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Sun coupled innovative Heat pumps

D2.4 – KPIs assessment based methodology

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Summary

SunHorizon (SH) will demonstrate up to TRL 7 innovative, reliable, cost-effective coupling of solar and HP technologies. SunHorizon addresses three main research pillars that interact each other towards project objectives achievement, demonstration and replication: i) optimized design, engineering and manufacturing of SunHorizon technologies, ii) smart functional monitoring for H&C, iii) Key Performance Indicators (KPI) driven management and demonstration.

Deliverable D2.4 establishes a list of indicators to assess the performances of SunHorizon standalone technology and combined packages during their operational phase and for the simulation scenarios to achieve project objectives. In order to develop this deliverable, the following main activities have been conducted:

- Collection of details from SunHorizon demo sites, which are relevant for the definition of the integral evaluation framework (inputs coming from task 2.1).

- Analysis of KPIs definition from shortcomings of other H2020 projects and previous experience.

- Specific sessions and discussions with consortium experts to gather inputs, demo-site requirements and to advance in a preliminary definition of the monitoring requirements.

- Develop a scale of relevance for KPIs according to Demo Site characteristics/requirements and define a KPI-based methodology (definition of boundaries, nomenclatures, IEA's square view, etc.).

As a result, KPIs are defined at component and system level, and divided in different categories: technical (energy-related), economic, environmental, and comfort categories. Along with the definition of the list of KPIs, data sources required for KPI calculation are defined, which will help to define the monitoring requirements and data gathering needs (link with WP4 of SH project). KPIs will be used throughout the project for different purposes such as support the control algorithms, maintenance, assessment of demonstrations, and optimization analysis, among others.

This study provides a complete and adapted methodology for performance assessment of the project, but also for sun coupled innovative heat pumps to sustain reliable demonstration results and set a robust basis for replication and scalability in future developments that will contribute to a more efficient energy supply and the decarbonisation of heating and cooling applications.

Keywords

Key Performance Indicators; Sun coupled heat pumps; Performance Assessment; KPI methodology; solar thermal collector KPI; hybrid solar collectors KPI; thermal driven heat pumps KPI; adsorption heat pumps KPI; photovoltaic panels KPI; compression heat pumps KPI

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1 Introduction

SunHorizon project aims to demonstrate that the proper combination of technologies (Technology Packages- TP from now on) such as solar panels (PV, hybrid, thermal) and heat pumps (thermal compression, adsorption, reversible) managed with a controller with predictive and pro-active maintenance among other capabilities, can avoid waste energy, identify malfunctioning of equipment, maximize energy coming from renewables, increase self-consumption, reduce local energy bills and cut of CO_2 emissions. By means of the proper definition of Performance Indicators (PIs), it is possible to determine the success of a project in reaching its objectives and creating an impact.

According to the *Guidelines for the Calculation of Project Performance Indicators* proposed by the European Commission *"The performance Indicators should be SMART (specific, measureable, achievable, relevant and time-bound) and should be defined in a way that quantifies its energy-related impacts both within the duration of the project and beyond its lifetime, demonstrating the contribution to the EU energy targets"* (EASME, 2017). Thus, Key Performance Indicators (KPIs) definition constitutes a crucial element for the overall evaluation of the SunHorizon project results. On the one hand, KPIs serve to summarize the results of the performance monitoring and assessment of each TP within SunHorizon, enabling the comparison between the baseline and the post-retrofit period of the energy solutions and providing insights of the improvements achieved. On the other hand, KPIs are useful for the development of the monitoring management platform, and the identification of datasets to be monitored, sensors and data acquisition equipment. Therefore, it will help to define the requirements of the architecture that will allow KPIs storage and visualization, enabling also local control and surveillance of demonstrator cases.

The main objective of this deliverable is to provide a list of KPIs and the methodology to assess them in order to be able to evaluate and quantify the performances of the SUNHORIZON standalone technologies and combined technology packages throughout the project. To this aim, theoretical KPIs at component and system level thresholds will be addressed, covering technical, environmental, economic, and comfort categories. The KPIs approach will be studied in parallel with conceptual design studies and represents a transitional moment to WP4 and WP5 developments. KPIs will serve along the project for different purposes (i.e. control, maintenance, assessment of demonstrations, optimization analysis) whose link with other tasks is explained in section 2.1.

D2.4 will be elaborated as a guide for practical application of KPI definitions and consistent evaluation methodologies during the rest of the project. Formerly, the document starts introducing the project and the methodology that will be followed throughout the project to define and divide the KPIs analysis. Next, the tasks' objectives, plan and links within the project are described. Later the indicators are defined within the following 3 categories:

- Key Performance Indicators (KPIs) which are later described specifically for each of the 8 demosites of the SH project
- Performance indicators (PIs) which are explained at technology level (6 technologies)
- Auxiliary indicators that support the overall calculations.

Then, the applicability of KPIs and PIs at each demosite and the assessments boundaries is explained in section 3.6. To conclude, the relationship of the KPIs with the stakeholders is described, which allows to identify the most significant categories for each stakeholder and to quantify the satisfaction accruing of the project.

2 Methodology

The aim of this deliverable is to describe the list of performance indicators that will serve throughout the project to evaluate technical, economic, environmental and comfort aspects of the proposed technology packages (TP) at each demonstration case. In order to do so, projects with similar approach and energy-technology related to SunHorizon's project has been reviewed, such as CESBA MED[1],CITyFiED[2], inteGRIDy[3], RESILIENT[4], SHIP2FAIR[5], CELSIUS[6], ReUseHeat[7], among others and other sources like SCIS management system, and the European commission guidelines. The most relevant information has been taken into consideration for the definition of KPIs.

On the other hand, information obtained from T2.1 is used to identify how the proposed TPs impact the different demonstration cases and how these impacts can be quantified. Contributions from partners and experts have been considered and discussed through dedicated calls, contrasting ideas and justifying a validated set of indicators. Also, maintenance reports and manuals from technology providers of SUNHORIZON's consortium have been taking into account. All the gathered information has been used to assure the consistency of the definitions with the overall objectives of the project, being useful for (i) Identifying monitoring requirements, (ii) Support the integral assessment of the SunHorizon TPs in the different demo environments and (iii) Assisting control, surveillance and maintenance algorithms and functionalities.

Some KPIs will be related to the type of demosite (i.e. climate, type of buildings…) in order to evaluate the impact of SunHorizon technologies in that specific scenario or to compare their performance with the current baseline, while other ones will be related more generally to the H&C technology itself. Furthermore, some indicators are more interesting for the occupant (to show it in a dashboard or the user-interface) and some others are more useful for a facility manager (e.g. efficiencies, maintenance indicators, etc.). For that reason, three main categories of indicators were devised, each addