of the ENVISION project.

In order to identify a list of key-performance indicators, the following roadmap has been followed:

- Methodology: first of all, the partners need to share an in-depth description of the methodology to be applied for the quantitative analysis both at specific and at a general level;
- Identification of common features: analyze the common aspects of ENVISION demonstrators by providing a set of general KPIs that will be used for the evaluation of the global impact of the ENVISION project;
- Specific case analysis: afterwards each demonstrator will be analysed by identifying specific tailored performance indicators aimed at progressively evaluating the technical, environmental, economic and social performances in comparison with the identified business as usual situation.

Where possible the KPI have been reported per conditioned cubic meter of intervention, in order to guarantee comparability of the results. Additionally by considering the conditioned cubic meter it is possible to overlook the overall entity of the intervention and better understand the repeatability in other buildings groups.

The set-up of tailored key performance indicators is a useful approach to provide a quantitative measurement of the performance of the ENVISION technology package and demonstrators during their operation in order to:

- guarantee transparency and consistency of monitoring procedures;
- evaluate the achievement of the prefixed targets by identifying possible deviations and strategies for improvement;
- compare the application of the innovative developed concepts with the respective business as usual situations;
- compare different technical solutions among them;
- communicate in a simple and understandable way the achievements related to the operation of each demonstrator to the involved stakeholders, public authorities, end-users and people benefitting of the application of the new technologies, increasing public awareness and acceptance at different levels and potential of replicability in similar contexts.

The identification of KPIs requires the set-up of a proper methodology consisting of different working phases described below:

- Analysis of the concept of each demonstrator: each demonstrator responsible partner could be interviewed in order to collect information on the objectives of the demonstrator, on the specific Heating and Cooling packages applied for reaching the objective, on the integration of the process with possible existing facilities, on the expected impact and on the relative reference context. An overall evaluation of the current monitored data and the foreseen monitored data will be interesting;
- Identification of the baseline situation: the baseline as usual situation needs to be identified for each demonstrator, aimed at defining a reference scenario toward which to compare the situation after the implementation of the ENVISION technologies. Baseline situation corresponds to the natural prosecution in the future of the situation prior to the implementation of the demonstrator and it will be inferred by collecting data from energy demand and use from the same site before the installation

and operation of the demonstrators or by similar contexts where the heating/cooling demand is managed in a conventional way;

- Definition of a list of specific KPIs: a list of specific technical, environmental, economic and social KPIs has to be identified and shared with each demonstrator responsible partner in order to ensure the convergence of the elaborated list to the real implemented project and to the specific context;
- Definition of common conventions and methodology for calculation of specific KPIs: a common nomenclature scheme has to be setup for the defined KPIs in order to harmonize the identification of the specific KPIs.
- A simple and useful approach could be to identified. In particular, an ID code to each indicator with a specific section indicating the name of the demonstrator, the typology of KPI (technical, economic, energetic and social) a progressive number for distinction and stage of design (baseline (B) or post renovation(P)). as reported in the figure below. A detailed codification is reported in the Appendix C.
- Moreover, when useful or when direct data are not provided, for each specific KPI a methodology of calculation has been set-up in order to provide consistent and transparent formula for the evaluation of the performance during the operation of the demonstrators. The formulas could be the mathematical combination of parameters monitored during the operation of the demonstrators with data/parameters which will be collected for the evaluation of the baseline situation.

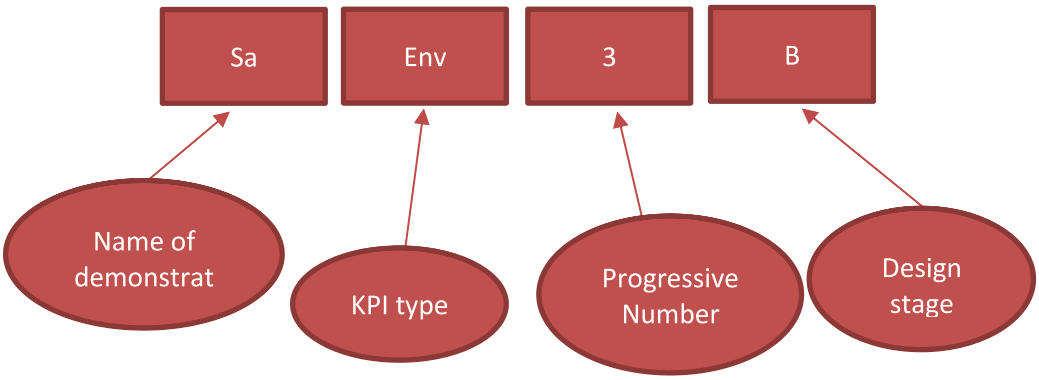


Figure 2 ID-code example for KPIs

- Definition of a list of generic KPIs: the different analyses performed on each demonstrator for the identification of specific KPIs have been combined in order to define common features to all the demonstrators following a bottom-up approach aimed at providing general indicators that can be representative of the ENVISION concept and vision increasing the potential for replication of the developed model.

For each demonstrator four categories of specific indicators could be identified:

- *Technical indicators*, aimed at evaluating the energy efficiency of the demonstrators and technology package during the operation;
- *Economic indicators*, providing the evaluation of the economic impact for the involved stakeholders and main end-users;
- *Environmental indicators*, providing estimations of the environmental impact deriving from the implementation of the ENVISION technology;
- *Social indicators,* aimed at estimating the main measurable social benefits due to the application of the technology.

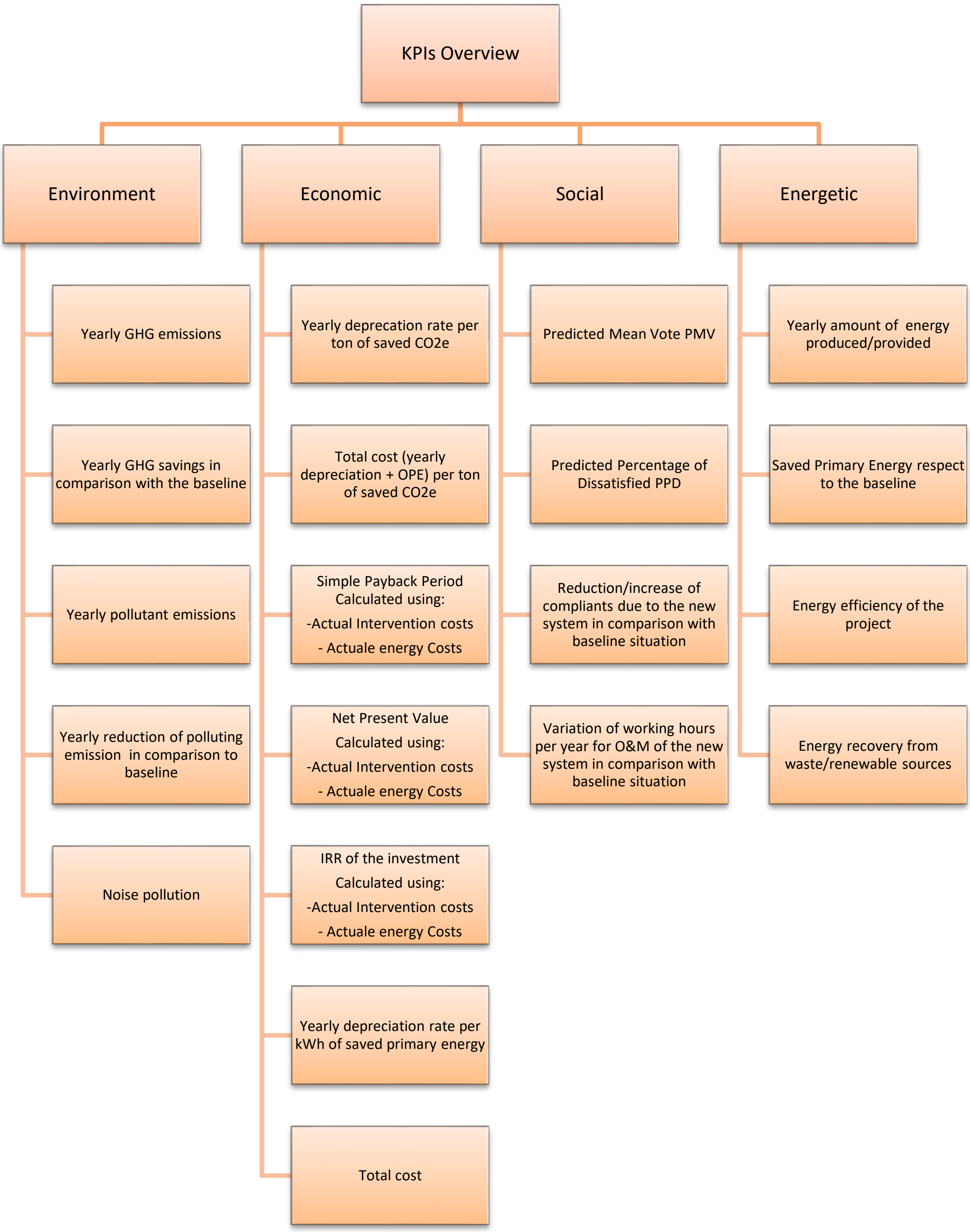


Table 4 – KPI’s Overview for each category

3.3 Generic KPIs

Generic KPIs are of relevant importance for the definition of common indicators which can summarize in a clear, measurable and communicable way the most important achievements of the ENVISION project under the technical, economic, environmental and social point of view.

The technology packages developed in the framework of the ENVISION projects have their own specificities and objectives in relation to the specific backgrounds in which they have been conceived and implemented.

The demonstrators cover different aspects related to the development of innovative systems such as, for example:

- Recovery of waste/renewable energy
- Storage and load control
- Development of ICT tools for the optimization of the energy management
- New applications of the district heating for end-users
- Expansion of the existing district heating network

Beyond the specific aspects analysed for each technology package, all the demonstrators developed in the project aim to significantly reduce CO_2 emissions, developing decentralized energy and district heating and cooling networks and utilizing energy in an efficient way.

Therefore, a common strategy for evaluating impacts at project level is needed in order to enable the learning from a diverse range of situations, supporting sustainable heating and cooling systems in relation to the achievement of the EU targets, increasing the potential for replication of the ENVISION technologies in other similar contexts.

To achieve this objective, generic KPIs need to be identified by following a bottom-up approach, starting from the analysis of each specific demonstrator and then performing a comparative analysis aimed at highlighting common features of the different cases under the identified macro-categories of interest (energetic, environmental, economic and social).

Here in the following some feasible and interesting KPIs are presented:

3.3.1 Environmental indicators

- Yearly GHG emissions related to the project: this indicator allows to evaluate different greenhouse gas emissions with different greenhouse effect together;

$$GHG_{\text{AFTER installation}} \qquad [\text{ton } CO_2eq / (m^3_c * year)]$$

Where m^3_c is the conditioned cubic meter of intervention.

The following table summarizes the CO_2eq emission factors for different fuels.

CO_2eq emission factors			
Energy carriers	tCO_2eq/tep	$kgCO_2eq/kWh$	$kgCO_2eq/GJ$
Diesel	3,07	0,2642	73,39
Fuel oil	3,14	0,2704	75,10
GPL	2,62	0,2252	65,56
Gasoline	2,98	0,2561	71,15
Natural Gas	2,32	0,1999	55,53
Process Gas	2,44	0,2096	58,21

CO_2eq emission factors			
Carbon	3,92	0,3373	93,68
Waste not renewable	3,52	0,3026	84,05

Table 1 CO_2eq emission factors

The emission factors depend on the overall energy strategy at national level. In the calculation shall be used the actual factors provided from the national energy companies for each energy carriers.

- Yearly GHG savings in comparison with the baseline situation: this indicator aims at providing an evaluation of the effectiveness of the project with reference to the greenhouse gas emissions;

$$\mathbf{GHG}_{\text{saving}} = \mathbf{GHG}_{\text{BEFORE installation}} - \mathbf{GHG}_{\text{AFTER installation}} \qquad [\text{ton CO2eq} /(m^3_c\text{*year})]$$

Where m^3_c is the conditioned cubic meter of intervention.

Yearly pollutants emission related to the project: these indicators allow to evaluate the amount of air pollutants emitted into the atmosphere from the ENVISION technologies;

- CO2 = Values obtainable directly by sensors [ppmv/m3]
- Particulate Matter (PM) = Values obtainable directly by sensors [mg/(m3*m3c)]
- VOC = Values obtainable directly by sensors [µg/(m3*m3c)]

Where m^3_c is the conditioned cubic meter of intervention.

Yearly reduction of pollutant emissions in comparison with baseline situation: these indicators aim at providing an evaluation of the effectiveness of the project with reference to the pollutant emissions;

- CO2 saving = CO2 BEFORE installation - CO2 AFTER installation [ppmv/m3]
- PM saving = PM BEFORE installation - PM AFTER installation [mg/(m^{3}*m^3_c)]
- VOC saving = VOC BEFORE installation - VOC AFTER installation [µg/(m^{3}*m^3_c)]

Where m^3_c is the conditioned cubic meter of intervention.

Noise level: this indicator allows to evaluate the end-user comfort levels, the noise level generated before and after the integration of the technologies at each demo site will be compared and the new value will need to meet the regulation;

- **NOISE LEVEL$_{\text{ENVISION}}$** = Values obtainable directly by specific sensors [dB(A)]
- ΔNoise level = NOISE LEVEL$_{\text{BEFORE Installation}}$ - NOISE LEVEL$_{\text{AFTER Installation}}$ [dB(A)]

3.3.2 Economic indicators

The evaluation of the economic indicators will be performed based on the economic data provided by the demo responsible partners on the following cost category: investment cost, depreciation time, operating costs, maintenance costs, savings/revenues deriving from the operation of the demonstrator.

- Simple Payback period (PBP): this indicator refers to the period of time required to recoup the funds expended for the installation of the ENVISION technologies, to reach the break-even point.

  Calculate Net Cash Flow NCF for each year:

  NCF1 = Cash Inflow Year 1 - Cash Outflow Year 1

  Calculate Cumulative Cash Flow CCF:

  CCF = (NCF1 + NCF2 + NCF3 + ….)

  Accumulate by year until Cumulative Cash Flow is a positive number: that year is the payback year.

- Net present value (NPV): is a measurement of profit calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time;

  NPV (i, N) = $\sum_{n=0}^{N} \frac{CF_n}{(1+i)^n}$ [€]

  Where:

  n is the time of the cash flow [years]

  i is the discount rate

  CF_n is the net cash flow

- Internal rate of return (IRR) of the new investment: this indicator allows to evaluate a rate of return of the ENVISION technologies. The internal rate of return **i** is given by solving the equation of the VAN.

  NPV = $CF_1 + \frac{CF_1}{1+i} + \frac{CF_2}{(1+i)^2} + \ldots + \frac{CF_n}{(1+i)^n} = 0$ [€]

  Where:

  CF_1 is the cost of the investment (installation of the ENVISION technologies) [€]

- Yearly depreciation rate per kWh of saved primary energy;

  $C_{Ep\ SAVED} = C_{Ep\ BEFORE\ Installation} - C_{Ep\ AFTER\ Installation}$ [€/kWh]

  Where:

$C_{EP\ SAVED}$	is the saved annual cost per kWh of saved primary energy [€]
$C_{EP\ BEFORE\ Installation}$	is the annual cost per kWh of primary energy before the installation of the ENVISION technologies [€]
$C_{EP\ AFTER\ Installation}$	is the annual cost per kWh of primary energy before the installation of the ENVISION technologies [€]

- Yearly depreciation rate per ton of saved CO_2e;

  $\mathbf{C_{CO2e\ SAVED} = C_{CO2e\ BEFORE\ Installation} - C_{CO2e\ AFTER\ Installation}}$ [€/ton CO_2]

  Where:

$C_{CO2e\ SAVED}$	is the saved annual cost per ton of CO_2e produced [€]
$C_{CO2e\ BEFORE\ Installation}$	is the annual cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]
$C_{CO2e\ AFTER\ Installation}$	is the annual cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]

- Total cost (yearly depreciation rate + operating costs) per kWh of saved primary energy;

  $TC_{Ep\ SAVED} = (C_{Ep\ BEFORE\ Installation} + OPE_{BEFORE\ Installation}) +$
  $- (C_{Ep\ AFTER\ Installation} + OPE_{AFTER\ Installation})$ [€/kWh]

  Where:

$TC_{EP\ SAVED}$	is the saved annual total cost per kWh of saved primary energy [€]
$C_{EP\ BEFORE\ Installation}$	is the annual cost per kWh of primary energy before the installation of the ENVISION technologies [€]
$OPE_{BEFORE\ Installation}$	is the operating cost per kWh of primary energy before the installation of the ENVISION technologies [€]

$C_{EP\ AFTER\ Installation}$	is the annual cost per kWh of primary energy before the installation of the ENVISION technologies [€]
$OPE_{AFTER\ Installation}$	is the operating cost per kWh of primary energy before the installation of the ENVISION technologies [€]

- Total cost (yearly depreciation + operating costs) per ton of saved CO2e.

$$TC\ C_{CO2e\ SAVED} = (C_{CO2e\ BEFORE\ Installation} + OPE_{BEFORE\ Installation}) + - (C_{CO2e\ AFTER\ Installation} + OPE_{AFTER\ Installation}) \quad [€/ton\ CO_2]$$

Where:

$TC_{CO2e\ SAVED}$	is the saved annual total cost per ton of CO_2e produced [€]
$C_{CO2e\ BEFORE\ Installation}$	is the annual cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]
$OPE_{BEFORE\ Installation}$	is the operating cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]
$C_{CO2e\ AFTER\ Installation}$	is the annual cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]
$OPE_{AFTER\ Installation}$	is the operating cost per ton of CO_2e produced before the installation of the ENVISION technologies [€]

All indicators shall be assessed both in presence and absence of the EU contribution and local feed-in tariffs (for RES or CHP production or related to energy efficiency improvement).

3.3.3 Social indicators

Thermal comfort is that condition of mind that expresses satisfaction with thermal environment. The environmental conditions required for comfort are not the same for everyone. For this reason it necessary resort to the statistical method such as Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). These two approved methods have been studied to provide information about the comfort perception indoor. Thermal comfort depend on the day-to-day variations, the age of the people, the adaptation, sex and seasonal and circadian rhythms. These two indicators have been chosen as social indicators.

- Predicted Mean Vote (PMV): this indicator aims at providing an evaluation of the thermal comfort. The PMV index corresponds to the average thermal sensation response of a large group of people, using the ASHRAE thermal sense scale below:

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Table 2 ASHRAE Thermal Sensation Scale

- Predicted Percentage of Dissatisfied (PPD): this indicator is a quantitative measure of the thermal comfort

  The environmental parameters that affect interaction between a person and their indoor environment, and thus influencing both PMV and PPD indices are:

  the air temperature [°C]

  the mean radiant temperature of walls [°C]

  the air speed [m/s]

  the relative humidity [%]

  the metabolic rate [met]

  the clothing insulation [clo]

  the air flow [m^3/h]

  The standard EN ISO 7730:2005 defines the comfort zone for PMV values within the recommended limits $-0.5 < PMV < 0.5$ corresponding to a PPD value not higher than 10%.

  Note: at least approximately the 5% of the people in a group will be dissatisfied with the thermal climate, even with PMV is equal to 0 (optimum microclimatic conditions).

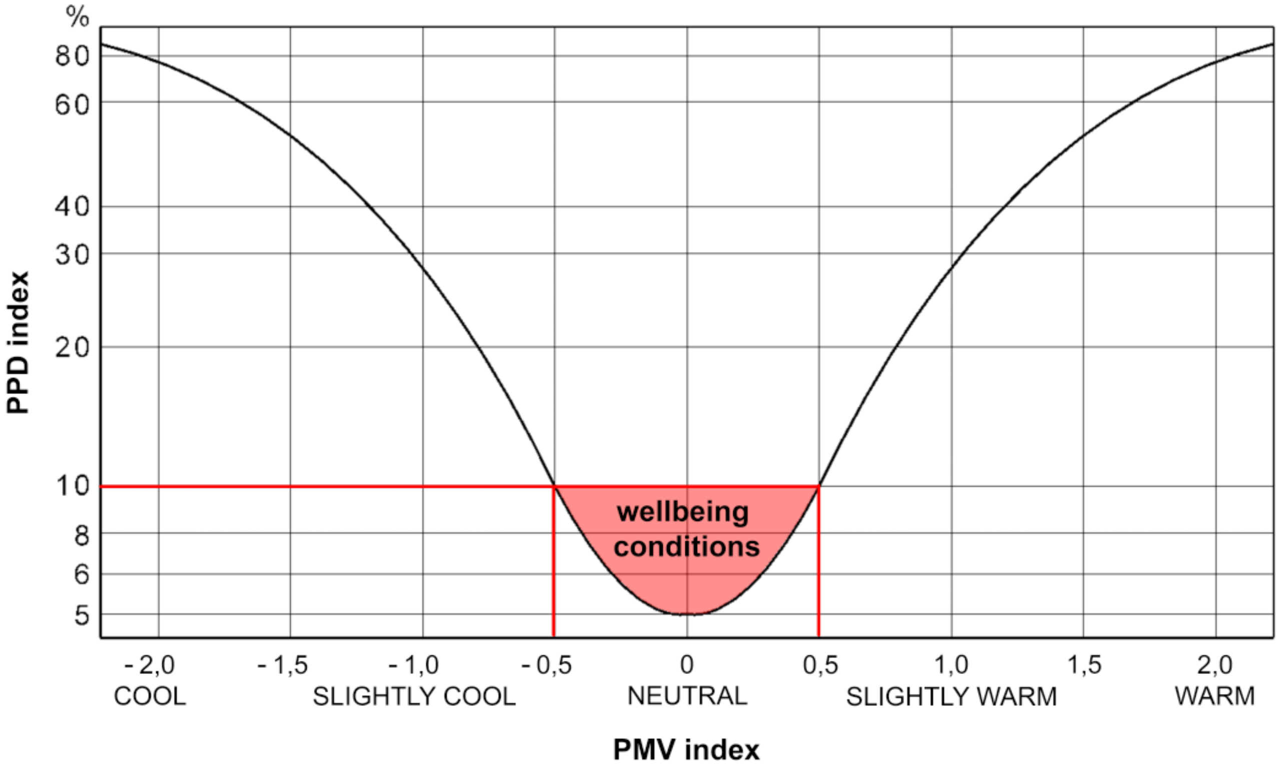


Figure 3 PMV and PPD indices and wellbeing conditions

- Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation;

$$\Delta_{PPD} = PPD_{BEFORE\ Installation} - PPD_{AFTER\ Installation} \quad [\%]$$

- Variation of working hours per year for O&M of the new system in comparison with baseline situation;

$$\Delta H_{O\&M} = H_{O\&M,\ BEFORE\ Installation} - H_{O\&M,\ AFTER\ Installation} \quad [h]$$

3.3.4 Thermal energy indicators

- Yearly amount of thermal energy produced/provided by the new system, $\mathbf{Q_{ENVISION}}$: this indicator is aimed at providing the size of the different pilots/technology package. This parameter is of significant relevance especially for the economic evaluations, stated that economic performances are strictly connected to the size of the different projects;

  $\mathbf{Q_{ENVISION}}$ = Values obtainable directly by thermal meters [kWh/(m^3_c*year)]

  Where m^3_c is the conditioned cubic meter of intervention.

- Saved primary energy in comparison with baseline situation, $\mathbf{Q_{SAVED}}$: this indicator aims at providing an evaluation of the effectiveness of the project with reference to the business as usual situation;

  $\mathbf{Q_{SAVED}} = \mathbf{Q_{BEFORE\ Installation}} - \mathbf{Q_{AFTER\ Installation}}$ [kWh/ (m^3_c*year)]]

  Where m^3_c is the conditioned cubic meter of intervention.

- Energy efficiency of the project, $\eta_{project}$: this indicator will be calculated as the ratio between the yearly amount of thermal energy produced/provided by the demonstrator and the primary energy used for the energy production;

  $\eta_{Project} = Q_{out} / Q_{in}$ [%]

- Share of waste/renewable energy, $\mathbf{Q_{RES}}$: this indicator is particularly significant for all the demonstrators where RES generators are coupled with the ENVISION packages;

  $\mathbf{Q_{RES}}$ = Values obtainable directly by thermal meters [kWh/ (m^3_c*year)]

  Where m^3_c is the conditioned cubic meter of intervention.

3.3.5 Electrical energy indicators

The amount of electrical energy E from a PV-panel is normally expressed in [kWh] (or [Wh] in case of very small amounts of energy). This is regardless if the panel is opaque as usual or translucent as in the Envision Technology. Therefore the usual KPI's of PV-panel performance can and will be used. This is according to norm IEC 61724-1:2017. A brief summary of this norm, including some example calculations will be given in this paragraph.

- The amount of electrical Energy **E** [kWh] is measured per minute, per hour, per day, per month, or per year. For clarity, most of the times, this will be made visible explicitly in the units; e.g. E_(10 April 2017) = 1.23 kWh/day. If not specified in this specific way, then it should be clear from the context over which time period the electrical energy is measured. For the Envision project, the measurement interval is at least 1 minute, hence all larger time intervals can be calculated from that raw data.

  When E is measured directly to a PV panel, this is DC energy. When measured after an inverter, this is AC energy. Sometimes an additional subscript DC or AC is added for reasons of clarity. Hence e.g. E_DC_panel_SCX1.1_(10 April 2017) = 0.105 kWh/day.

- Specific Yield **Y**: To be able to compare panels or systems more easily, it is common to divide the energy by the rated power R at Standard Test Conditions (STC)4 in [kWp]. This parameter is defined by the PV-industry to be able to compare PV-panels and PV-systems. Specific yield Y is now defined as:

$$Y = \frac{E_{DC}}{R_{\text{rated}}}$$

  The unit of Y is always [kWh/kWp]. For clarity one can add the time related to the energy measurement. Hence, Y will then be expressed e.g. as [kWh/kWp/day]. When PV-panels or PV-systems are installed at the same location (test site) and under the same tilt angle, then this Y can be used for a direct comparison of the performance of the systems.

- Performance Ratio **PR**: when PV-panels or PV-systems are not installed at the same location or under a different tilt, and one still would like to compare the panels or systems, then the parameter 'Performance Ratio' (PR) is most suited. To calculate PR, the irradiance G has to be measured in the same plane as the panels, the so-called Plane-Of-Array (POA). It must also be summed over the period of interest, which is the same period for which the energy measurement is done. Suppose we take the example of one day, then we can sum from sunrise till sunset5:

$$H_{POA} = \int_{t=sunrise}^{t=sunset} G_{POA}$$

  The unit of HPOA is [kWh/m^2/day]. The parameter HPOA shows directly the opportunity for capturing the sunlight. For example, an average Dutch spring day would give about HPOA ≈ 3.3 kWh/m^2/day. If a PV-technology would be able to capture all this energy, then it would produce this amount of electricity. This is not the case. Typical PV-technology has a conversion efficiency of about 16% 6. With the help of the rated power R which was measured by the manufacturer at 1 kWp/m^2 (artificial) sunlight, we can measure the percentage that a specific panel should be producing. E.g. consider a Pilkington panel, that is rated with R=145 Wp. Then it could give in total on this day: 0.145 * 3.3 = 0.479 kWh/panel/day. The expected performance would be called 100% if we actually would measure 479 Wh of DC-energy coming from that specific panel.

  The dimensionless parameter Performance Ratio is now calculated over a specific period:

$$PR_{day} = \frac{Y\ [\frac{kWh}{kWp}/day]}{H_{POA}[\frac{kWh}{m2}/day]} 1[kWp/m2]$$

  where PR is most commonly expressed as a percentage [%]. Only when a full year of measuring energy and irradiance has been done for a PR-calculation, then PR can be used without any subscript. For all other periods of interest the subscript is mandatory; e.g. PR_{month} will be used much in the Envision measurements. In all cases whether it is not clear if AC- or DC-measurements are used an additional subscript is used; e.g. PR_{DC_month}.

4 Standard Test Conditions are defined by IEC 61215 as: module temperature should be 25°C and irradiance should be 1000 W/m2 with an air mass 1.5 (AM1.5) spectrum.

5 Because there is only noise in the measurement data before sunrise and after sunset.

6 The exact number varies between a few % to nearly 50% depending on the PV-technology, but is not relevant for this explanation.

Coming back to the example used in this paragraph. Suppose we actually measured 400 Wh of DC-energy for the example day, then the PR is just the division of the measured value by the reference yield value which was calculated at 470 Wh/panel/day above. Hence PR_(10 April 2017) = 400/479 = 84%.

3.3.6 Generic KPIs checklist

All the KPIs described previously could be summarized in a table as the following one in order to have at a glance a comprehensive evaluation of the status of the pilots and to make a comparison among them.

When possible, the analysis of the following KPIs need to be carried out through the use of real measured data through the ENVISION equipment (from pre- and post-retrofitting phase). When this will not be possible due to the limitations imposed by the Project, i.e. for environmental and social KPIs, a literature review and appropriate references will be needed.

A first assessment could aim to evaluate the suitability of these KPIs to the project's goal and if the available data could be used to monitor them:

	General KPIs	UM	Variable
ENERGETIC	The yearly amount of thermal energy produced/provided by the new system	*kWh/year*	• Data from impeller type heat and heat/cooling energy meters: flow and return temperature [°C], energy flow [kW], flow rate [m³/year] • Indoor temperature [°C] • Outdoor temperature [°C]
	Saved primary energy in comparison with baseline situation	*kWh/year*	• Consumption of each energy source [kWh/year; m³/year] • Type of energy source and its conversion factor
	Energy efficiency of the project	*%*	• Generation losses [kWh] • Distribution losses [kWh]
	Energy recovery from waste/renewable sources	*kWh/year*	• Data from energy meters - renewable energy [kWh]
ENVIRONMENTAL	Yearly GHG emissions related to the project	*ton CO_2eq /year*	• CO_2 [ton CO_2eq];
	Yearly GHG savings in comparison with the baseline situation	*%*	• Consumption of each energy source (baseline) [kWh/year; m³/year] • Consumption of each energy source (project) [kWh/year; m³/year] • Type of energy source and its conversion factor
	Yearly pollutant emissions related to the project	*kg/year*	• CO2 [ppmv]; • Particulate Matter (PM) [mg/m³]; • VOC [µg/m³]
	Yearly reduction of polluting emission in comparison to baseline	*%*	• CO_2 [ppmv]; • Particulate Matter (PM) [mg/m³]; • VOC [µg/m³]

	Carbon footprint	*ton C/year*	• Carbon dioxide equivalent (CO_2eq) with the relevant 100-year global warming potential (GWP100)
	Ecological footprint	*gha*	• A measure of how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices.
	Noise pollution	*dB(A)*	• Noise Level before and after the installation of ENVISION technologies [dB(A)]

Table 3 Generic KPIs checklist – part A

	General KPIs	UM	Variable
ECONOMIC	Simple Payback period	*years*	• Costs of each installation [€] • Saved primary energy [kWh/m^{2}year]
	Net present value	*€*	• Time of the cash flow [years] • Discount rate • Net cash flow
	IRR of the new investment	*%*	• Costs of each installation [€]
	Yearly depreciation rate per kWh of saved primary energy	*€/kWh*	• Saved primary energy in comparison with baseline situation [kWh/m^{2}year] • Costs of each energy source [€] • Costs of each installation [€]
	Yearly depreciation rate per ton of saved CO_2e	*€/t CO_2e*	• Saved ton of CO_2e in comparison with baseline situation • Costs of each energy source [€] • Costs of each installation [€]
	Total cost (yearly depreciation rate + OPE) per kWh of saved primary energy	*€/kWh*	• Saved primary energy in comparison with baseline situation • Costs of each energy source [€] • Costs of each installation [€] • Operating costs of each installation [€]
	Total cost (yearly depreciation + OPE) per ton of saved CO_2e	*€/t CO_2e*	• Saved ton of CO_2e in comparison with baseline situation • Costs of each energy source [€] • Costs of each installation [€] • Operating costs of each installation [€]

SOCIAL	Predicted Mean Vote (PMV)	-	• Indoor Air Temperature [°C] • Indoor Relative humidity [%] • Mean radiant Temperature [°C] • Air speed [m/s] • Skin wittedness • Metabolic Rate [met] • Clothing insulation [clo] • Air flow [m3/hour]
	Predicted Percentage of Dissatisfied (PPD)	*%*	• Indoor Air Temperature [°C] • Indoor Relative humidity [%] • Mean radiant Temperature [°C] • Air speed [m/s] • Skin wittedness • Metabolic Rate [met] • Clothing insulation [clo] • Air flow [m3/hour]
	Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation	*%*	• PPD before ENVISION installation • PPD after ENVISION installation
	Variation of working hours per year for O&M of the new system in comparison with baseline situation	*hours/year*	• Working hours per year for O&M of the new system (baseline and project situation) [hours/year]

Table 4 Generic KPIs checklist – part B

As explained in the following chapters, during the ENVISION project, all necessary modules for calculating KPI's will be implemented into Dimosim,_which will be used therefore to allow a comparison with the measurements from the pilot sites as well as for replication studies.

3.4 Specific KPIs

For what it concerns Pilot Specific KPIs, these are mainly related to the technologies implemented in the ENVISION technology package present in the pilot and the targets of the demosites, its finality and its end-users.

Here below a short list of possible specific KPIs considering the ENVISION technology package:

3.4.1 For gas absorption/electric heat pumps

Heat Pumps specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Yearly thermal energy production of each heat pump	MWht/year	
Yearly gas and electric energy consumption of each heat pump	MWht/year	
Coefficient of Performance, COP	-	$COP = \frac{Power\ output}{Power\ input}$
Energy Efficiency Ratio, EER	-	$EER = \frac{output\ cooling\ energy\ in\ BTU}{input\ electrical\ energy\ in\ Wh}$

Heat Pumps specific KPIs		
Heating Seasonal Performance Factor, HSPF	-	$HSPF = \frac{output\ heating\ energy\ in\ BTU}{input\ electrical\ energy\ in\ Wh}$
Seasonal Energy Efficiency Ratio, SEER	-	$SEER = \frac{output\ cooling\ energy\ in\ BTU\ (over\ a\ season)}{input\ electrical\ energy\ in\ Wh\ (same\ season)}$
Gas utilization efficiency (GUE)	-	$GUE = \frac{Heat\ transferred\ to\ the\ medium\ to\ be\ haeted}{Energy\ consumed\ by\ the\ burner}$

Table 5 Specific KPIs for gas absorption/electric heat pumps

3.4.2 For solar panels installed in one-way substations connected to the district heating network

Solar Panels specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Yearly thermal energy provided of solar panels	kWht/year	Values obtainable directly by thermal meters
Yearly thermal energy demanded in subs by users	kWht/year	Values obtainable directly by thermal meters
Saved primary energy in comparison with baseline situation	kWht/year	$Q_{SAVED} = Q_{BEFORE\ Installation} - Q_{AFTER\ Installation}$
Efficiency of the system	%	$\eta = \frac{Peak\ power}{Panel\ Area}$
Deviation between thermal energy produced and estimated theoretical energy	%	• Thermal energy produced: obtainable directly by thermal meters • Theoretical thermal energy: technical data sheet

Table 6 Specific KPIs for solar panels connected to the district heating network

3.4.3 For Thermal storage tank

Thermal storage tank specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Volume of the storage tank	l	Values obtainable by technical data sheet
Heat loss	kWht	Values obtainable directly by thermal meters (input and output)

Table 7 Specific KPIs for solar panels connected to the district heating network

3.4.4 For DH application

DH application specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
District heating supply temperature (yearly average, summer average and winter average)	°C	Values obtainable directly by thermal meters
District heating return temperature (yearly average,	°C	Values obtainable directly by thermal meters

DH application specific KPIs		
summer average and winter average)		
Relative distribution losses	%	

Table 8 Specific KPIs for DH application

3.4.5 For One-way substation tested in the experimental district heating network and connected to the virtual test bench in static tests

One-way substation specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Domestic hot water power	kW_t	Values obtainable directly by technical data sheet
Space heating power	kW_t	Values obtainable directly by technical data sheet
Network, SH and DHW supply and return temperatures	°C	Values obtainable directly by thermal meters
Electrical consumption	kWh_e	Values obtainable directly by electrical meters
Heat losses	kW_t	Values obtainable directly by thermal meters (input and output)
Heat exchangers thermal efficiency	-	$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}}$
Differential pressure between supply and return network lines	bar	Values obtainable directly by barometers

Table 9 Specific KPIs for One-way substation tested in the experimental district heating network and connected to the virtual test bench in static tests

3.4.6 For One-way substation tested in the experimental district heating network and connected to the virtual test bench in 12 days' dynamic tests

One-way substation specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Total Energy supplied to space heating loop	kWh_t	Values obtainable directly by thermal meters
Total Energy supplied to domestic hot water loop	kWh_t	Values obtainable directly by thermal meters
Network, SH and DHW supply and return temperatures	°C	Values obtainable directly by thermal meters
Electrical consumption	kWh_e	Values obtainable directly by electrical meters
Heat losses	kWh_t	Values obtainable directly by thermal meters (input and output)
Number of ON/OFF heating cycles	-	Values obtainable directly

Table 10 Specific KPIs for One-way substation tested in the experimental district heating network and connected to the virtual test bench in 12 day's dynamic tests

3.4.7 Electrical PV-Panels

One-way substation specific KPIs		
Key Performance Indicator	Unit	Evaluation technique
Electrical Energy	kWh	Amount of electrical energy produced
Specific yield	kWh/kWp	Energy/ Rated Power R at Standard Conditions
Performance Ratio	-	Specific yield /irradiance measured at Plan OF Array

4 Demonstrators monitoring plan

In this chapter, a monitoring plan applicable for each demo cases is proposed. Accordingly with KPIs calculation, a sensors deployment plan will be developed and monitoring strategy will be declined for each demo case in a suitable way.

Monitoring strategy is based on the energy flows across the system boundary as described in the EN UNI 15603 standard as following showed:

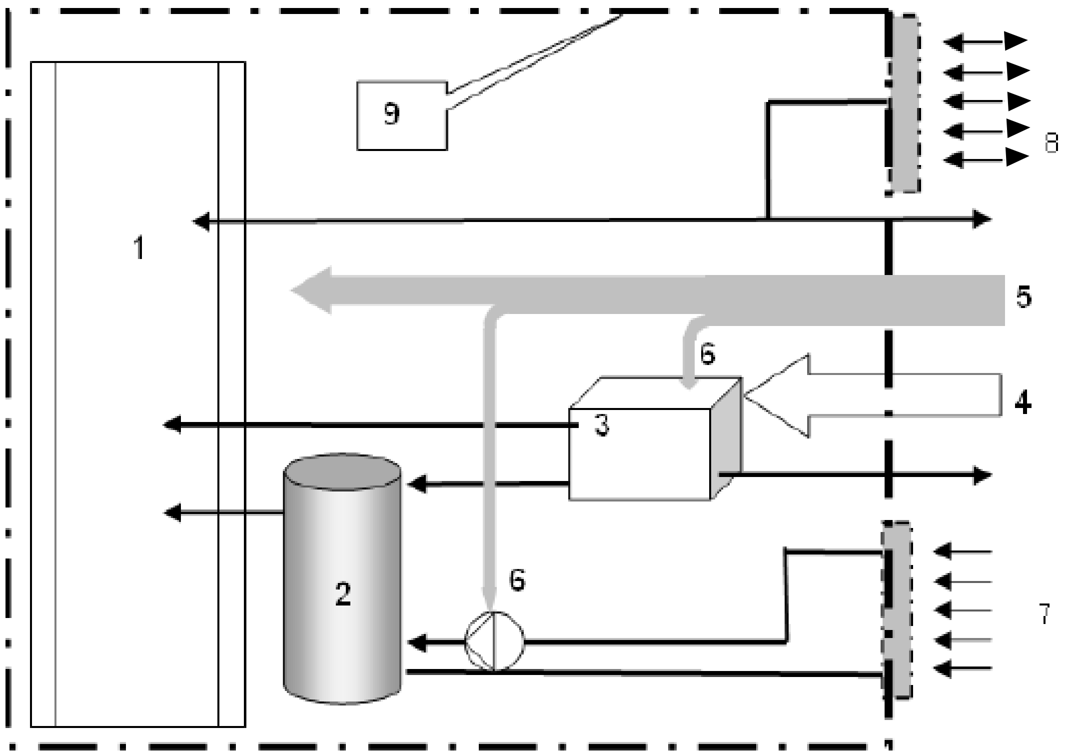


Figure 4 – Boundary – Energy flows throughout the monitoring plan.

Where:

1 = end user;

2 = thermal storage;

3 = boiler;

4 = fuel;

5 = electricity;

6 = auxiliary energy;

7 = Envision panel or technology;

8 = heating district network exchange;

9 = reference boundary.

The amount of all energy carriers delivered to the building and exported by the building shall be measured and reported, the instantaneous power is indicative of the proper functioning of the system.

By linking the climatic data with those measured from the Envision technology it will be possible evaluate the overall performance of the system in different climatic conditions by coupling the result interpolation method and energy signature method. Another important result achievable using a monitoring method, in consideration of Envision technology replicability, is to found the external temperature at which the system components have the best performance.

4.1 Proposed instrumentation

In this paragraph the instrumentation required to implement the monitoring plan will be introduced as well as the physical parameters.

Regarding the climatic data a weather station is required in order to record air temperature outdoor, air humidity and solar radiation (both direct and indirect). As example it is reported below a picture:

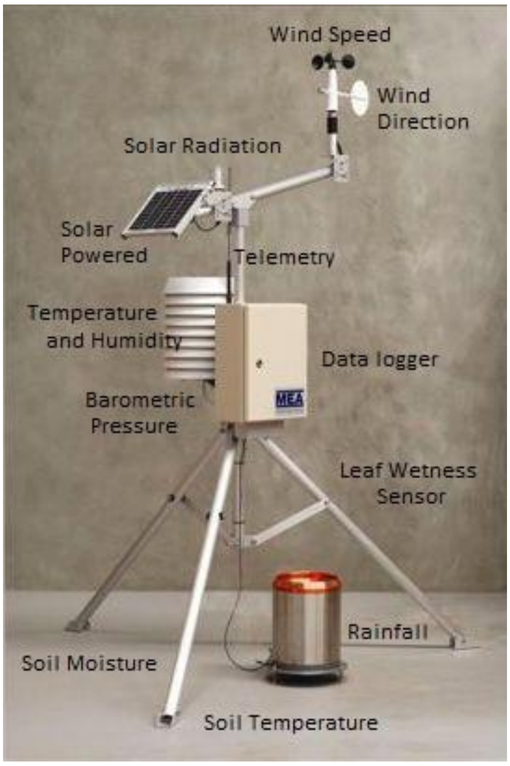


Figure 5 – Example of weather station.

The analysis of Envision panel performances should be taken into account of the overall thermal transmittance through the wall. A thermal transmittance will be measured and monitored before and after Envision technology installation. In this way, envelope characteristics of Envision solutions will be evaluated too. For these reason will be used the thermofluximeter that will monitor the thermal flow throughout the panel. Additionally by measuring external surface temperature of the panel it will possible determine accurately also the summer behavior of the wall by observing the thermal wave shift respect to the external surface temperature. Internal temperature will be monitored to proper determine the internal comfort conditions.

Figure 6 – Thermofluximeter in place

Heating flow exchanged between Envision technology and the district network shall be monitored in order to quantify the energy supply from the system and calculate the rate of energy demand satisfied using envision technology. Additionally will be installed the heating meter which will measure and record the supply and return temperature in the pipe. These measure will be used to better understand the amount of heat that passes through the Envision panel. Heat meter shall have remote operations and will be linked to a building management system.

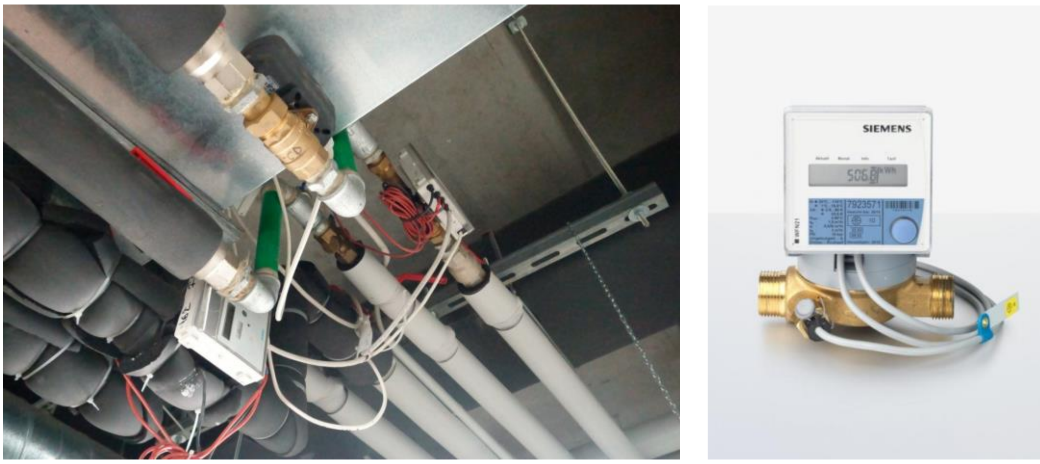


Figure 7 - Heat meter with remote operation

The evaluation of the net primary energy saved using Envision technology cannot leave out of the auxiliary energy. The auxiliary energy is defined as electrical energy used by technical building systems for heating to support energy transformation to satisfy energy needs. It include energy for pumps.

Electricity will be monitored through device that can act as a standalone server and also control I/O modules and monitor and manage field bus device which will support open building protocols and will be remote controlled.

Figure 8 – Electricity meter device

The device will have dedicated memory for historical data and another one for backup in order to ensure that the data will be safe from damage or loss. It will possible manually backup or restore the device to a storage location on a PC or network.

All the monitoring instruments will measure the variables at the same in time in order to facilitate comparison and variables relation and make easy the comparison. For this reason, a time synchronization among the monitored variables is required.

4.2 Savona Campus' demo site

One of the Europe demo-site is located in the Savona Campus, and it is one of the venues of the University of Genoa. The Campus includes classroom and office buildings, students' apartments, library, auditorium, canteen, laboratories, and sport facilities. The total area is around 60.000 m2 with around 1700 students.

A "Smart Polygeneration Microgrid (SPM)" is installed throughout the Campus and provides electric and thermal energy with a district heating network (DHN). In particular, the SPM includes several commercial CHP units, traditional prime movers and renewable generators. The system also includes absorption refrigerators for heating and cooling, battery-charging stations for electric vehicles and sodium nickel batteries that can thus supply the campus with electricity for three hours. The SPM is connected to the National electrical grid in a single point.

The ENVISION harvesting technologies (solar façade modules and ventilated windows) will be properly integrated into the "Smart Polygeneration Grid" in order to test and evaluate their performances and impact on the DH network management strategy.

The following sections describing the deployment activities to be performed at demo sites level are duplicated for both the technologies that will be tested and demonstrated: the NIR absorbing & coloured coating and the heat harvesting ventilated window.

The ENVISION harvesting technologies (solar façade modules will be tested and evaluated in order to estimate their performances and their impact on the SPM.

The ENVISION's impact on the Savona Campus will lead to a wider use of renewable resources and low emissions technologies to supply the buildings demands. The use of façade modules allows exploiting a wider range of Near Infra-Red (NIR) solar irradiation and leads to a building renovation thanks to the different colours available.

The available surface for façade modules is around 100 m^2 and, considering the energy harvesting around 1.5 GJ/m^2 per year (as estimated in ENVISION proposal), the heat power in output will be used to supply the buildings thermal demand through the DHN. A thermal storage will be used in order to optimize the system management.

The campus energy grid delivers water at 75°C and returns it back at 55°C. As consequence, in order to supply thermal energy in DHN, the generation units must deliver water at 75°C temperature. The chance to exclude part of the circuit enhance the possibility for testing different technology through a local-dedicated cycle.

The ENVISION framework will be tested considering the connection to the grid. Testing campaign of ENVISION system will be carried out in the laboratory of UNIGE.

In order to evaluate the panel and system performances, different measures need to be taken. The most important performance parameters are heat exchanged, temperatures, pressure drops, electrical generation and electrical consumption.

4.2.1.1 General description

The energy harvesting façade module will be installed on the buildings of the Innovative Energy System Laboratory (IESL), connected to the Savona Campus Smart Polygeneration Microgrid.

In Figure 9, the system layout of the Southern demo-site is reported. The system is composed by a number of façade modules, a heat pump, a mGT, and a thermal storage.

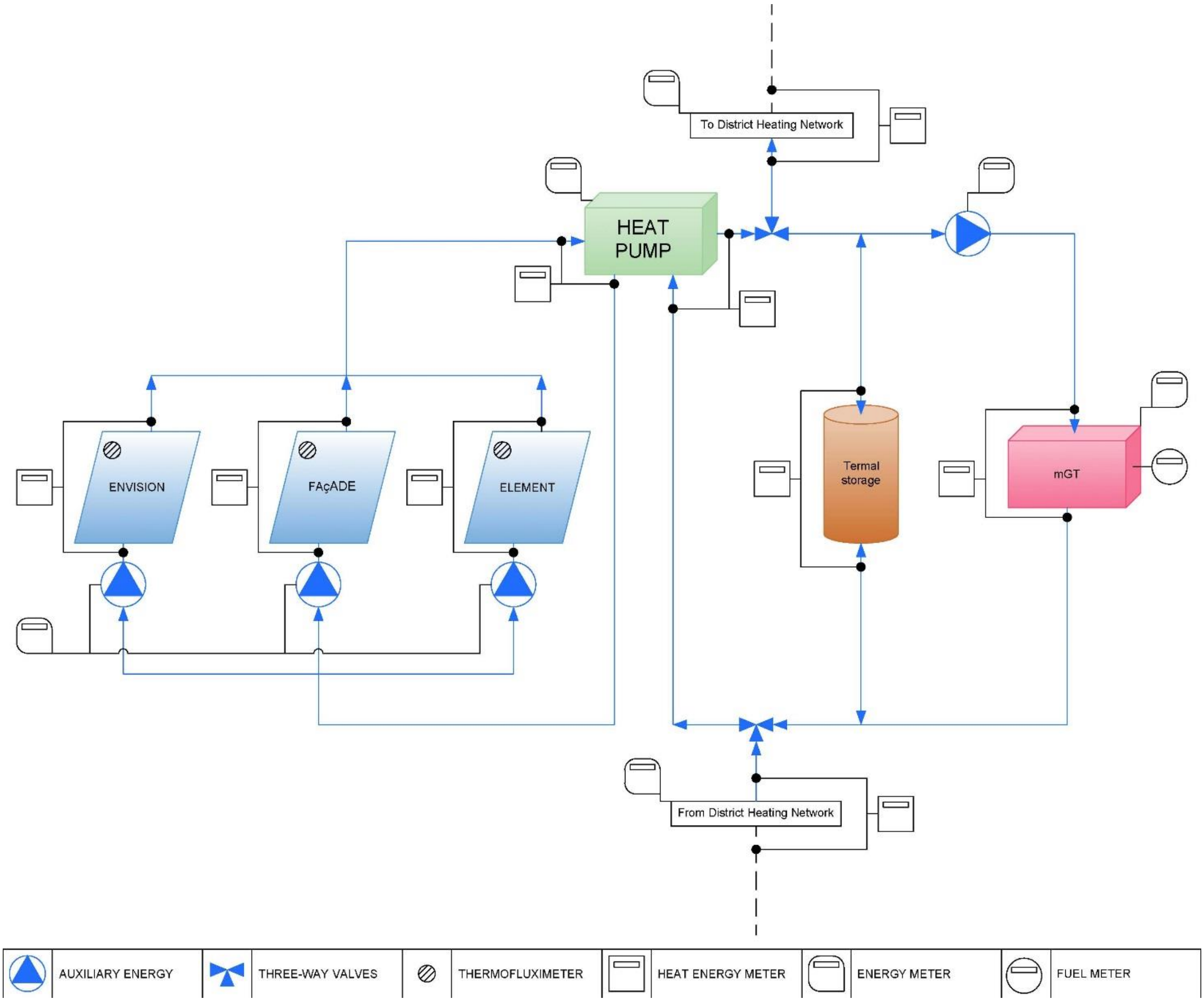


Figure 9 Plant lay-out

The façade solar panels are installed in an internal loop. The hot water flow rate produced the panels, enters the heat pump that has the role to enhance the water temperature up to the 75°C, compatibly with the DHN constraints. Hence, the heat pump is the interface between the façade modules loop and the DHN. Moreover, it is installed in parallel to the mGT and the thermal storage that compose the second loop. The mGT operates in a CHP configuration in order to provide both thermal and electric energy to the grid.

Two buildings will be involved in the ENVISION project. The façade modules will be installed on the walls of a building used as a warehouse (BUILDING 1). The available surface of this building is around 96 m^2. Close to the building 1, there is the second one with an height of 6.5 m where the mGT and the heat pump system will be installed (BUILDING 2).

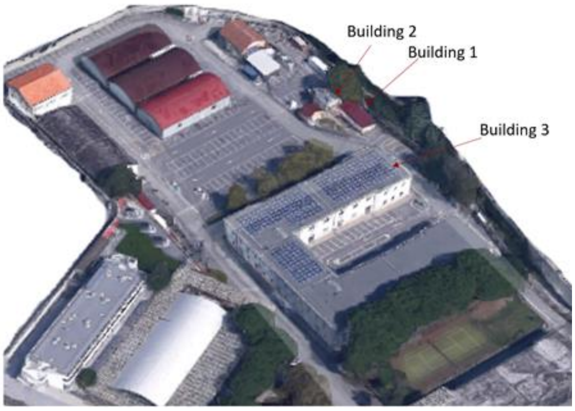


Figure 10- Savona Campus' aerial vision

4.2.1.2 Intervention description

A new water piping connection between the demo-site and the DHN must to be installed.

The *building 1* needs to be renovate and the access to the buildings will be closed with the installation of a gate. Some electrical works must be done in order to connect the demo-site to the smart grid electrical cabinet.

The mGT that will be installed has a size of 100kW. The façade modules are provided by TNO and based on the availability. The heat pump size depends on the number of the façade panels installed. Assuming to cover the entire available surface (around 100m^2), a heat pump size of 8kWth can be considered. The thermal storage has a size not below 500 l.

Verify the mGT correct operation. Verify the Heat Pump correct operation. Check the outlet temperatures provided by the façade modules in order to set the system performance. Validation of sensors system. Test of the developed control system in order to optimize the system management.

For what concerns the ventilated windows test rig, the chosen place in the beginning is one of the office in Delfino building, as in Figure 11. The window has a South orientation, therefore heat capture is optimized.

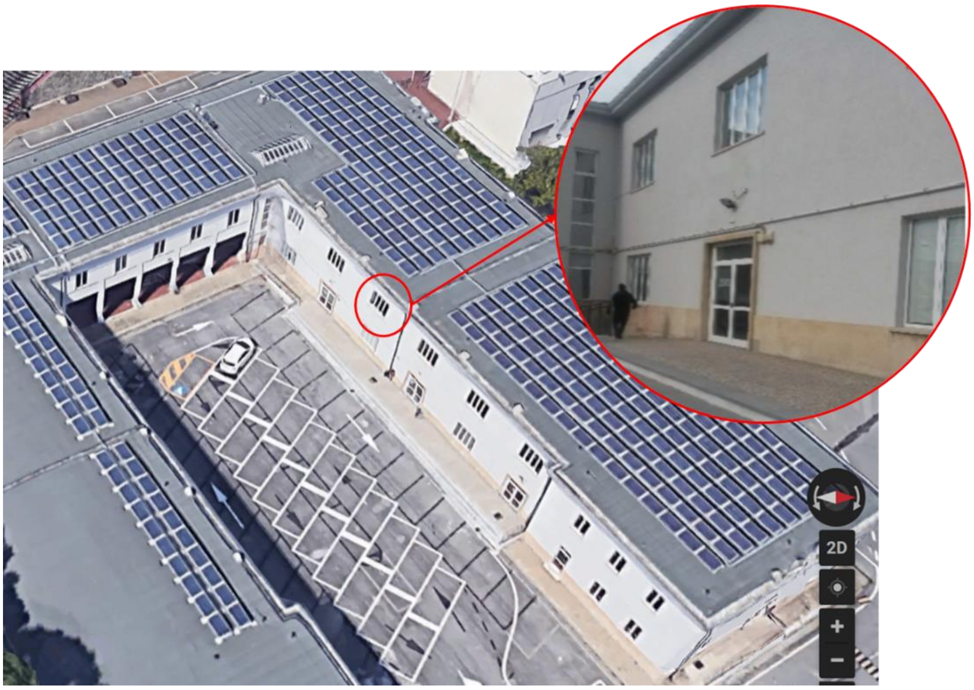


Figure 11 Delfino office outside detail for ventilated windows installation

The office has a conditioned environment in its inside, with a room size of around 30 m^2 where usually only one person works during common office working time. In order to evaluate the window performances, a “twin office” with the same dimensions will be used for a comparison with the ventilated window room performances.

Nevertheless it is very relevant that the possibility of a hot water circuit requirement, in case of a ventilated window configuration with a heat exchanger, could lead to the necessity to find a new installation place inside the Campus where a water circuit is available. In the next months, when BGTech will perform more tests on their prototype, the provided info will lead to find the installation place that can comply both UGT and BGTech requirements.

The ENVISION framework will be tested considering the connection to the grid. Testing campaign of ENVISION system will be carried out in the laboratory of UNIGE.

In order to evaluate the panel and system performances, different measures need to be taken. The most important performance parameters are heat exchanged, temperatures, pressure drops, electrical generation and electrical consumption.

Heat flow is one of the most important system parameters.
The point where it will be evaluated are:

- Façade solar panels
- Heat pump cold side
- Heat pump hot side
- Micro Gas Turbine

In order to measure the heat flow, it is necessary to evaluate temperature and mass flow values. Then the heat flow will be obtained as in (1)

$$\dot{Q} = \dot{m} * c_p * (T_{out} - T_{in}) \quad (1)$$

Where c_p is the specific heat for the considered fluid, in this case water (with a small percentage of glycol).

Therefore, temperatures and mass flow sensors need to be installed for heat transfer evaluation. Depending on solar façade panels configuration, different sensors configuration schemes must be considered in order to measure the different panels' performance indicators. The aspects that mostly affect panels performances are:

- Colour of the panel surface
- Orientation

In order to understand the influence of different aspects, it will be necessary to evaluate and compare the thermal energy produced by both panels with same color but different orientation, and panels with different colour but same orientation. To do this aim the panel surface temperatures will be measured. Assuming to cover the whole available surface with panels (around 100 m^2), 4 orientations can be evaluated.

Different detail levels of measurement campaign can be considered:

- Low detail: temperatures and mass flows are measured only in two points placed immediately in inlet and outlet the façade panels pipelines. See Figure 12-below.

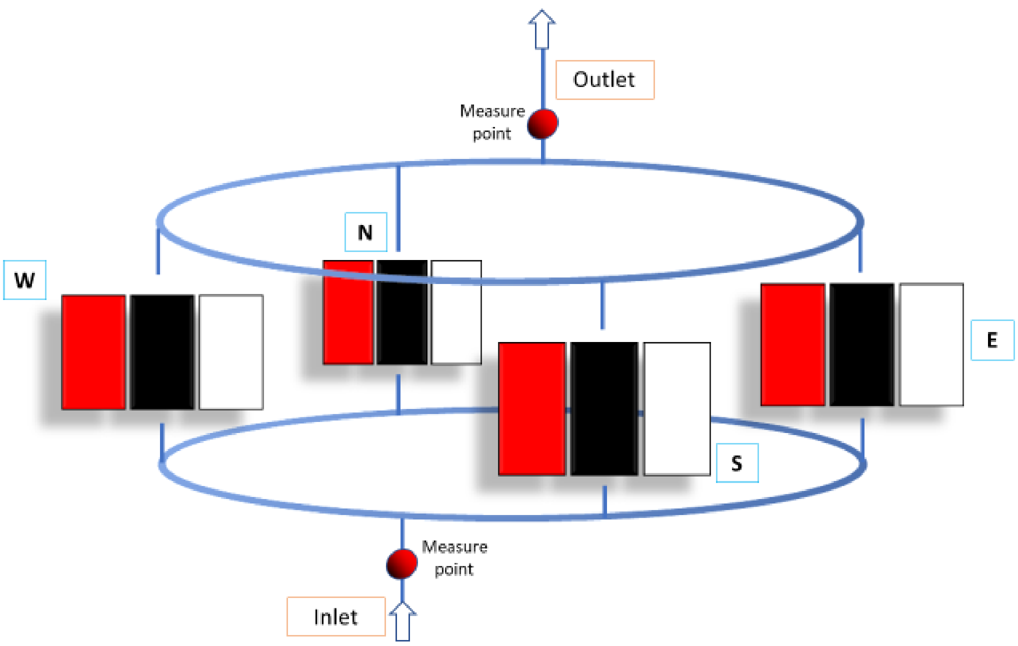


Figure 12- Low Detail Measurements

- High detail: temperatures and mass flows are evaluated for one panel per colour (or more panels if placed in series) in each different direction. See Figure 13- High Detail Measurementsbelow.

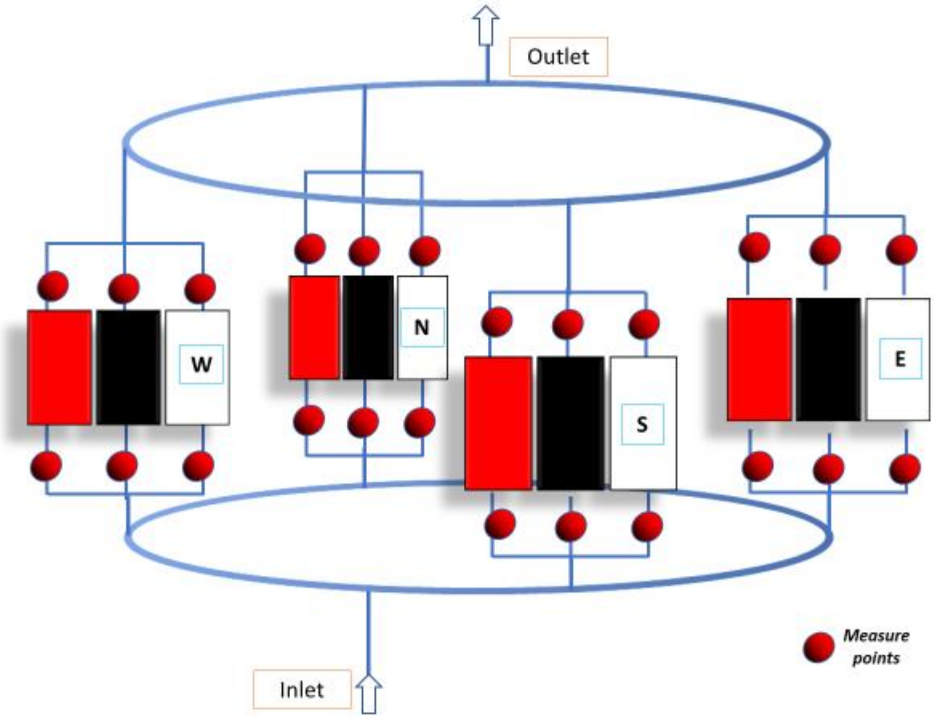


Figure 13- High Detail Measurements

- Medium detail: a compromise in terms of costs and measurements complications between the two different detail levels proposed could be applied.

In order to evaluate the panel performances, the surface temperatures will be measured. For a good measurement campaign the surface temperatures will be measured once for each panel type, then for a chosen colour the surface temperature will be evaluated also in different orientation.

4.2.1.3 KPI List

Please refer to the Appendix C for the complete list of KPIs that will be calculated for the Savona Campus demonstrator.

4.2.1.4 Sensors

Six ***sensors type*** will be necessary for surface panel temperature measurements.

Pressure drops

In order to evaluate panel performances, the measure of pressure drops through panel pipes is fundamental. Moreover, the evaluation of system pressure drops is necessary to properly define the recirculation pumps size. Pressure drops could depend on the kind of panels (if there are differences in terms of construction and not just of colour) but they do not depend on orientation. Therefore, it could be assumed that pressure drops will be evaluated as difference between the pressure measured immediately before and after the façade panels pipelines (as in Figure 12).

Electrical energy generation

The test rig placed at the University of Genoa Savona Campus can be considered as a cogenerative system able to produce both thermal and electrical power. Therefore, the amount of produced electrical energy need to be evaluated to understand the system behaviour. The responsible component of electrical energy generation is the micro-Gas Turbine. This component already provides a monitoring system for electrical generation; therefore no additional sensors will be installed.

Electrical energy consumption

The systems needs recirculation pumps to guarantee an uniform fluid flow. Heat pump is also installed in order to reach the temperature requirements (about 75°C) of District heating Network after pre-heating through façade panels. Electrical energy consumed by these systems will be directly or indirectly evaluated considering the overall energetic balance of the system.

4.2.1.4.1 Measurements system configuration

The plant layout with expected measuring points is reported in Figure 14. The presence of three different circuits can be seen from Figure 14 : **façade panels circuit** (with solar panels, small storage and heat pump cold side), **main circuit** (with mGT, thermal storage and heat pump hot side) and the **loads circuit** that lets the heat flowing to thermal dissipators (inside TPG labs) or to District Heating Network users. A detailed description of measuring campaign for different circuits is reported In following paragraphs.

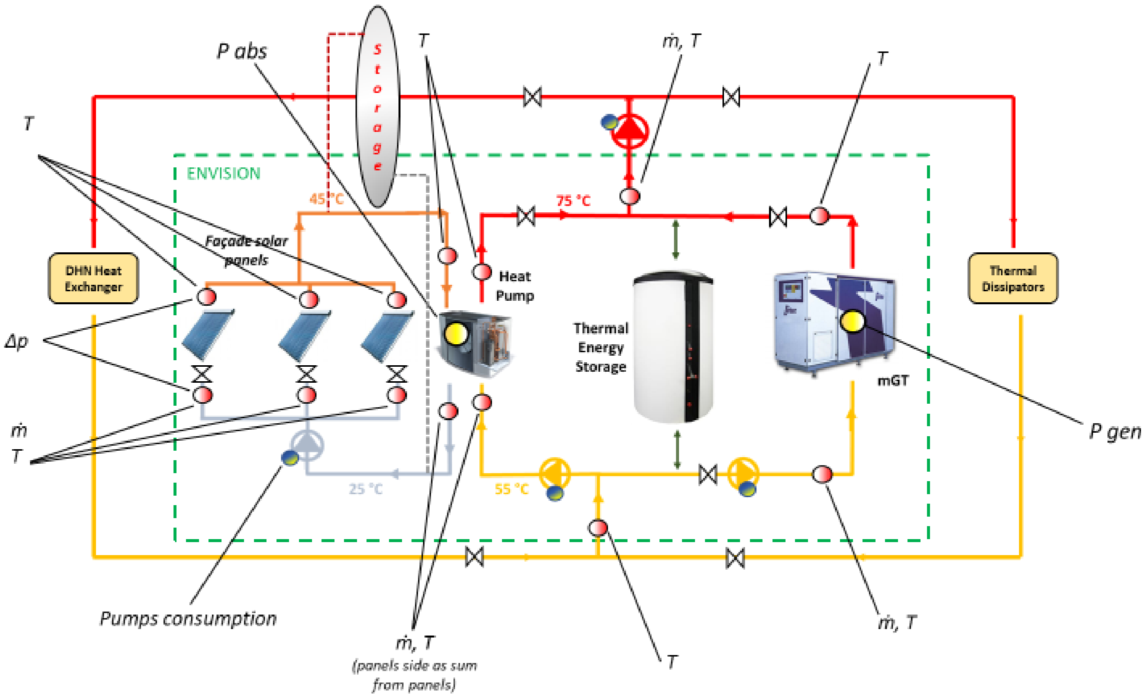


Figure 14- Plant system and measured point

Façade panels circuit

As explained before, number and position of the different sensors depends on the detail level that it is decided to analyze and on panels delivery that will be available for Southern Demosite. Reasonably, three different panels colours are expected to be used in the test rig. The panels will be then installed in 4 orientations. Therefore the number estimation of necessary sensors can be done depending on the detail level that it is required to reach.

- Low detail:
    - 1x mass flow meter + 1x temperature meter + 1x pressure measure placed in the pipeline at the inlet of the panels ramification
    - 1x mass flow meter + 1x temperature meter + 1x pressure measure placed in the pipeline at the outlet the panels ramification

  TOTAL AMOUNT considering 3 types of panel:

    - 2x temperature meters
    - 2x mass flow meters
    - 2x pressure sensors

- High detail:
    - [(1x mass flow meter + 1x temperature meter placed in inlet of each series of same kind panels) x 4 orientations + 1x pressure measure placed before each series of same kind panels] x N° of panel kinds.
    - [(1x mass flow meter + 1x temperature meter placed in outlet of each series of same kind panels) x 4 orientations + 1x pressure measure placed in outlet of each series of same kind panels] x N° of panel kinds.
    - 1x temperature meter placed at the inlet of heat pump cold side
    - 1x temperature meter placed at the outlet of heat pump cold side

  TOTAL AMOUNT considering 3 types of panel:

    - 26x temperature meters
    - 24x mass flow meters
    - 6x pressure sensors

- Medium detail:

- In order to simplify measurements system configuration, reducing costs maintaining a good monitoring campaign, a compromise between the two detail levels proposed is considered. In this configuration it is supposed that pressure drops are the same for each panel, therefore mass flow rates and pressure drops are measured once for all the panels. Another estimation is done in terms of orientation: only one panel type will be compared in terms of orientation, scaling the differences found for the other types.
- With this configuration the sensors list is:
    - (1x temperature meter placed in inlet of the sample panel kind) x 4 orientations + (1x temperature meter placed in inlet of each panel kind) x (N° of panel kinds – 1)
    - (1x temperature meter placed in outlet of the sample panel kind) x 4 orientations + (1x temperature meter placed in outlet of each panel kind) x (N° of panel kinds – 1)
    - 1x pressure sensor + 1x mass flow meter in inlet of the panels ramification
    - 1x pressure sensor + 1x mass flow meter in outlet of the panels ramification
    - 1x temperature meter placed in inlet of the heat pump cold side
    - 1x temperature meter placed in outlet of the heat pump cold side

  TOTAL AMOUNT considering 3 kinds of panel:

    - 14x temperature meters
    - 2x mass flow meters
    - 2x pressure sensors

Main circuit

For what concerns the main circuit, the number of installed sensors can be easily determined. The mass flow is evaluated after the main circuit ramification and in one of its branch (on the other branch, it is calculated as difference from two others). The temperature is then calculated in inlet and outlet of main circuit ramification. In addition, for systems performance evaluation, temperatures are also measured in inlet and in outlet of mGT and heat pump.

TOTAL AMOUNT:

- 2x mass flow meters
- 6x temperature meters

4.2.1.4.2 Sensors description

In this section the meters expected to be used for ENVISION and a short description of their main charachteristics are reported.

Temperature meters

To measure temperatures a thermo-resistance PT 100 is used (Figure 15 and Figure 16). RTD elements are wire-wound or thin film devices that work on the principle of the temperature coefficient of electrical resistance of metals. The electrical resistance of metals varies with temperature. RTDs are positive temperature coefficient sensors, i.e. their resistance increases with temperature. Platinum is characterized by chemical stability and electrical properties which are highly reproducible. Therefore, industrial measuring methods are nowadays based on platinum resistance thermometers. Their abbreviation is „Pt100“ because the value of resistance (fundamental value) is exactly 100 Ω at a temperature of 0 °C. Please, refer to DIN EN 60751 for more details and exact fundamental values for all temperatures between –200 °C (18.52 Ω) and +850 °C (390.48 Ω). Unlike thermocouples, RTDs do not produce electric energy. They require an electrical current to produce a voltage drop across the sensor that can be measured. Thermo-resistances are divided in class A and class B depending on their tolerances.

Figure 15- PT 100 temperature meter class A

PT 100 meter class A specifications	
Probe length	100 mm
Probe diameter	3 mm
Min Temp	-30 °C
Max Temp	+350 °C
Tolerance at 0°C	±0.15 °C

Figure 16- PT 100 temperature meter class B

PT 100 meter class B specifications

Probe length	250 mm
Probe diameter	3 mm
Min Temp	-50 °C
Max Temp	+500 °C
Tolerance at 0°C	±0.3 °C

For surface temperature measurements, thermocouple sensors will be used (Figure 17). One possible choice could be a type K thermocouple. This type is the most common type of thermocouple that offers the widest range of operating temperatures. K-type thermocouple cables typically work in most applications because they have a nickel base and good corrosion resistance. A K-type Thermocouple cable is ideal for testing and development applications and can be used for measuring surfaces, air temperature and liquids. Applications may include detecting air temperatures in refrigerators, freezers and ovens.

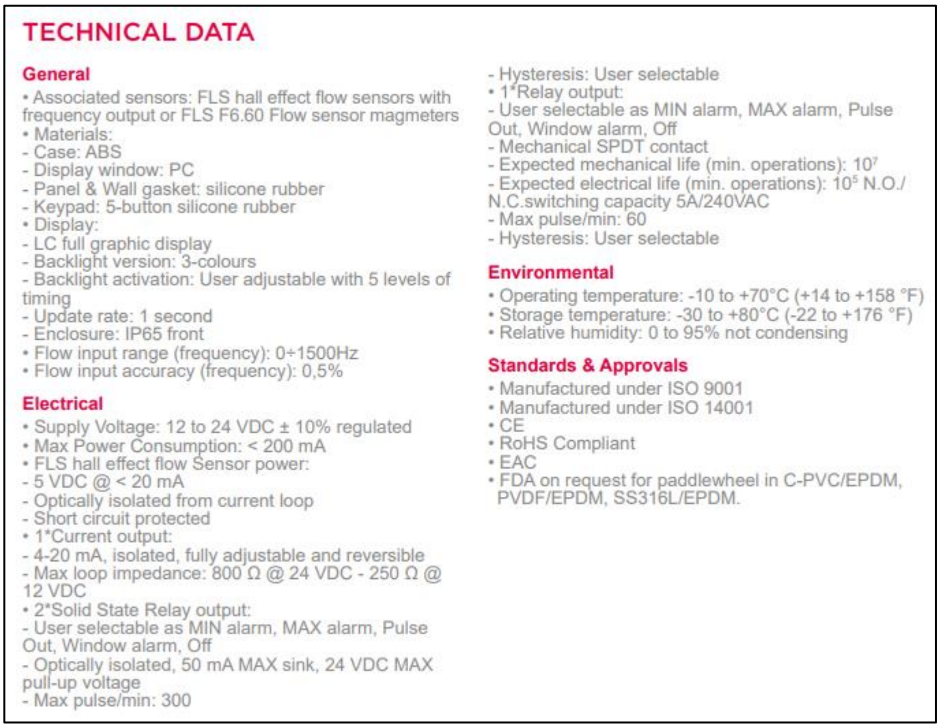
Figure 17- K-type thermocouple

K-type thermocouple specifications

Probe length	2000 mm
Probe diameter	0.3 mm
Min Temp	-50 °C
Max Temp	+400 °C
Tolerance from -45°C to 135°C	±1.5 °C
Response time	0.7 s

Hot water mass flow meter

The mass flow meters currently used in Savona Campus are not anymore available on the market, therefore new sensors will be used. UGT experience leads to choose sensors with the charachteristics reported in Figure 18.



TECHNICAL DATA

General
• Associated sensors: FLS hall effect flow sensors with frequency output or FLS F6.60 Flow sensor magmeters
• Materials:
- Case: ABS
- Display window: PC
- Panel & Wall gasket: silicone rubber
- Keypad: 5-button silicone rubber
• Display:
- LC full graphic display
- Backlight version: 3-colours
- Backlight activation: User adjustable with 5 levels of timing
- Update rate: 1 second
- Enclosure: IP65 front
• Flow input range (frequency): 0÷1500Hz
• Flow input accuracy (frequency): 0,5%

Electrical
• Supply Voltage: 12 to 24 VDC ± 10% regulated
• Max Power Consumption: < 200 mA
• FLS hall effect flow Sensor power:
- 5 VDC @ < 20 mA
- Optically isolated from current loop
- Short circuit protected
• 1*Current output:
- 4-20 mA, isolated, fully adjustable and reversible
- Max loop impedance: 800 Ω @ 24 VDC - 250 Ω @ 12 VDC
• 2*Solid State Relay output:
- User selectable as MIN alarm, MAX alarm, Pulse Out, Window alarm, Off
- Optically isolated, 50 mA MAX sink, 24 VDC MAX pull-up voltage
- Max pulse/min: 300
- Hysteresis: User selectable
• 1*Relay output:
- User selectable as MIN alarm, MAX alarm, Pulse Out, Window alarm, Off
- Mechanical SPDT contact
- Expected mechanical life (min. operations): 10^7
- Expected electrical life (min. operations): 10^5 N.O./ N.C.switching capacity 5A/240VAC
- Max pulse/min: 60
- Hysteresis: User selectable

Environmental
• Operating temperature: -10 to +70°C (+14 to +158 °F)
• Storage temperature: -30 to +80°C (-22 to +176 °F)
• Relative humidity: 0 to 95% not condensing

Standards & Approvals
• Manufactured under ISO 9001
• Manufactured under ISO 14001
• CE
• RoHS Compliant
• EAC
• FDA on request for paddlewheel in C-PVC/EPDM, PVDF/EPDM, SS316L/EPDM.

Figure 18- Mass flow meter specifications

Figure 19- Mass flow meter

Pressure sensors

An example of pressure meter currently used at Savona Campus is shown in Figure 20**Error! Reference source not found.**

For ENVISION application, same kind of probe will be used. It is an analogic output sensor that measures the relative pressure with a precision of ±0.1% and a time response of 10 ms.

Figure 20- Pressure probe

Pressure probe specifications

Supply voltage	From 7 to 28 V
Min Pressure	70 mbar
Max Pressure	4 bar
Accuracy	±0.1%

4.3 Delft's demo site

The Northern Europe demo-site is located in Delft, Vosmaerstraat 4- 50. At this location there is a three story apartment building present with 24 units and four stairwells, built in 1955 and renovated in the 80s. The apartment's average surface is about 70 m^2. The length of the building is 66.02 meters with a width of 11.00 meters. The total plant of the demo site is 726.22 m2.

Figure 21- Delft's demo site geographical position and view from above

The front façade's orientation is of an azimuth of 38 ° to the east from the south orientation. Therefore, it is facing south-east. Except for some trees on a distance variation from 4 to 12 meters- there is hardly any shadow from adjacent buildings, which makes it suitable for the elements of the Envision project.

Figure 22- Delft's demo site front and east façade

The construction of the building is a concrete skeleton, showing a visible grid on the façade. This architectural element was common in the fifties and sixties, when there was little energy consumption awareness. It creates a direct thermal flow from the outdoor to the indoor.

The building was renovated in the eighties. A major element of the renovation is the sandwich panels that fill the concrete grid. The panels have an R_c of 1,25 m^2K/W, which corresponds an high thermal transmittance ($U=0.8\ W/m^2K$) if compared to the maximum U-values defined in the actual energy performance standards.

Figure 23- Proposed design of the Vosmaerstraat 5-40 located in Delft.

The individual natural gas heaters, now located above the kitchen sink will be removed, just like the Individual gas meters and piping. The existing electrical system must be renovated because of the introduction of electrical cooking, solar PV panels, electrical pumps etc. In the basement, next to the staircase there are two open spaces (see Figure 24) available for the installation of new services. The current gas meters and ducts are also located in those areas. Therefore, since the space and connexion is already there and easily accessible for installation and maintenance work, those areas of the building would be suitable for the installation of new plumbing or air ducts for ventilation for the distribution to the apartments,.

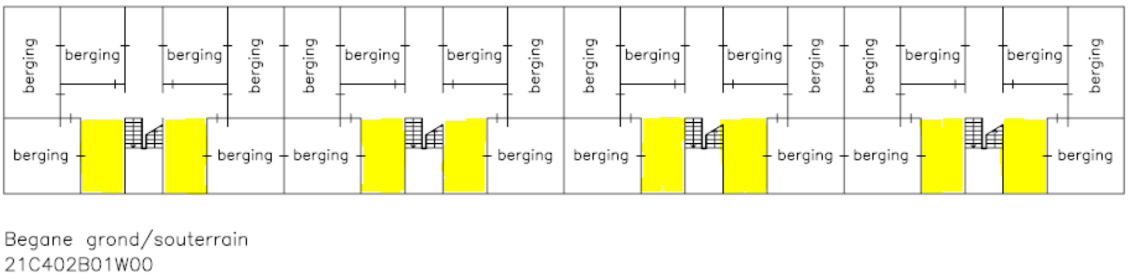


Figure 24- basement layout (open space in yellow).

At the front façade, the heat collectors will be installed below the window frame in order to keep the same window area as before renovation. In both end façades, the existing small windows will be removed and both façades will be covered by new prefab façade elements includingEnvision heat collectors. The total surface of new installation is still being evaluated and depends on the exact partitioning between the open and closed parts of the façade. For this calculation the architectural design has to be completed, including the building permit. However, some estimations have already been made.

The roof of the building is slightly tilted and with a surface of about 500 m^2 suitable for the installation of PV panels (+/- 300 solar panels, 14 panels per apartment). Since the PV glass solution from NSG, limits the view out, it is not suitable for placement in the windows of the apartments. However, the stairwells have stacking glass windows, covering the full width and height of the façade as it can be seen in the Figure 25. This glass will be replaced by the PV glass solution of NSG. It is a suitable place for this technology, because the light will be able to get in to the staircase, but since it is not a occupied area, a partially limited view out is accetable. Both standard PV and the PV glass are going to produce the electricity for the HP and the household consumption.

Figure 25- Back façade of the Delft demo site

The building will be also connected to the electric grid, in this way, the production of electricity which is not directly consumed will be exported to the grid and, when the PV panels do not harvest enough energy to keep up with the demand, electricity will be imported from the grid. Furthermore, the city of Delft is working on a grid of sustainable city heat networks. This project is in the early stages of evaluation and may take at least ten years to be completed. As soon as such a network is available, a connection can be made.

Energy demand and use calculation are reported in the “APPENDIX A”.

4.3.1.1 Intervention description - concept

The 24 apartments of the building are divided in 8 groups of 3 apartments that have a joint entrance, staircase and basement as in can be seen in the Figure 40 below. Therefore, the energy system, will be design for one staircase group and replicated in the other ones.

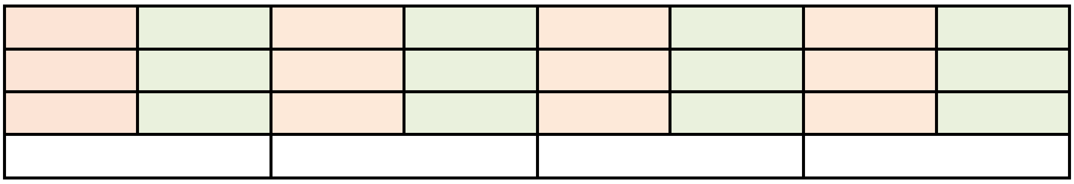


Figure 26- Apartment groups that share entrance and basement

The overall concept consists of electrical and thermal harvesting elements, water to water heat pumps (collective or individual) to increase the temperature, an electric heater as a back-up system and (under evaluation) a heat ground exchanger and vessels for heat storage. Therefore, a gas free system, that is in line with European and Dutch objectives to diversify the energy sources while decreasing the gas dependency. The delivery sets are standard equipment that provide both heat for space heating (SH) and heat for domestic hot water (DHW).

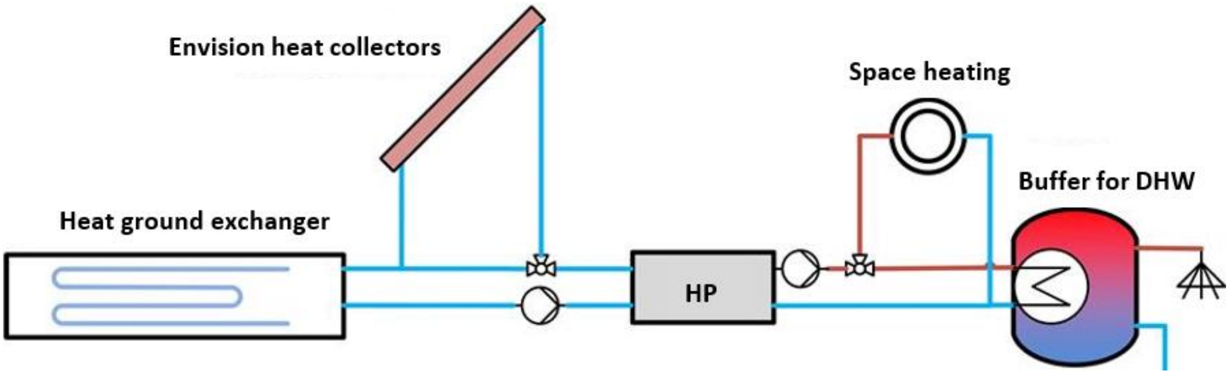


Figure 27- Simplified energy installation scheme for Delft demo site

As stated before, the overall installation concept is in progress and the final configuration may be subject to changes. At the moment two scenarios (see Figure 28 and Figure 29) are considered based on the first sensitivity analysis based on the following parameters:

- Energy efficiency
- Initial investment
- Complexity
- Implementation of Envision technology
- Maintenance costs
- Replicability
- Accessibility
- Area usage.

These two scenarios are further analysed to assess which one would adapt to the Envision technologies, the tenants needs and where monitoring at components level applies:

- Collective heat pump located in the basement
- Individual heat pump located inside the apartment of the tenants

In order to make a decision between these two scenarios, further and more detailed analysis will be done. For these, the previous sensitivity parameters will be used , in addition to the scope of legislation barriers and noise generated by the equipment. For this purpose BAM Energy System will execute dimensioning and economic calculations. At the same time, EDF will carry out further simulation in order to validate and assist calculations with furhter detail.

The thermal energy storage is needed in the ENVISION concept in order to temporarily store the excessive heat produced and have enough energy available for the daily/weekly/seasonal consumption. The final configuration is still under evaluation, for the monitoring plan the configuration considered in the concept phase is assumed (ground loop and a collective vessel).

Two different scenarios has been taken into account in order to better understand the Envision techonologiy performances. These scenarios are following showed in the Figure 28 and Figure 29.

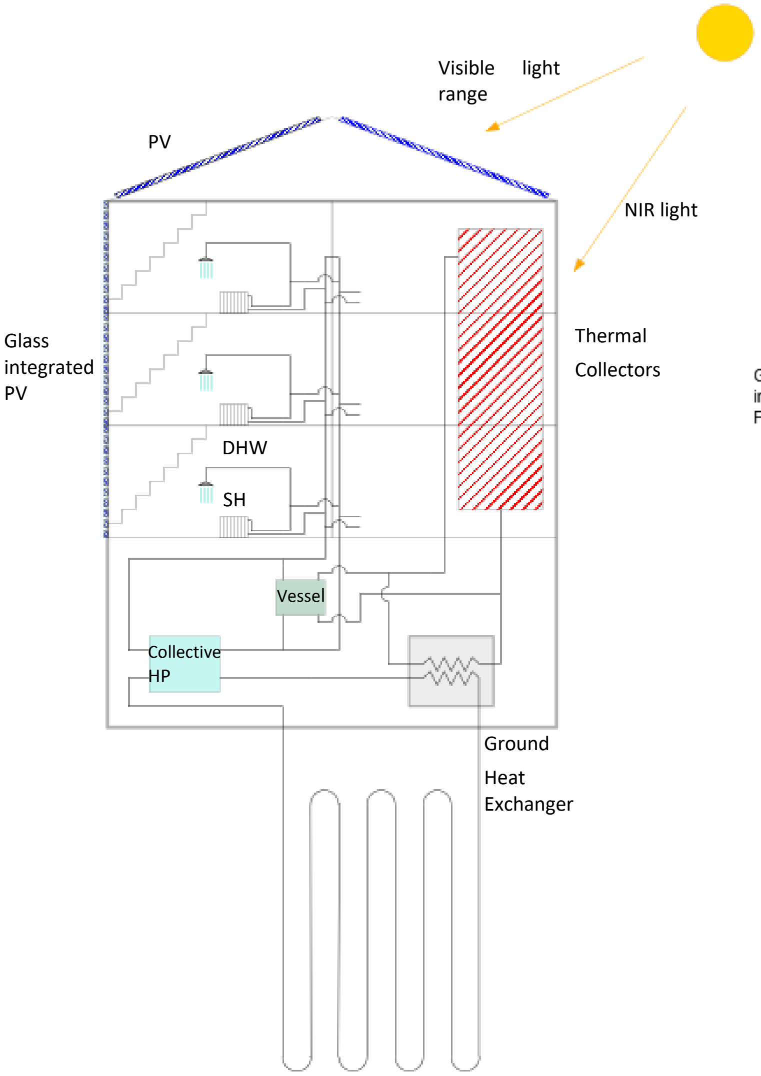


Figure 28- Envision concept for Delft with collective high temperature HP

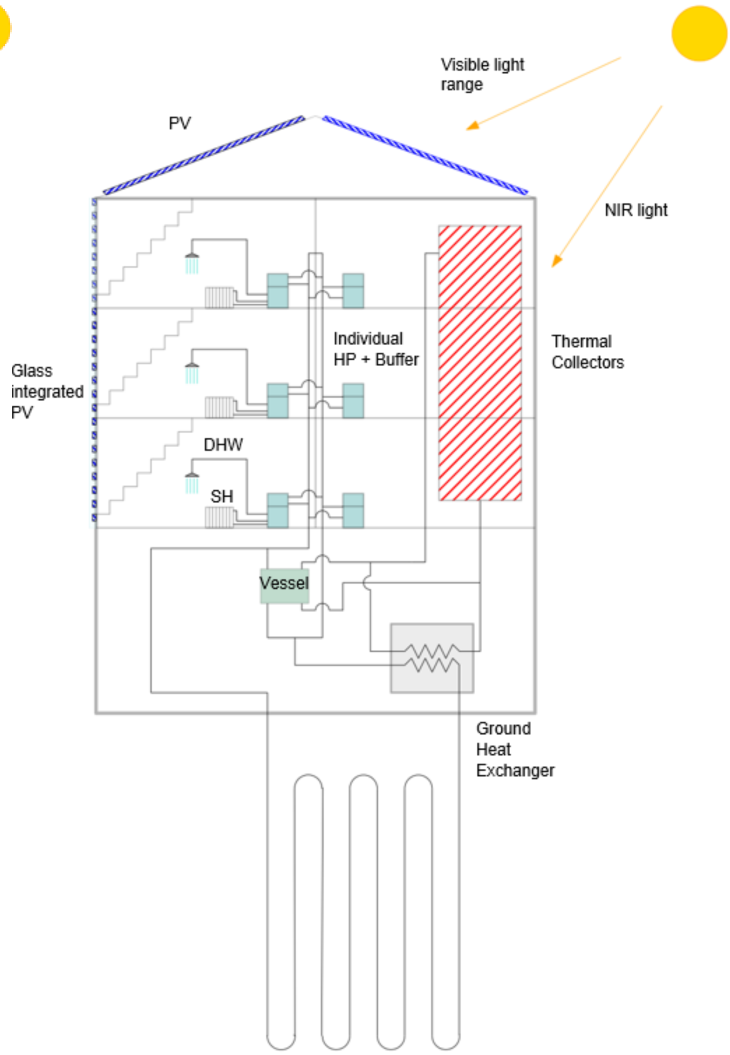


Figure 29- Envision concept for Delft with individual HP

4.3.1.2 Comparison of elements within the energetic concepts

This section deals with the comparison between centralized plant and independent plant configuration. Strengths and weaknesses of these two alternative are highlighted. The two different plant layout are illustrated in the following schemes:

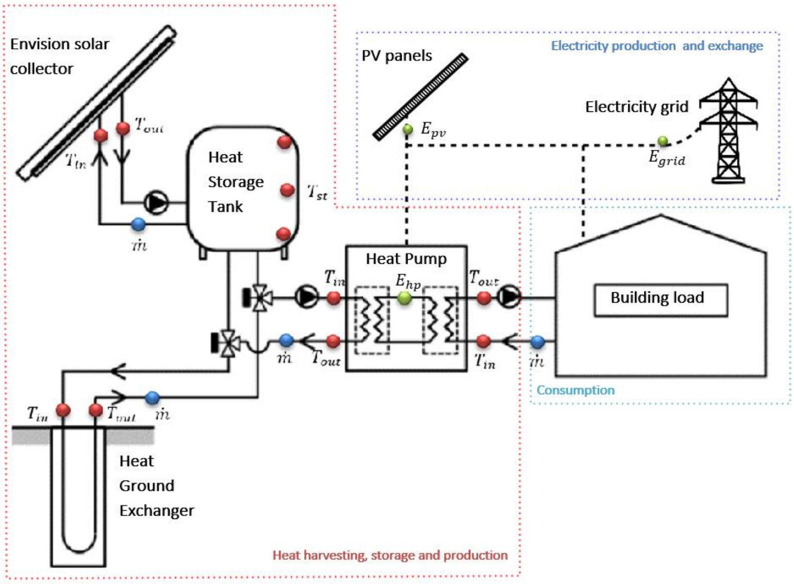


Figure 30- Plant system and measured points for collective scenario

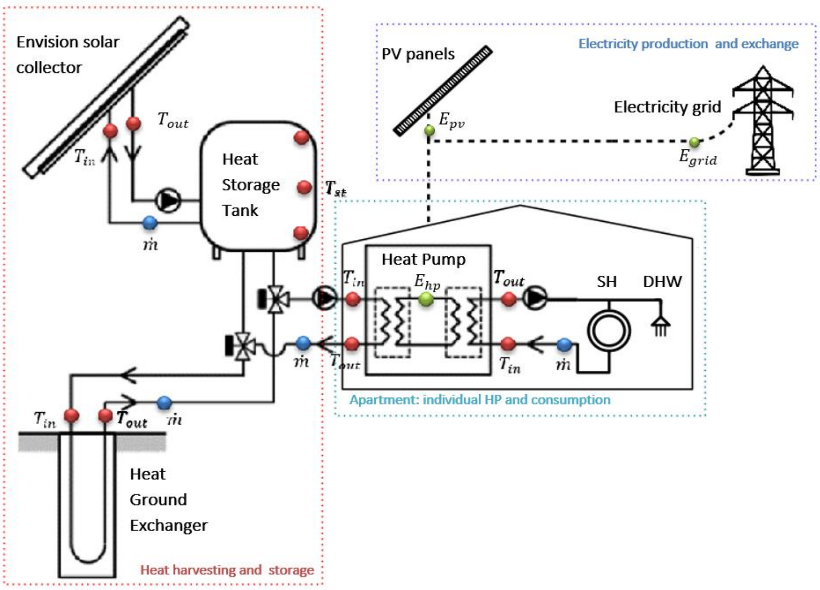


Figure 31- Plant system and measured points for individual scenario

Heat pump

The *centralized* solution has a better accessibility and less area usage, but the energy efficiency is not as high because significant heat losses would take place, due to the transportation of high temperature water to different levels of the building.

The *individua*l HP approach is energetically more efficient and more suited for the each apartment's needs. However, space for the installation of the HP has to be available inside the apartment. As a result, the maintenance of the HP could be difficult by the reduced accessibility. Furthermore, some noise complaints could arise from the tenants.

Ground Heat Exchanger

It could be used as a seasonal storage. In other words, as a heat storage in summer for the overproduction of heat from the thermal collectors and then as a heat source for the heat pump when the heat production of the collector is low in winter.

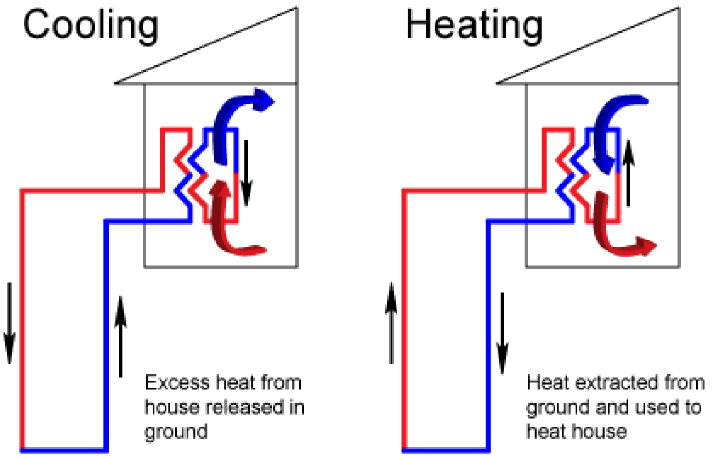


Figure 32- Ground heat exchangers seasonal modes

In case that there is need for cooling, the heat ground exchanger could be used for free cooling at night.

Collective Storage

A vessel located in the basement could be used for daily collective storage in order to store the heat produced during the day to use it in the evening or morning, when usual DHW and SH demand increase.

Electrical back up booster

This component is primarily used for control of the temperatures and make them compatible with the Envision technology and the HP ones.

The heaters can also be used as a back-up system in case there is a failure in the techniques or when the HP is not able to deliver enough heat (for instance, due to bad weather conditions).

Ventilation system

A mechanical ventilation will be introduced during renovation. A dedicated Outdoor air system with heat recovery will be probably placed in the attic. The hot exhausted air from the kitchen and the bathroom will be extracted and transported to the attic. Through a heat exchanger the heat from the exhaust air will be transferred to the fresh and cold air from the outside. Therefore, the space heating demand of the houses will be lower, thanks to the pre-heating of fresh clean air before introduced to the living rooms and the bedrooms.

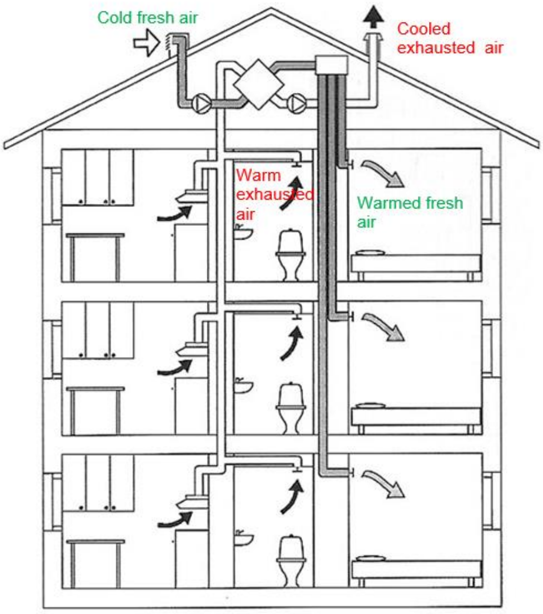


Figure 33- Ventilation system with heat recovery

4.3.2 Key validation activities

The main goal of this demo site is to test the adaptability and performance of the ENVISION concept to an existing residential building. Therefore, is it very important to measure the total demand of energy in the building, as well as the local production of energy by means of ENVISION technologies. At the same time, as demand and production may not happen simultaneously it is interesting to analyze the self-consumption and the energy storage performance combined with an external source as the grid. In order to check if the indoor comfort levels are met, indoor air variables will be monitored. Addittionally the air fresh change rate will be monitored to evaluate benefits of the dedicated outdoor air system.

More specifically, to assess the system performances the following parameters will be monitored:

- Energy demand
- Harvested energy
    - Thermal energy
    - Electrical energy
- Electricity exchange with the grid
- Electricity exchange with the grid
- Heat pumps performance
- Stored heat
    - Outdoor conditions
    - Indoor conditions.

Heat exchanged

Heat flow is one of the most important system parameters. The systems where it will be evaluated are following listed:

- Façade solar panels
- Heat pump cold side
- Heat pump hot side
- Storage heat in the ground

In order to measure the heat flow, it is necessary to evaluate temperature and mass flow values. Then the heat flow will be obtained as in:

$$\dot{Q} = \dot{m} * c_p * (T_{out} - T_{in})$$

Where c_p is the specific heat for the considered fluid, in this case water with glycol.

Electricity production and exchange with the grid

PV integrated glass and standard PV panels are going to generate electricity locally. The electricity will be used by the HP, pumps and devices in the apartments. When the consumption is lower than the production of the PV, the exceeding electricity will be provided to the grid. At the same time, electricity will be taken from the grid connection when the production is lower than the demand. The electricity production will be measured in kWh by a 3 phase meter in the inverter and the grid exchange will be measured in the smart meter.

Heat pump performance

Several information can be obtained from heat pump:

- Consumed electricity (kWh)
- Operational mode (stop/heating/legionella)
- Space heating delivered (GJ)
- Set point temperature (°C)
- Indoor temperature (°C) (in order to active the HP)

Indoor air conditions

CO_2 level will be measured in order to monitor air quality. This measurement will be used also to monitor the occupancy in the rooms and for the activation of the ventilation system. Therefore it would be possible to evaluate the adaptability of the Envision technologies to different tenants behaviours.

Weather conditions

Weather data is taken from an open source nearby weather station. However, due to the demostration nature of this project weather station will be place in the building, in order to measure the following points:

- Solar influx or irradiance on the building
- Outdoor temperature
- Wind speed
- Humidity conditions of the air

Thermal loss throughout piping

In order to manage the complete energy balance in the building, the heat losses through piping will be monitored.

4.3.2.1 Baseline assessment

Measurements will take place before the renovation in at least two apartments, so as to evaluate indoor air quality and comfort before and after renovation as well as energy consumption. Ideally, one will be located on the top corner and one between other apartments. However, this will depend on the cooperation of the tenants, since they have to agree and volunteer in order to obtain the permission to monitor their homes . The sensors are intended to be place on January 2019 and will measure for a period of one year before renovation. Once the renovation has taken place, the measurements will continue for another whole year, so as to compare both scenarios.

In order to analyse indoor air quality and comfort, temperature (T), relative humidity (RH) and CO_2 levels will be measured in the liveable areas; thus, living room and main bedroom. People spend most of the time indoor in these areas and therefore comfort is very important there and additionally CO_2 levels can be rise significantly.

In the so called wet areas (kitchen and the bathroom), the temperature (T) and relative humidity (RH) will be measured. Additionally, in the kitchen fine dust (PM) will be measure. This is often created while cooking and it is harmful for the health of the tenants if it is not extracted well by ventilation. People do not usually expend a long time in these areas but when they do, air quality and conditions are changed rapidly (due to hot water evaporation and cooking).

Needed equipment

- Sensors*
    - Living room (T, RH, CO_2)
    - Main bedroom (T,RH, CO_2)
    - Kitchen (T , RH, PM)
    - Bathroom (T, RH)
- Gateway (data collection) & 4G modem (connectivity with BA platform)

*Standalone (Change battery every 6 months)

Location

- Sensors:
    - In an inner wall (Away from the window and door , height 1,5m)
- Gateway and 4G modem
    - Meter kast (fuse box)

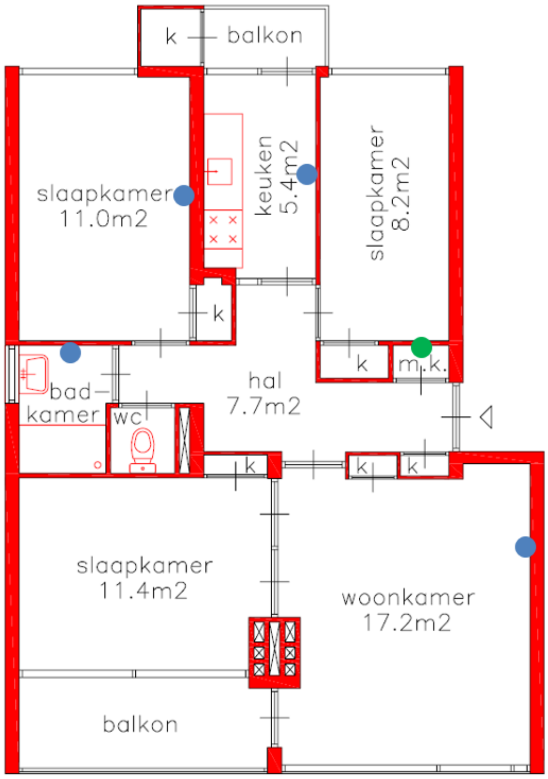


Figure 34 : Placement of monitoring equipment in an apartment layout

4.3.2.2 Building management system

The SLA (Service Level Agreement) describes services that apply within the BAM 'zero-by-meter' propositions and 'almost energy neutral buildings' in the residential sector; i.e. renovation and new construction. The product requirements are based on the monitoring and control infrastructure needed to manage the performance, services and feedback for the user and for BAM Energy Systems. This infrastructure must make data available so that continuity, accessibility and data enrichment are possible, in addition to the management of the installations. The monitoring and control infrastructure is applied to BAM installations, so integration with these installations is of great importance. The following components are part of the infrastructure:

- Sensors for measuring energy flows
- Interfaces with installations such as heat pumps, inverters buffers and ventilation installations.
- The gateway (hardware for data collection, platform for local software and access).
- Communication infrastructure between different installations (local), between different modules up to the data access point (data transmission via m2m, 4g or other solutions).
- Access to data transmission hardware.
- Accessing data from the data acquisition platforms to BAM backend.

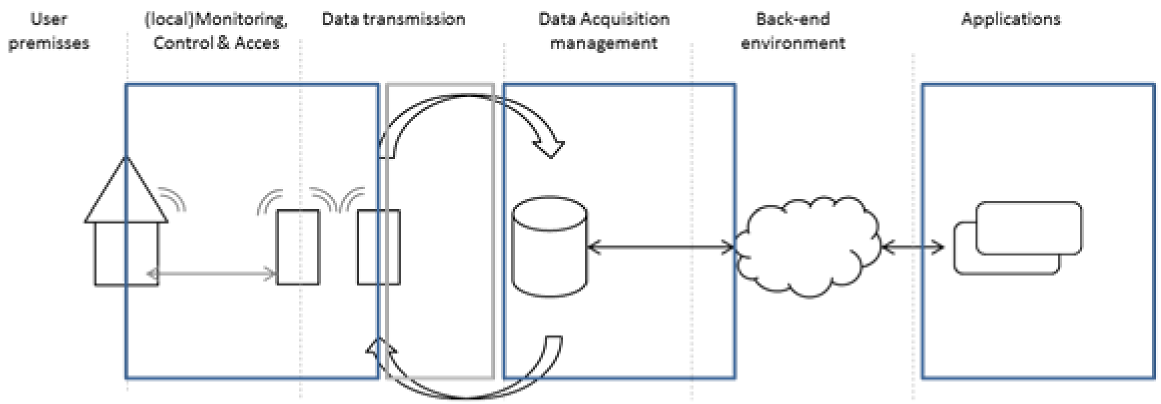


Figure 35- Schematic representation of infrastructure

A distinction is made on the basis of the various services provided in this SLA. The basic service is the managed gateway service. Additional services consist of a dashboard for user feedback and possible other future services.

The sensors and switchgear are integrated as much as possible in a control cabinet. The function of the gateway is the connecting factor between the sensors and the data platform. The Gateway must therefore support a number of protocols and interfaces:

- Standard: DSMR 4.0 (p1 port), Modbus (RS485), Wireless Mbus, Ethernet (RJ45)
- Wifi, 3 or 4G, Zigbee, ZWave (additional options)

The gateway solution must be flexible in order to be able to integrate possible additional options (possibly as hardware extension). In addition, the standard EEBus must be supported from the Gateway software.

BAM Building Analytics makes use of the SkySpark platform. This application automatically analyzes data from automation systems, metering systems and other smart devices to identify issues, patterns, deviations, faults and opportunities for operational improvements and cost reduction. SkySpark is an open platform enabling data from a wide range of sources to be continuously analyzed. Combining an extensive library of standard analytic functions and custom analytics developed by BAM, BAM Building Analytics allows to capture their knowledge in "rules" that automatically run against the data produced by equipment systems. BAM Building Analytics tells operators what they need to know about the performance of their systems. It can be used in many ways including:

- database for real-time and historical sensor data
- crunching sensor data and applying data transformations
- analytics of sensor data
- visualization of above

Main analytic applications are reported as follows:

- portfolio level analysis: performance of a portfolio of buildings against energy and other KPI's
- systems level analytics: relationships between systems across different weather or load conditions
- equipment level analytics: identifying faults in the operation of specific pieces of equipment

Where BAM Building Analytics really shines is its ability to analyze time-series data from sensors and control systems. Once you have modelled your system and imported the data, BAM Building Analytics provides a suite of tools to write functions to query the data and apply data transformations such as rollups and normalizations. One of the most powerful features is the ability to crunch through your data looking for conditions which matter most, such as equipment failures or non-optimal operation.

SkySpark includes a rich set of applications to visualize your data and analytic results. All of these intuitive presentations are displayed in a standard web-browser using HTML5 technology – no plug-ins are required. SkySpark can also output analytic results to third party applications via open, published API's.

Figure 36- SkySpark's Apps

Some of these interesting APPs are the following ones:

<u>SiteSpark App</u>
Shows analytic results as timelines and bubble charts showing timing, duration, frequency, and cost of issues.

Figure 37- Charts from the SiteSpark App

KPI App

Automatically calculates key performance indicators and presents them in “candle charts”.

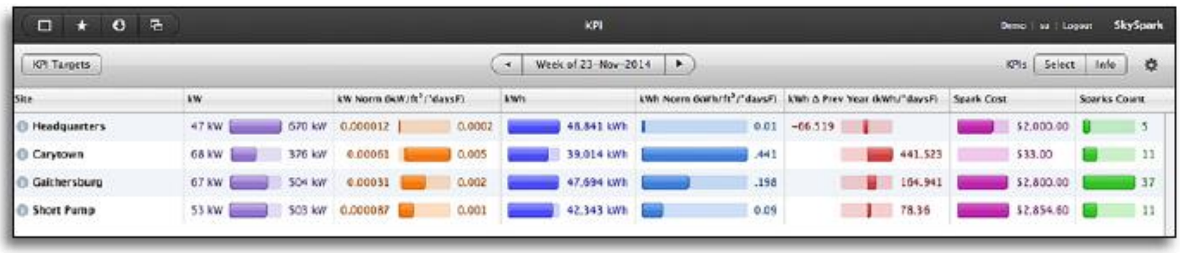


Figure 38- Chart from KPI App

Energy App

Provides a comprehensive suite for analysis of energy resources including electrical demand, consumption, cost, as well as water and gas usage. The unique Operations view automatically aligns energy usage data with equipment operational status showing you exactly how your equipment systems are affecting energy use.

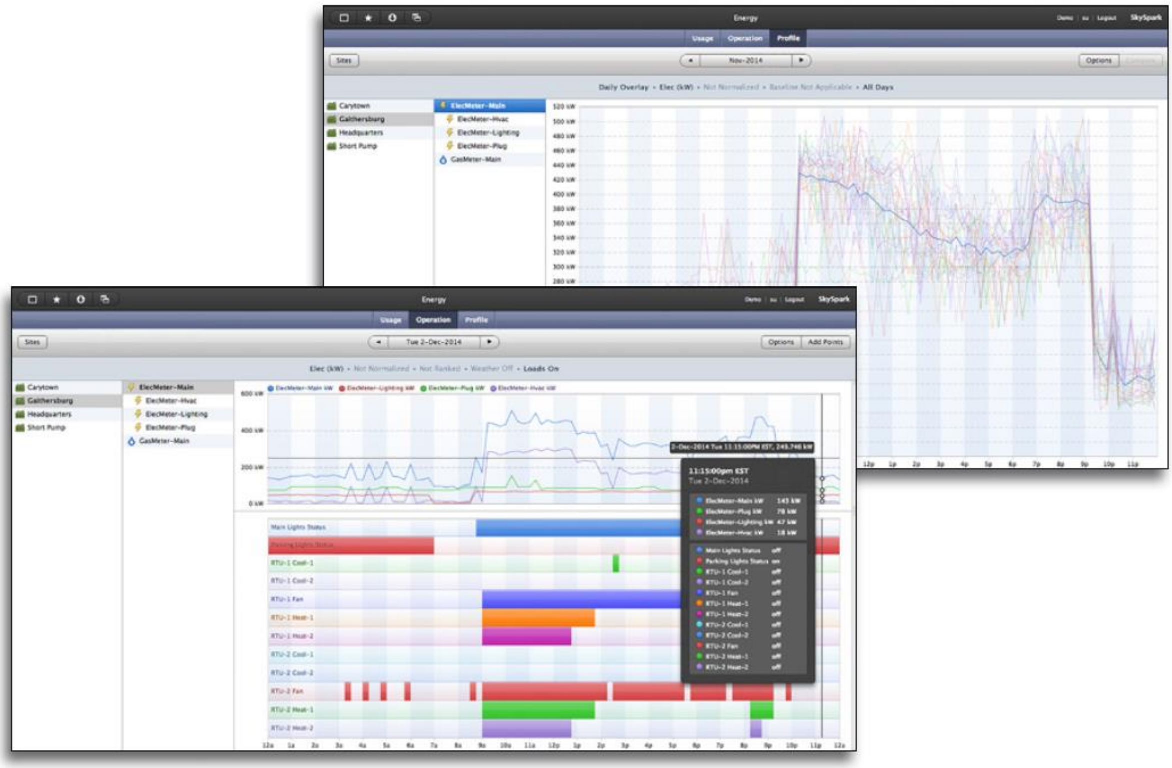


Figure 39- Charts from the Energy App

4.3.2.3 KPI List

Please refer to the Appendix C for the complete list of KPIs that will be calculated for Delft demonstrator.

4.3.3 Complete list of sensors/meters

This is the list of sensor that are planned to install in the building in Delft in order to monitor and evaluate the performance or Envision technologies and the concept as a whole in an actual apartment building:

- Temperature (°C)
    - Temperature meters for water
        - HP : inlet and outlet condenser and evaporator side
        - Thermal collector: inlet and outlet of a ground of collectors
        - Storage tank: in three levels
        - Ground Heat Exchanger: inlet and outlet
    - Temperature meters for air
        - Indoor (next to the thermostat)
    - Surface temperature (PV glass) , maybe just staircase temperature
- Flow meters (m^3/h)
    - Water
    - Air
- Energy meters (GJ)
    - Space heating delivered
    - Solar collectors produced
    - Heat exchanged in the ground
- Electric meters (kWh)
    - PV panels in the roof
    - PV glass in staircase
    - HP consumption
    - Water pump consumption
    - Mechanical ventilation consumption
    - Household device consumption
- Outdoor weather station
    - Irradiance (w/m2)
    - Temperature (°C)
    - Wind Speed (m/s)
    - Relative humidity (%)
- Indoor air quality
    - CO2 level (ppmv/m^3).

4.3.4 Characteristics of sensors/meters

- Temperature (°C)

ø5.8 temperature sensor

Technical data on temperature sensors

	Direct short temperature sensor	ø5.8 mm temperature sensor
Element	Pt500 according to EN 60751	
Time constant τ0.5	2 s	5 s
Minimum submersion depth	17 mm	22 mm
Diameter	ø3.6 MM/ø5.5 mm	ø5.8 mm
Material	AISI 316L, W-no. 1.4404	
Silicone cable	2 x 0.25 mm²	
Cable lengths	1.5 m, 3 m	1.5 m, 3 m, 5 m, 10 m

- Flow meters (m3 /h)

MULTICAL® 21/flowIQ® 2101 is a hermetically closed compact static water meter intended for the registration of cold and hot water consumption. The water meter uses the ultrasonic principle and has been constructed on the basis of Kamstrup's experience since 1991 with the development and production of static ultrasonic meters. MULTICAL® 21/flowIQ® 2101 has been subjected to a very comprehensive OIML R49 type test with a view to securing a long-term stable, accurate and reliable meter. One of the water meter's many advantages is the fact that it has no wearing parts, which entails longevity. Furthermore, the meter has a low-flow cut-off (start flow) of only 2 l/h for Q3 = 1.6 m³/h and 2.5 m³/h and 3.2 l/h for Q3= 4.0 m³/h, which provides accurate measurement also at low water flows.

Accuracy MPE (maximum permissible error) MPE according to OIML R49 Meter approved 0.1…30 °C ± 5 % in range Q1 ≤ Q < Q2 ± 2 % in range Q2 ≤ Q ≤ Q4 At 30 °C < t < 70 °C ± 5 % in range Q1 ≤ Q < Q2 ± 3 % in range Q2 ≤ Q ≤ Q4

Accuracy

MPE (maximum permissible error)

MPE according to OIML R49

Meter approved 0.1...30 °C

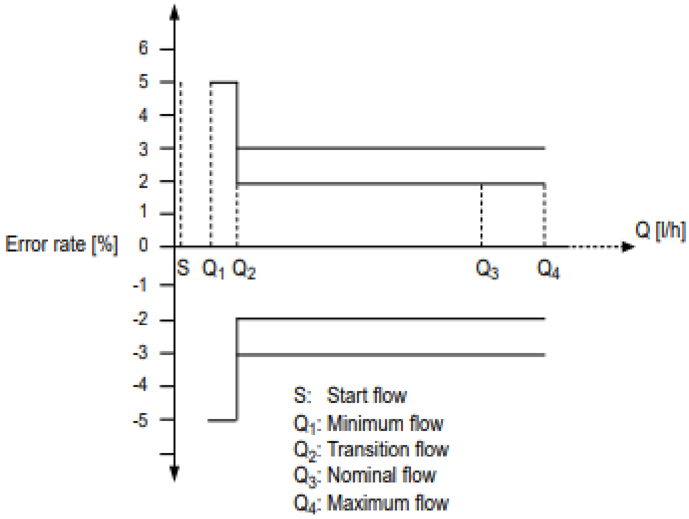
± 5 % in range $Q_1 \leq Q < Q_2$

± 2 % in range $Q_2 \leq Q \leq Q_4$

At 30 °C < t < 70 °C

± 5 % in range $Q_1 \leq Q < Q_2$

± 3 % in range $Q_2 \leq Q \leq Q_4$



- Energy meters(GJ)

  MULTICAL® 602 calculates energy based on the formula in prEN 1434-1:2009, in which the international temperature scale from 1990 (ITS-90) and the pressure definition of 16 bar is used.

  The energy calculation can in a simplified way be expressed as:

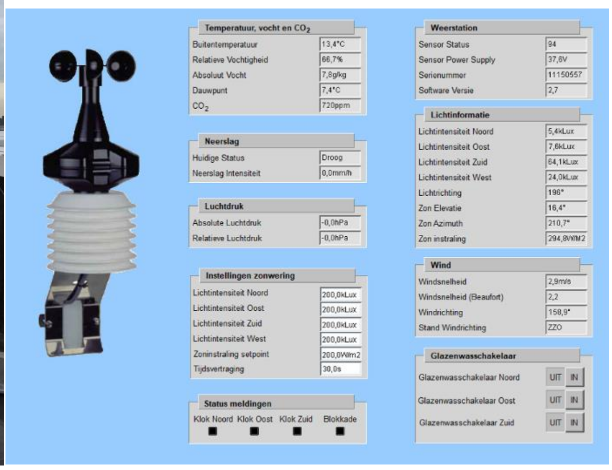
  Energy = V x ΔTx k.

  - V is the supplied water volume
  - ΔT is the temperature difference measured
  - k is the thermal coefficient of water

  The calculator always calculates energy in [Wh], and then it is converted into the selected measuring unit.

- Electric meters (kWh)

- Outdoor weather station
  Thies Clima sensor, type WNHTF
  - Irradiance (w/m2)
  - Temperature
  - Wind Speed (m/s)
  - Relative humidity (%)



- Indoor air quality

Indoor Air Quality Detector: HWM-MAQ Green Building Series Š

- PM2.5
- PM10
- CO_2
- TVOC
- air temperature
- relative humidity

Number of sensor

The number of sensor will differ depending on the final decision of the energetic system. The individual concept will require more sensor due to the fact that will be composed by more installations. The table below show the estimation of the amount of sensor for both possible scenarios.

Apart from the sensor for the energy installation and the indoor conditions, one weather station will be place in the rood in order to evaluate the performance of the system in different conditions.

Concept / Component	Parameter	Differentiation	Unit	Timest	Sensor	Nr. / Collective	Nr. / Individual
Envision solar collectors	Temperature	Inlet	°C	15 min	Temperature probe	8	8
		Outlet	°C	15 min	Temperature probe	8	8
	Flow		m^3/hour		Flow sensor	8	8
	Produced heat		GJ		Indirectly calculated		
Heat storage tank	Temperature	Upper layer	°C	15 min	Temperature probe	8	8
		Middle layer	°C	15 min	Temperature probe	8	32
		Lower layer	°C	15 min	Temperature probe	8	8
Heat pump	Temperature	Inlet generation	°C	15 min	Temperature probe	8	24
		Outlet generation	°C	15 min	Temperature probe	8	24
		Inlet consumption	°C	15 min	Temperature probe	8	24
		Outlet consumption	°C	15 min	Temperature probe	8	24
	Flow	Inlet generation	m^3/hour	15 min	Flow sensor	8	24
		Outlet consumption	m^3/hour	15 min	Flow sensor	8	24
	Electricity consumption		kWh	15 min	kWh Meter	8	24
	Heat generated		GJ		Indirectly calculated		
Building load	Setpoint temperature		°C	15 min		24	24
	Actual temperature		°C	15 min	Temperature probe	24	24
	Heat delivered		GJ	15 min	Indirectly calculated	24	24
	Electricity consumption		kWh	15 min	Indirectly calculated	24	24
Ventilation	CO_2 level	living room	ppm/m^3	15 min	CO_2 meter	24	24
		bedroom	ppm/m^3	15 min	CO_2 meter	24	24
Boiler	Temperature	Outlet	°C	15 min	Temperature probe	8	24
	Electricity consumption		kWh	15 min	kWh Meter	8	24
Outdoor weather conditions	Irradiance		W/m^2	1 hour	weather station	1	1
	Temperature		°C	1 hour	weather station	1	1
	Wind speed		m/s	1 hour	weather station	1	1
	Relative humidity		%	1 hour	weather station	1	1
Heat ground exchanger	Temperature	Inlet	°C	15 min	Temperature probe	8	8
		Outlet	°C	15 min	Temperature probe	8	8
	Flow		m^3/hour	15 min	Flow sensor	8	8
PV panels	Electricity production		kWh	15 min	kWh Meter	8	24
	Electricity grid exchange		kWh	15 min	kWh Meter	8	24
PV glass	Electricity production		kWh	15 min	kWh Meter	8	24
	Electricity grid exchange		kWh	15 min	kWh Meter	8	24

Table 11: Number of sensor per scenario

4.4 Pilkington demonstrator

Pilkington set the target to implement the Pilkington Sunplus™ BIPV Technology into a Pilkington Building for the Envision project. After the evaluation of the potential of refurbishment of the building at “De Hoeveler 25 – 7547 SB ENSCHEDE” in the Netherlands which had negative outcome due to the cost of the renovation (general poor performances for the entire envelope of the building, including roof and floors) the Pilkington management decided to renovate the front façade of the Pilkington Austria office. The location of the building is Bundesstraße 24, 5500 Bischofshofen, Austria

Figure 40- Pilkington Austria location and office façade

4.4.1.1 *Intervention description*

The current façade has been installed in 1992 and includes double glasses (4mm – 16mm – 4mm) with U value of 1,5 W/m^2. The poor insulation causes high heating costs during winter, too much solar heat during the summer and generally a poor comfort for the occupants. The refurbishment of the façade offers also the opportunity to create a NSG “Showroom Façade” for Architects, customers and other market partners and an “Experience Center” to learn more about our Pilkington Sunplus™ BIPV. In addition, considering that the Pilkington Sunplus™ BIPV technology is tested in ENVISION in The Netherlands at Solarbeat the Pilkington Austria office allows to test the PV glass in a central European location.

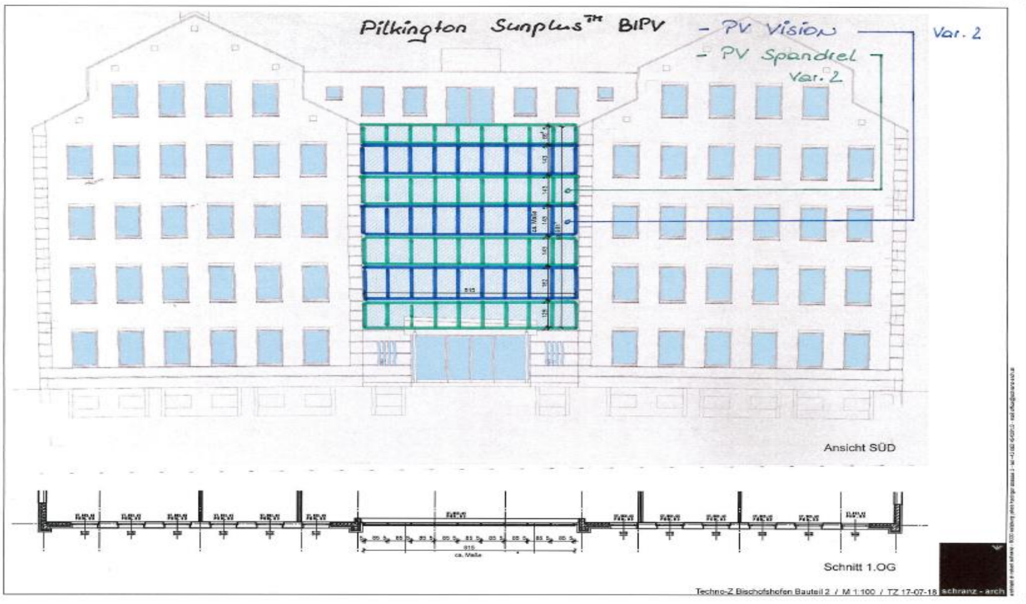


Figure 41- Pilkington Austria layout of the façade renovation project

The front façade of the Office Pilkington Austria to be renovated is oriented to about 171° south-east and in the final configuration will include the following elements:

- 27 pieces (9- 800 x 1600 mm and 18 - 800 x 1420 mm) of Pilkington Triple Sunplus™ 51% Coverage – about. 32 m² Pilkington Sunplus BIPV Vision in 9,5 mm - 12 mm SZR -   Pilkington Low E Pro-T S3 - 6 mm -   12 mm SZR -   Pilkington Optitherm S3 6 mm - to be manufactured by Pilkington Enschede
- 36 pieces (9-800 x 1260 mm, 18 -800 x 1430 mm and 9-800 x 860 mm) of spandrels - abt. 36 m² - full black monocrystalline - Solar Strings width about 10 mm
- Frames: supplied by Wicona GmbH - Pirching 90, A-8200 Gleisdorf - Model Wictec 60

Figure 42- Proposed layout of the frame

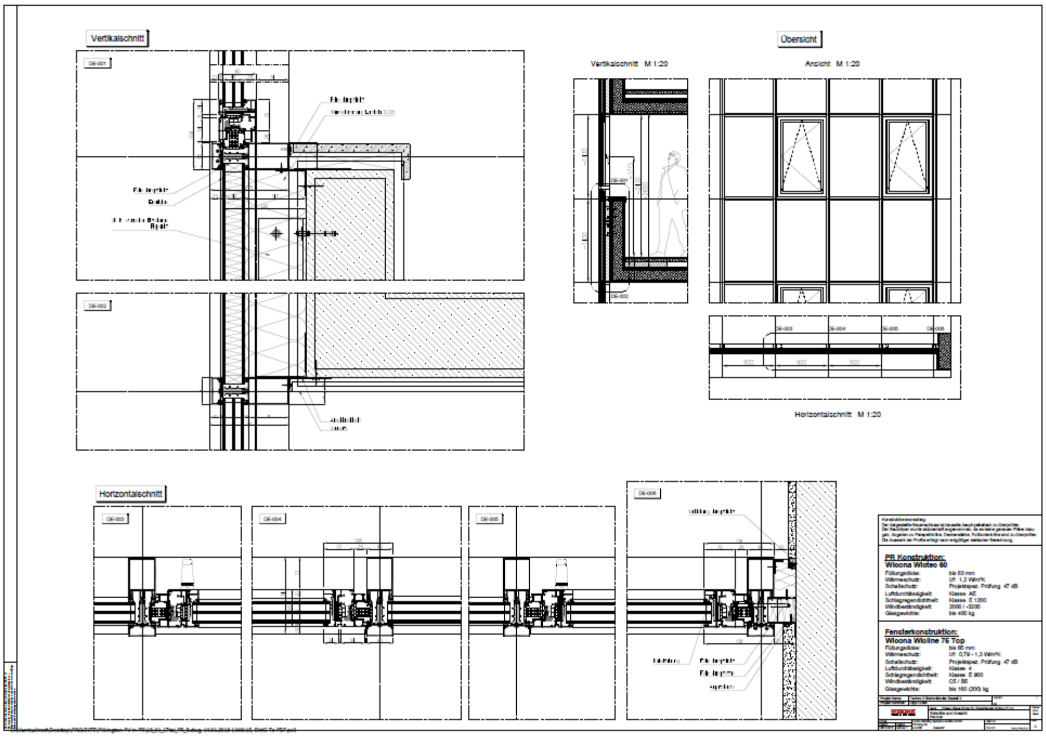


Figure 43- Layout and details of the new façade

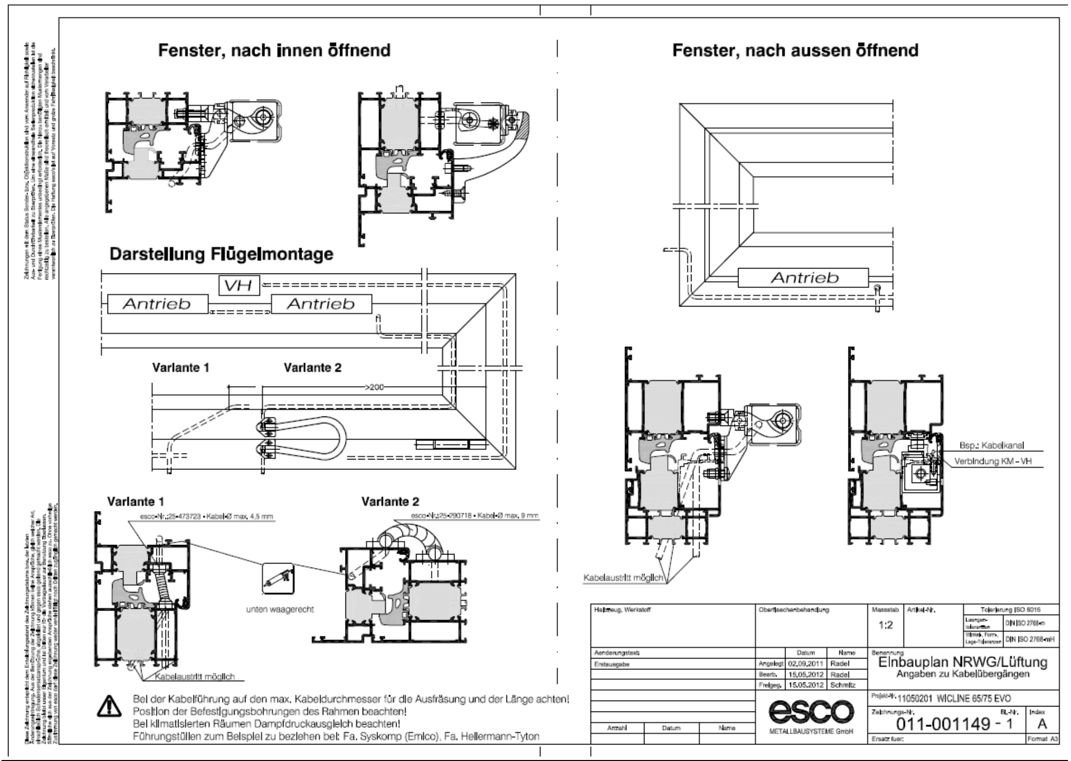


Figure 44- Deatails of the frzme of the new façade

4.4.1.2 Measurements and sensors

Because the parameter Performance Ratio (PR) is a defined as the division between actual energy yield and irradiance on the so-called Plane-Of-Array (POA), both parts of that division need to be measured.

As mentioned, the DC measurement of electrical power and yield would normally beyond the scope of WP5.1 (too much monitoring). It is described in the experimental setup of WP3.1.

For the AC measurement we like to rely on the monitoring software of the inverter of choice. At the moment of writing this inverter has not been chosen yet. As example, we show a screenshot of the monitoring of another project at SEAC-SolarBEAT that makes use of SolarEdge. In the following figure it is possible to see an example of monitor Portal.

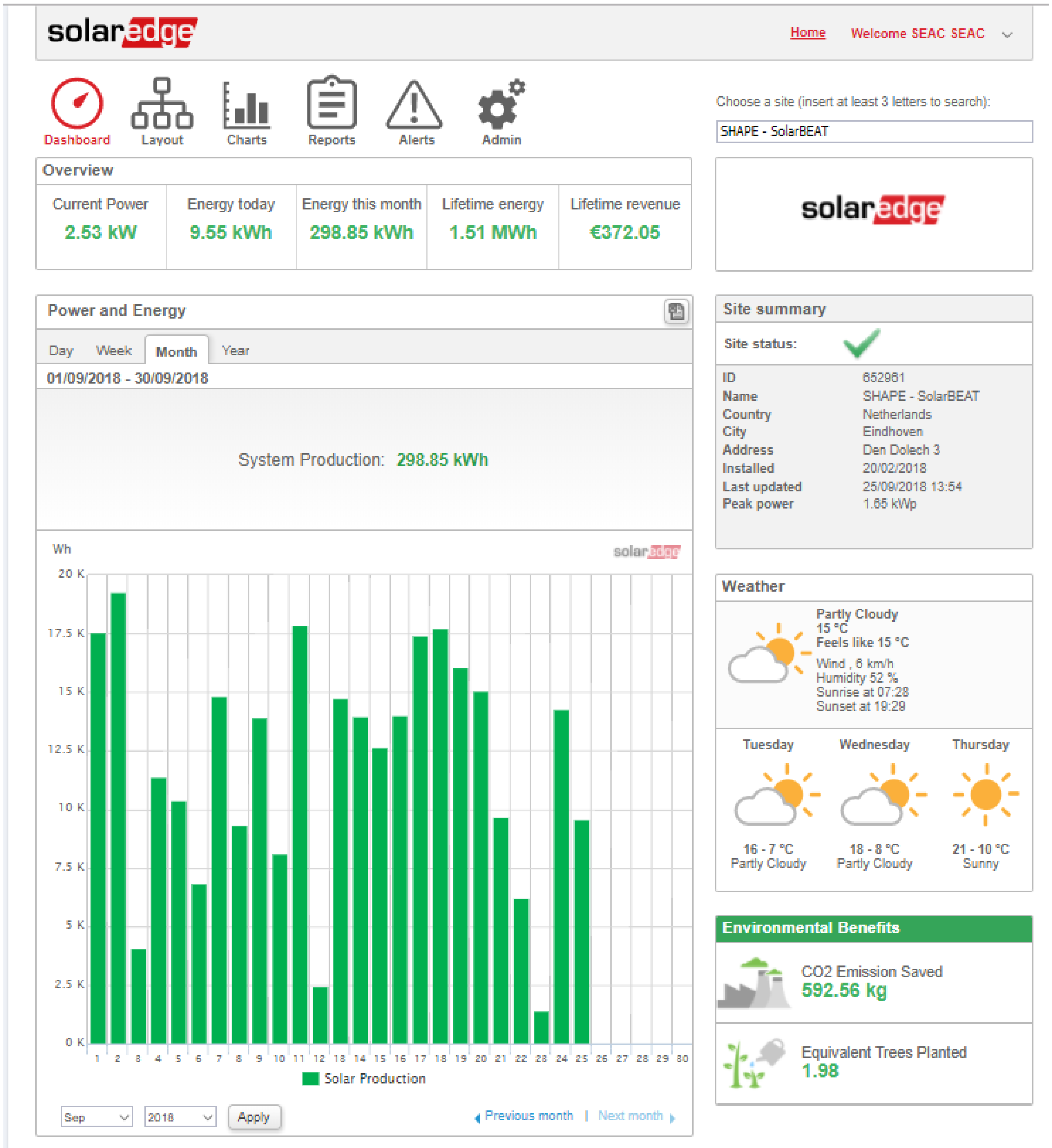


Figure 45: Screenshot of Monitor Portal. SolarEdge taken as an arbitrary example.

In the unlikely event that this option is not available, then we recommend to install an AC-kWh meter. TNO-SEAC would prefer the kWh-meter of company UPP, because other projects are also equipped with this kWh-meter; see Figure 46.

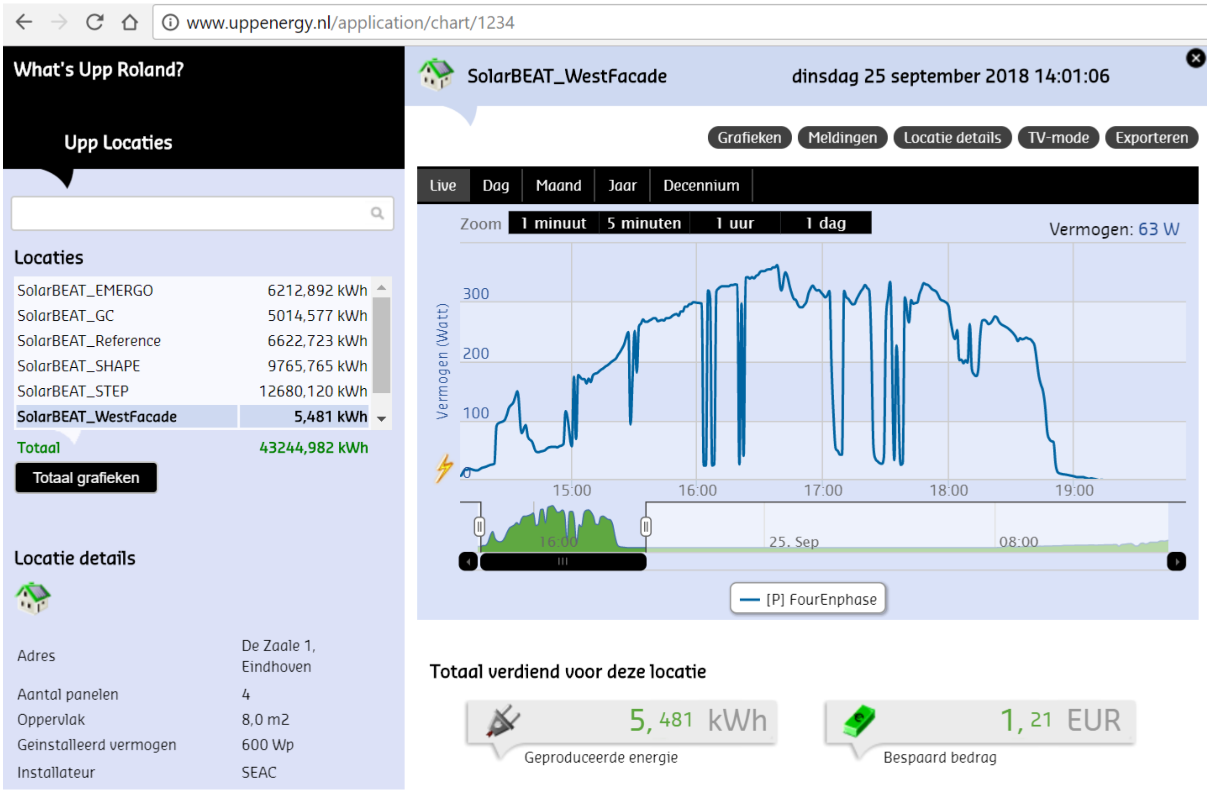


Figure 46: Screenshot of UPP kWh-measurement.

Because both options provide their data on a website, TNO-SEAC can do the analysis in Eindhoven, the Netherlands, even if the WP5.1 demonstrator is far away in Austria. Please note that a stable internet connection is mandatory.

4.4.1.3 Irradiance Measurement Equipment

In WP3.1 the highest quality irradiance sensor is used, which is a secondary standard pyranometer, EKO MS-802. For the WP5.1 demonstrator this would be superfluous. Either a first class pyranometer (like e.g. EKO MS-60) or a secondary class pyranometer (like e.g. EKO MS-40) would be good enough.

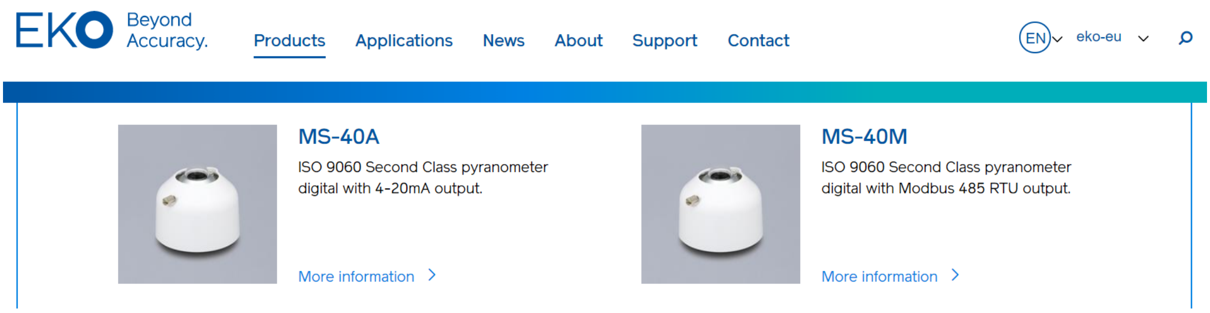


Figure 47: Secondary class pyranometer as irradiance sensor.

This pyranometer needs to be installed on a representative spot in the façade. That can be on many locations. One likes to stay away from the lowest part of the façade, where shading could have an impact. The precise location of the pyranometer will be determined during the next upcoming field trip in November 2018. Finally, the data from this pyranometer needs to connected to a data logger (either by analog connection or by digital MODBUS 485 RTU) or directly to the inverter. Again this will be decided on the field trip in close collaboration with the local electrical installer.

4.4.1.4 Weather Data Equipment

Finally, it is advised to have good quality weather information. This could be from the nearest official weather station from an Austrian meteo institute. Still to find out what is public available from this institute. Moreover, it will be investigated if the building has already a weather station (often this is the case for controlling blinds and other building climate systems). If none of the above is readily available, then a small weather station needs to be installed in the façade itself. This will be discussed with the local electrical installer.

Figure 48: Weather station Lufft WS600 of which TNO-SEAC has good experience

4.4.1.5 Appendix: Measurement Planning

For outdoor PV-system analysis a one full year analysis is highly recommended. The reason is that every period of the year will have its specific climatic conditions that have an influence on the performance. Of most importance, of course, is the irradiance. Moreover, the experience with PV-facades in the international PV-community is much more limited than with PV-roofs (flat or pitched). But not only irradiance is important, also ambient temperature and wind speed will influence performance.

Therefore from the first day of installation onwards, the performance will be monitored. TNO-SEAC recommends to extract each month a performance report. This can largely automated with software. But the analysis of that month-report is up to the experts. TNO-SEAC can compose the monthly report (provided that the internet connection is stable and measurement data comes in flawless) and send that report e.g. by e-mail to Pilkington-NSG. That report will also include some typical observations of that month. In case of installation problems, they will become clear soon (worst-case within 30 days), and mitigation action can be arranged from Pilkington-NSG.

More details of the measurement plan will be discussed in the upcoming field trip to Austria.

A new water piping connection between the demo-site and the DHN must to be installed.

4.4.1.6 KPI List

Please refer to the Appendix C for the complete list of KPIs that will be calculated for Pilkington demonstrator.

5 Envision technology assessment methodology

To meet specific requirements in comparison of the ENVISION technologies in European territory, a methodology of efficiency evaluation has been developed. For sake of clarity, a technical assessment of the integration of the ENVISION technologies in a building located in southern Italy will show different results if compared with the same building (understood as combination of the building envelope, plants and occupant behaviour) located in Norway. In this chapter, a methodology will be proposed, to evaluate the performance of the ENVISION technologies installed in different demo sites, based on measurements and monitoring protocols developed according to the tailored Key Performance Indicators (KPIs) abovementioned.

In order to provide a methodology that is suitable in different climates and that provides an measurement of the effectiveness of the ENVISION technology application, energy signature has been pointed as the appropriate methodology to be used. Some modification have been included in order to take into account the ENVISION operating principle into the mathematical calculations.

The energy signature method provides a straightforward way of estimating and comparing the performances of the technologies between different climatic context, in view of a potential repeatability in other European regions. Daily energy signatures can generate more robust energy consumption benchmarks and provide additional information about the whole system composed by occupants-building envelope- HVAC plants. Energy signature is commonly based on total energy supplied to the building, usually broken down by fuel type, but could be also based on metered data for particular situation. In the ENVISION application, for example, the overall energy supplied from the public grid (electricity, gas, e.g.) could be reduced by the quantity of energy released to the grid from the building. This methodology is usually applied to analyse energy consumption during heating season, but it is also applicable for cooling season.

Viceversa, starting from the energy signature it is possible apply the definition of KPI's defined in Chapter 3 in order to point out the results based on climatic conditions.

5.1 Problem Definition

After defining the KPIs for the different aspects such us social, energetic, environmental and economic, it is possible compare different demonstrators (or different buildings) between them. Each demonstrator could be compared with other technological solutions in the same climates by using the KPIs defined until now.

However in order to compare the effectiveness of the ENVISION solution in different climates a new evaluation methodology is required. For this reason it is necessary to use a well tested and standardised methodology able to evaluate (for example with interpolation) the effects of installed ENVISION technologies in different countries in Europe. As known climatic conditions across Europe can significantly vary from countries (as showed in the figure below) so the methodology calculation will be used to identify approximately the energy consumptions of the same building as it would be placed in different countries and measure its energy performances.

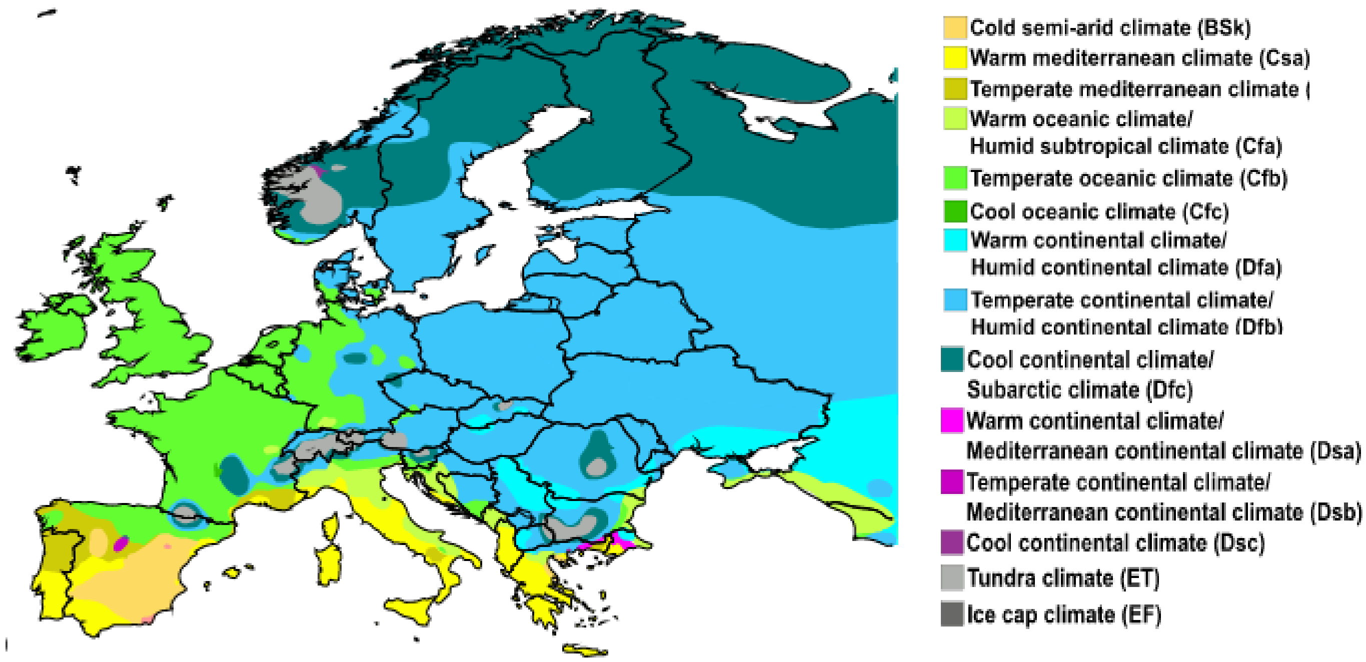


Figure 49 – European Climates

In the following chapter it will be demonstrated how the definition of energy signature, as proposed in the annex B of the UNI EN ISO 15603:2008, is suitable and adaptable to the ENVISION project for the comparison of same technology solutions in different climates. This methodology is consolidated and provides information not only related to the building envelope and plants, but also related to the occupants behaviour (for example the internal set point temperature) and external temperatures.

Energy signature it is applicable both in heating and cooling seasons notwithstanding for cooling application more attention must be paid in order to identify the variables involved in the calculation. The definition of energy signature assume as hypothesis that external temperature is the most influential parameter related to the energy consumption. During winter the external temperature is actually the most influential parameter, but during summer internal loads and solar gains could affect significantly the calculation results, this is the main limit of this methodology.

5.2 Proposed Solution

The Energy Signature (ES) of a building is a method of assessment, described in Annex B of EN 15603, in which the energy consumption for heating and cooling is correlated with climatic data over a suitable period.

Energy consumptions (heating, cooling, hot water), as well as an average external temperature or accumulated temperature difference, are recorded at regular intervals and reported on a graphical representation that provides useful information on the energy performance. The energy signature allows a direct comparison between the calculated values with the actual consumption of the demonstrators and provides fast feedback on the performances of the ENVISION technologies.

In line with EN 15603 indications, this monitoring method assumes that the internal temperature is constant and it is useful in buildings with stable heat gains and relatively low passive solar gains.

The first step to define the Energy Signature of each demonstrator is to collect the energy consumption data (heating, cooling, hot water) and the average external temperature at regular intervals (e.g. an hour is sufficient) over a certain period. The average external temperature can be measured directly or can be recovered from available neighbouring weather station data.

The evaluation methodology proposed is based on the following assumptions:

- the presence of an ongoing monitoring (based on hourly or sub hourly measurements) common to all the demo sites, before and after the integration of the ENVISION technologies;
- all the KPIs calculations should be based on a predefined minimal data set (in some cases, the installation of additional sensors and meters should be necessary).

The assessment procedure has two main steps:

- implement energy signature method,
- calculate the new KPI's based on the energy signature method.

In order to evaluate the performance of each demo site, it is necessary to compare the KPIs calculated before and after the integration of the ENVISION technologies at each demo or case study. The following figure shows a simplified scheme of the step required:

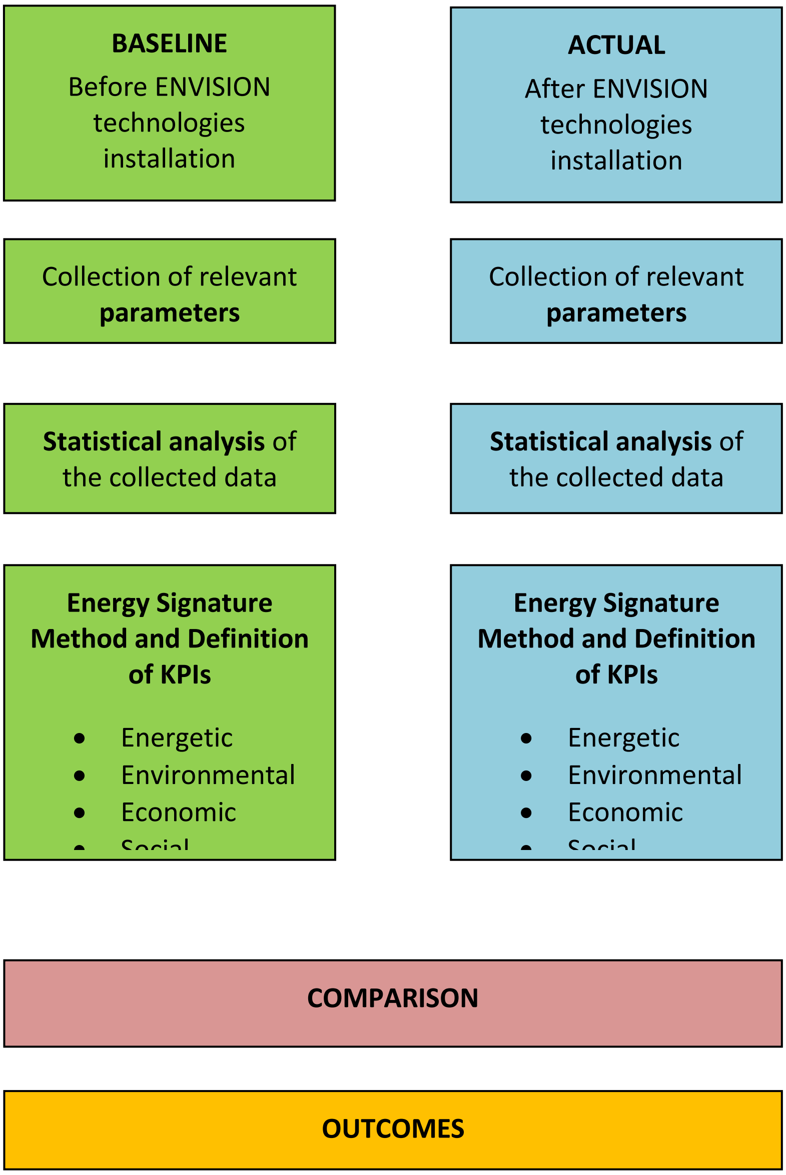
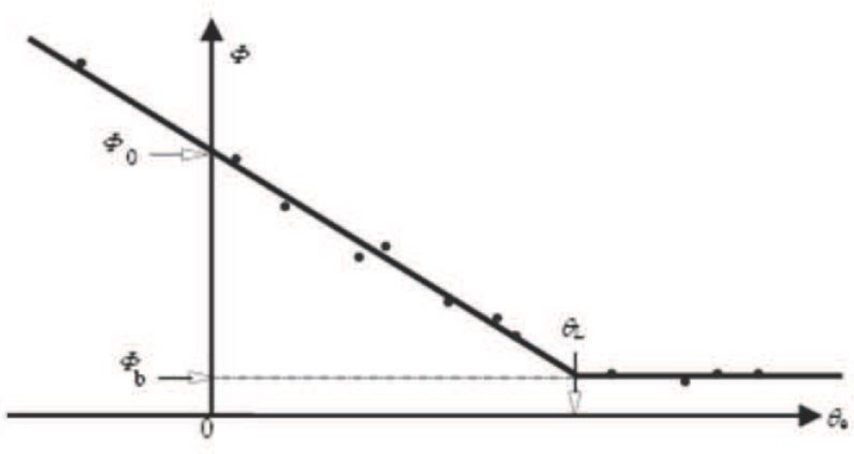


Figure 50 Scheme of the steps for evaluate the performance of the ENVISION technologies.

Afterwards it is necessary to obtain the average power by dividing the energy consumption by the duration of the time interval between successive records (e.g. in hours).

The average power, in this case related to heating season, and the average external temperature are plotted on a graph, as the one below. The diagonal line is drawn using a linear regression of the dots that represents the measurement campaigns conducted during the heating season.



Key:

Φ	average power between two successive records
Φ_0	power at 0 °C
Φ_b	base power, not dependant on external temperature (e.g. for system loss and hot water)
θ_L	heating limit external temperature
θ_e	external average temperature between two successive records

Figure 51 Example of an Energy Signature (source: EN 15603)

The horizontal line (or with nearly-zero slope) represents the system loss and the energy services other than heating and cooling (e.g. hot water) independent of the outside temperature.

The line drawn during the heating (or cooling) season is characterised by a power Φ_0 at 0 °C and a slope (gradient) H:

$$\Phi = \Phi_0 - H \cdot \theta_e$$

where:

Φ	is the average power
θ_e	is the average outside temperature
H	is the slope of the diagonal line, represents the sensitivity of the building to changes in external temperature

$$H = (\Phi_0 - \Phi_b) / \theta_L$$

The above equation can be compared to the global, simplified average energy balance of the building:

$$\Phi = H' (\theta_i - \theta_e) + \Phi_a - \eta(A_e \cdot I_{sol})$$

where:

H'	is the heat transfer coefficient of the building
θi	is the average internal temperature
Φ_a	includes system loss and average power for services other than heating. As a first approximation, this power does not depend on external temperature, and, if the pattern of use of the building is constant, this power can be assumed to be the average power measured during the intermediate season
η	is the utilisation factor of solar gains
A_e	is the equivalent solar collecting area
I_{sol}	is the solar irradiance

Comparing the two above equations H' = H and:

$$\Phi_0 = H \cdot \theta_i + \Phi_a - \eta(A_e \cdot I_{sol})$$

Seasonal energy use for heating can be estimated from the following equation:

$$Q_h = (\Phi_0 - H \cdot \theta_e)\, t$$

Where:

t is the duration of the heating season

An estimate of the energy requirements can be obtained for a period less than the whole heating season. In any case, to obtain a good accuracy for H and Φ_0, it is necessary a large range of external temperatures θ_e.

An estimate of the confidence interval of the energy use for heating is calculated by:

$$\delta Q_h = \sqrt{[t^2\delta\, \Phi_0{}^2 + \theta_e{}^2\delta\, H^2 + t^2H^2\delta\theta_e{}^2 + (\Phi_0 - H\theta_e)^2\delta t^2]}$$

The energy signature, calculated as previous described, is able to provide a qualitative analysis on the evaluation of the energy consumption of a building.

The dispersion of the individual measurements above or below the line characterising can result from several causes:

- Variable solar or internal gains;
- Varying heat transfer coefficients, e.g. resulting from the effect of wind on a permeable building envelope, malfunctioning of the heating or cooling system.

5.2.1 Energy Signature for Air conditioning applications

As shown above, the energy signature method consists in plot of the energy consumption of a building versus the mean ambient temperature, usually on daily basis. A daily time step allow a level of detail with useful information in a readily assimilated form and requires a limited amount of data analysis. During cooling season there are several factors that impact in the energy consumptions in addition to the external temperature as solar gain and night day temperature variations (that are usually greater during summer), dehumidification load and the internal heat gains which contribute negatively in the energy needs. For this reason the graphic representation is slightly different from the heating season.

Another difference from heating and cooling season is that the methodology must be adapted depending on the type of cooling plants used for HVAC of the rooms. Main critical point is if the system has air primary supply separated from the cooling and how the AHU (air handling unit) is composed.

Application of energy signature during cooling season are following reported just as an example:

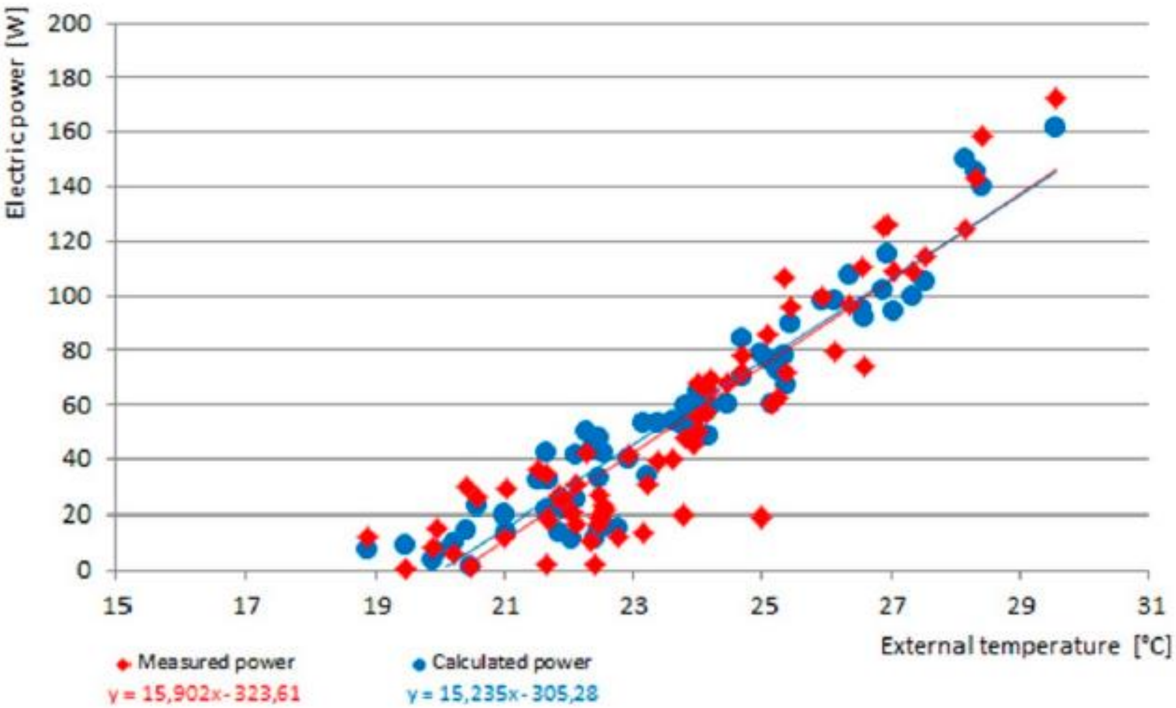


Figure 52 – Example of energy signature during cooling season – Heat Pump Calculated and Measured

The main limitation of this method is that is based on one only hypothesis, which is, that the main variable that affect heating (and cooling) consumption is the external temperature.

5.2.2 Energy Signature: step by step calculation

The energy signature of a building is made with readings at regular intervals (possibly weekly or at least monthly) of the natural gas meter (or any other fuel) and with the average outdoor temperatures.

It might be useful built a table as the following:

Example of useful table for the energy signature							
• meter reading date		31/01/17	28/02/17	31/03/17	……	……	Season
• days of the periods	gg	31	28	31	……	……	……
• hours of the periods	h	744	672	744	……	……	……
• hours/day plant operation	h/gg	12	12	12	……	……	……
• period of plant operation	h	372	336	372	……	……	……
• natural gas meter	Stm3	2.000	3.500	4.800	……	……	……
• natural gas consumption	Stm3	2.000	1.500	1.300	……	……	……
	MWh	19,4	14,6	12,6	……	……	……
• energy produced and exchanged with the grid by ENVISION technologies	MWh	……	……	……	……	……	……
• generator average power	kW	……	……	……	……	……	……
• daily average power	**kW**	**……**	**……**	**……**	**……**	**……**	**……**
• outdoor temperature	**°C**	**6,9**	**7,5**	**10,4**	**……**	**……**	**……**

Notes:

- Date of the meter readings
- Number of days between two readings
- Number of hours between two readings
- Daily hours of plants operation
- Total hours of plants operation between two readings
- Meter readings at the indicated dates
- Natural gas consumption between two readings (Stm^3). The energy consumed by the generator $\mathbf{Q_g}$ (MWh) is obtained multiplying Stm^3 by methane lower calorific value.
- Energy produced and exchanged with the grid by ENVISION technologies $\mathbf{Q_{exc,Th}}$.
- The average power of the generator is obtained dividing the energy consumed by the generator $\mathbf{Q_g}$ minus the energy produced and exchanged with the grid by ENVISION technologies $\mathbf{Q_{exc,Th}}$ by the hours of the period (point 3).
- The average absorbed power of the generator in 24h is obtained dividing the energy consumed by the generator $\mathbf{Q_g}$ minus the energy produced and exchanged with the grid by ENVISION technologies $\mathbf{Q_{exc,Th}}$ by the period of plant operation (point 5).
- Average outdoor temperatures (on 24h) between two readings.

With the collected data, it is possible to draw the following graphic. The points are distributed with good approximation along a straight line that show us how the building/plant system reacts to external temperature variations. This straight line is obtainable by linear regression.

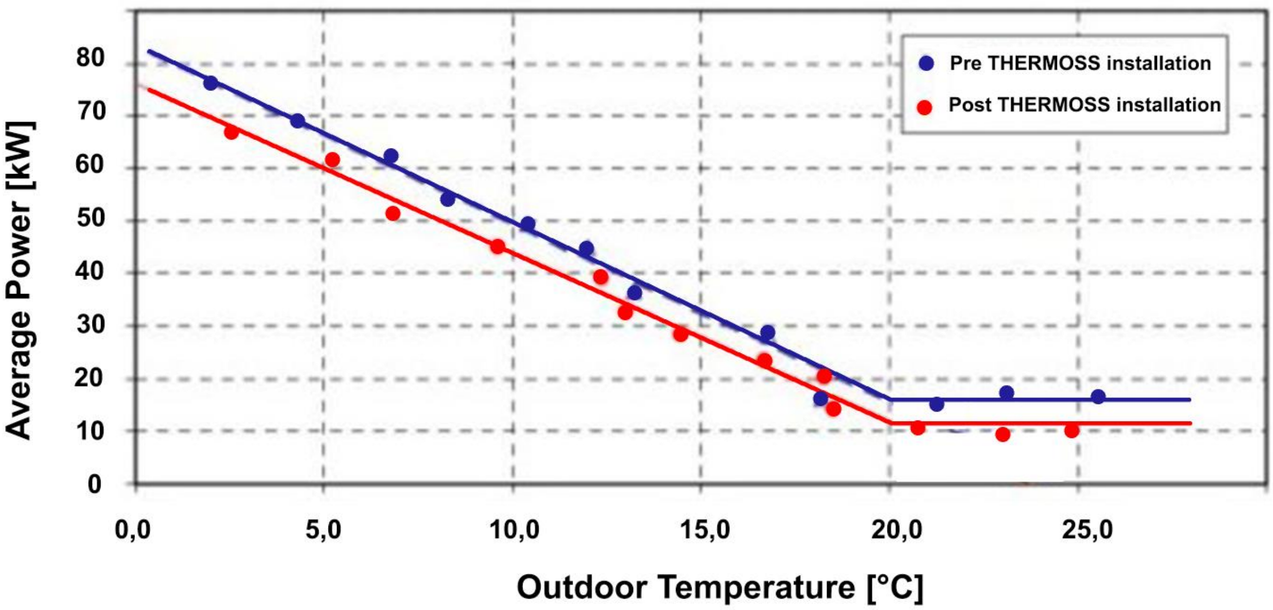


Figure 53 Example of an Energy Signature before and after the installation of the ENVISION technologies

The daily average power $\Phi_{Post\ inst.}$ after the ENVISION technologies installation is calculated, for each time interval, as follow:

$$\Phi_{Post\ inst.} = (Q_g - Q_{exc,Th}) / h$$

where:

Q_g	is the energy consumed by the generator (or get from the district heating network)
$Q_{exc,Th}$	is the energy produced by the ENVISION technologies and exchanged with the district sotto iheating network
h	total hours of plant operation

Weekly readings could be optimal where there are not computerised monitoring system. A weekly period is very close to the climatic variation cycles and the duration is sufficient to mediate the transient effects of the plants. Instead a daily frequency readings are suggested, if monitoring systems are installed, to have a overall framework of the consumptions behaviour.

The main advantage of using the energy signature method is the possibility of extrapolate the points and carried out the power required for heating the building in different climates. For example by looking a Figure 6 above, it is possible say how much energy the building would consume if external temperature would decrease below zero degrees.

5.3 Energy signature for KPI's

Starting from the energy signature results it is possible to calculate the environmental, economic and energetic KPI's. Indeed energetic, environmental and economical aspects are strictly related between them through performance factors, energy conversion factors and energy prices. Using the definition provided in Chapter 3 it is possible define the generic KPIs related to the energy consumptions derived from energy signature method. .

It is important to point out that PMV and PPD method (social KPI's) are independent from the context because are based on statistical method which put in relation the percentage of satisfaction people indoor.

After determining the energy signatures results it is possible follow the scheme reported in the figure below and compare results.

6 Conclusions

This document was created starting from the necessity of developing an evaluation methodology for comparison of the different ENVISION technologies in order to foster the transfer and replication in different European regions. Particularly this document aims to provide a calculation method (based on measurement method) for evaluation of the intervention under the following impacts category: economic, social, environmental and energetic. The definition of KPIs to collect as much information as possible in terms of economic, social, environmental and energetic aspects have been defined creating a list of KPIs for each impact category, as showed in Table 2 (next page).

In particular environmental KPI's are strictly related to the energetic ones through the emission factors, as well as the economic KPI's are linked to the energy consumptions and installation/operational costs. Social KPI's are connected to the statistical approach of the PMV and PPD that are independent from the context. The assessment of the indicated KPIs is subject to the available measured information, which are mostly related to the energy performances. For the other KPIs, estimations need to be carried out, according to the literature and other available sources. DIMOSIM has been identified as the most suitable tool for assessing the demo site performances from the energetic, economic, social and environmental point of view.

The KPIs, thus defined, do not allow to take into account of the weather impact in the achievement of energy efficient solutions. For example, if the energetic KPI applied to one technology is higher than another one, the difference could be caused from the higher external temperature dependent from the climatic zone.

The solution of this problem leads to the definition of the energy signature for ENVISION technology evaluation and implement a new set of KPI's based on energy signature results.

The development of the energy signature requires a modest amount of work: some fuel meter readings and the availability of external medium temperatures.

Comparing the energy signature and KPI's before and after the installation of the ENVISION technologies, it is possible to assess immediately the performance of each demonstrator, and extrapolating the energy signature results it is possible evaluate how one building would consumed if it would be placed in different climatic context. The energy signature method it is relevant in the frame of ENVISION Project, as it provides a straightforward way of estimating and comparing the performances of the technologies between different climatic context, in view of a potential repeatability in other European regions.

7 References

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8 Abbreviation list

[ATO] - Antimony-doped Tin Oxide
[BIPV] – Building Integrated Photovoltaic
[CR] - Concentration Ratio
[COP] - Coefficient of Performance
[CCF]-Cumulative Cash Flow
[DHW] - Domestic hot water
[DHN] – District Heating Network
[EER] - Energy Efficiency Ratio
[ES]-Energy Signature
[EU]-European Union
[GUE] - Gas Utilization Efficiency
[HSPF] - Heating Seasonal Performance Factor
[HVAC] – Heating Ventilation Air Conditioning
[IGU] – Insulated Glass Unit
[IESL] – Innovative Energy System Laboratory
[IRR] - Internal rate of return
[KPI] - Key Performance Indicator
[mGT] – micro Gas Turbine
[NCF] - Net Cash Flow
[NIR] – Near Infrared Reflectance
[NCF] - Net Cash Flow
[NVP] - Net Present Value
[OPE] - Operating Expenses
[PMV] - Predicted Mean Vote
[PBP] - Payback period
[PPD] - Percentage of Person Dissatisfied
[PV] - Photovoltaic system
[PVB] – PolyVinilButiral
[RES] - Renewable energy system
[SEER] - Seasonal Energy Efficiency Ratio
[SEAC] – Solar Energy Application Centre
[SPM] – Smart Polygeneration Microgrid
[TRL] – Technology Readiness Level
[TSA] – Total Solar Absorbance

APPENDIX A - Delft's demo: Energy demand and dimensioning

A first estimation has been done, in order to get a better idea of the demand of the building and how much heat and electricity can be harvested in all the surfaces of the building: The apartments approximately need 2851 kWh/year/apartment electricity:

Fields	Values	Unit
Energy demand		
Living area	70	m^2
Space heating	25	kWh/m^2
	1,750	kWh
	6.30	GJ
Domestic hot water	21	kWh/m^2
	1,498	kWh
	5.39	GJ
Auxiliary energy heating	7.0	MJ/m^2
	490	MJ
Cooling	12.00	MJ/m^2
	840	MJ
Ventilation	4.95	MJ/m^2
	347	MJ
Household equipment	26	kWh/m^2
	1,820	kWh
Efficiency heat pump - space heating	5.00	-
Efficiency heat pump - hot tap water	3.00	-
Energy usage		
Space heating	350	kWh
Auxiliary energy space heating	53	kWh
Domestic hot water	499	kWh
Cooling	91	kWh
Fans	38	kWh
Subtotal building	1,031	kWh
Domestic	1,820	kWh
Total electricity consumption	**2,851**	**kWh**

In order to evaluate if the ENVISION technologies would be able to cover the electricity consumption of the apartments, the following estimations have been made. A first assumption of available area for energy harvesting technologies has been done. Taking in to account the solar radiation on each orientation and estimation of the available heat collection has been made, as well as , the first estimation of PV panel production.

The PV panels will generate 3754 kWh/year per apartment :

Yearly electricity generated at the roof (standard PV)		
Roof surface	500	m^2

Quantity	300	PV panels
Available quantity per apartment	14	PV panels
Power PV panel	335	Wp/panel
Conversion factor	0,8	Wp/(kWh.year)
Production	**3754**	kWh/year

Table X: Yearly electricity generated at the roof (standard PV)

With a yearly electricity generation of 3754 kWh/year per apartment and a yearly electricity demand of 2851 kWh/year apartment it seems there is already a surplus of electricity available. However, the imbalance and seasonal differences in electricity demand need to be assessed and included in the calculation.

PV integrated glass will also be placed in the staircase and will generate 78.24 kWh/ apartment:

Yearly electricity generated at the staircase (PV glass)		
Available area	65	m^2
Produced	1.3	GJ/m^2
Efficiency panel glass	16%	-
Area of use	50%	-
Produced per apartment	78.24	kWh/ apartment

Table X: Yearly electricity generated at the staircase (PV glass)

NIR harvesting thermal collectors, will probably be placed in every façade , here is an estimation of the available area and the heat they would be able to produce on a yearly basis per apartment. Considering that the Envision collector has a 60 % of efficiency compared to the standard ones.

Yearly electricity generated in the façade (NIR thermal collectors)		
South (front) facade		
Degrees (reference north)	130	degree
Available area	97	m^2
Produced per m^2	2.42	GJ/m^2
Produced total	142.59	GJ
Produced per apartment	5.94125	GJ/apartment
West (end) facade		
Degrees (reference north)	220	degree
Present	90	m^2
Available area	70	m^2
Produced per m^2 (in theory)	2.53	GJ/m^2
Produced per m^2 (with shadows)	1.3	GJ/m^2
Produced total	54.6	GJ
Produced per apartment	2.275	GJ/apartment
East (end) facade		
Degrees (reference north)	30	degree
Present	90	m^2
Available area	70	m^2
Produced per m^2	1.24	GJ/ m^2

Produced total	52.08	GJ
Produced per apartment	2.17	GJ/ apartment
North (back) facade		
Degrees (reference north)	-50	degree
Available area	36	m2
Produced per m^2	1.3	GJ/m2
Produced total	28.08	GJ
Produced per apartment	1.17	GJ/apartment
Total		
Available area	273	m^2
Available area per apartment	11.375	m^2
Total produced	277.35	GJ
Produced per apartment	11.55625	GJ/ apartment

Table X: Yearly electricity generated in the façade (NIR thermal collectors)

In total, the estimate available area for thermal collector in all the façade is 273 m^2 . Which by apartment will be around 11,4 m^2. All together all the solar collectors will produce about 277,35 GJ per year, which would be around 11,56 GJ per apartment.

To sum up, with a yearly electricity generation of 15,6 GJ and heat generation of 11,56 GJ per apartment and a yearly electricity demand of 8 GJ per apartment it seems there is already a surplus of energy and that the building will be an energy positive building. However, the imbalance and seasonal differences in electricity demand need to be assessed and included in the calculation.

APPENDIX B - Pilkington demo: Energy calculation

Pilkington-NSG

Pilkington **Sunplus™** BIPV (new string design: 298 mm)

Preliminary Energy Estimate

Tool: http://pvwatts.nrel.gov/pvwatts.php

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Project Data	
Project name	
City	
Solar Data	
PV system	
Tilt (Degrees)	90
Assumptions	
System loss (%)	14
Inverter Efficiency (%)	96
DC to AC ratio	1.1

Electrical specifications per cell unit

Pilkington	cell size (cm)	Pmp (W)	Voc (V)	Isc (A)	Vmp (V)	Imp (A)
Pilkington **Sunplus™** BIPV Vision	8.1x15.6	1.117	0.618	2.38	0.507	2.2
Spandrel	80 x 126	132				
	80 x 86	94				
	80 x 143	151				

Window and Panel Parameters

System	Orientation	W (cm)	L (cm)	N cells W	N cells L	Power(W)	Qty	Total Power(kW)
Vision (SW)		80	160	4	19	84.9	9	0.76
Vision (SW)		80	142	4	16	71.5	18	1.29
Spandrel (SW)		80	126	1	1	132.0	9	1.19
Spandrel (SW)		80	143	1	1	151.0	18	2.72
Spandrel (SW)		80	86	1	1	94.0	9	0.85
								0.0
Total							**63**	**6.80**

Pilkington-NSG

Pilkington **Sunplus™** BIPV

Preliminary Energy Estimate

Tool: http://pvwatts.nrel.gov/pvwatts.php

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KWh/Year of energy savings due to Solar Production (PV Watts)

System	Orientation	DC System (kW)	PV Watts (Kwh/year)
S1	182	6.8	4.397
S2		0.0	
S3		0.0	
S4		0.0	
Total :		**6.8**	**4.397**

APPENDIX C - KPI List

KPIs codification

KPIs codification: Each KPI is identified by using four fileds that are following reported:

1)

Name of demonstrator	Code
Savona Campus	Sa
Delft demo	De
Pilkington	Pi

2)

Generic

Generic KPIs	Code	Number	Description	Unit
Environmental	Env	1	Yearly GHG emissions	[ton CO2eq /(m3c*year)]
Environmental	Env	2	Yearly GHG savings	[ton CO2eq /(m3c*year)]
Environmental	Env	3	CO2	[ppmv/m3]
Environmental	Env	4	Particulate Matter	[mg/(m3*m3c)]
Environmental	Env	5	VOC	[µg/(m3*m3c)]
Environmental	Env	6	Noise Level	[dB(A)]
Economic	Eco	1	Simple Pay back time	[year]
Economic	Eco	2	Net Present Value	[€]
Economic	Eco	3	Internal Rate of Return	-
Economic	Eco	4	Yearly depreciation rate per kWh	-
Economic	Eco	5	Yearly depreciation rate per ton of saved CO2	-
Economic	Eco	6	Total cost (yearly depreciation rate + operating costs) per kWh	[€/kWh]
Economic	Eco	7	Total cost (yearly depreciation + operating costs) per ton of saved CO2e	[€/ton CO2]
Social	Soc	1	Predicted Mean Vote (PMV)	[%]
Social	Soc	2	Predicted Percentage of Dissatisfied (PPD)	[%]
Social	Soc	3	Working hours per year of E&M system	[hours/year]
Thermal	Thr	1	Yearly amount of thermal energy produced from Envision Technologies	[kWh/ (m3c*year)]]
Thermal	Thr	2	Energy efficiency of the project	[%]
Thermal	Thr	3	Share of waste/renewable energy	[kWh/ (m3c*year)]]
Electrical	Elc	1	Electrical energy consumptions -detaliled	[kWh/(mounth and/or day and/or hour)]
Electrical	Elc	2	Specific Yield: energy divided by power for defined time step	[kWh/kWp]

Electrical	Elc	3	Renewable Energy production	[kWh/(mounth and/or day and/or hour)]

Specifc

Specific KPI	Code	Number	Description	Unit
Equipment efficiency	COP/EER	1	Efficiency of Heat Pump (heating /cooling)	[kWht/kWhe]
Solar Panel efficiency	Solar_Eff	1	Efficiency of the solar system (thermal production)	[%]
Thermal Storage heat loss	Storage_losses	1	Heat loss from storage devices	[kWh]
District Heating heat exchange	DH_th_exchange	1	Heat exchanged from district heating substation	[kWh]
One Way Substation efficiency	DH Substation_Eff	1	Substation Efficiency	[%]
One Way Substation heating cycles	DH heating_cycles	1	Number of ON/OFF heating cycles	-
PV electrical efficiency	PV_Eff	1	Photovolatic efficiency	[kWh/kWp]

3) Progressive Number = (1, 2, 3,…)

4) Design Stage

Design stage	Code
Baseline	B
Post Renovation	P

Savona Campus KPIs – List

Name of demonstrator	KPI type	Progressive number	Design stage
Sa	Thr	1	P
Sa	Thr	2	P
Sa	Thr	3	P
Sa	Elc	1	P
Sa	Elc	3	P
Sa	COP/EER	1	P
Sa	Solar_Eff	1	P
Sa	Storage_losses	1	P
Sa	DH_th_exchange	1	P
Sa	DH Substation_Eff	1	P
Sa	DH heating_cycles	1	P
Sa	PV_Eff	1	P

Delft KPIs – List

Name of demonstrator	KPI type	Progressive number	Design stage
De	Env	1	B
De	Env	2	B
De	Env	2	P
De	Env	3	B
De	Env	4	B
De	Env	5	B
De	Env	6	B
De	Env	6	P
De	Eco	1	P
De	Eco	2	P
De	Eco	3	P
De	Eco	4	P
De	Eco	5	P
De	Eco	6	P
De	Eco	7	P
De	Soc	1	B
De	Soc	1	P
De	Soc	2	B
De	Soc	2	P
De	Soc	3	B
De	Soc	3	P
De	Thr	1	P
De	Thr	2	P
De	Thr	3	P
De	Elc	1	B
De	Elc	1	P
De	Elc	2	B
De	Elc	2	P
De	Elc	3	B
De	Elc	3	P
De	COP/EER	1	P
De	Solar_Eff	1	P
De	Storage_Losses	1	P
De	DH heating_cycles	1	P
De	PV_Eff	1	P

Pilkington Office KPIs - List

Name of demonstrator	KPI type	Progressive number	Design stage
Pi	Elc	3	P
Pi	Pv_Eff	1	P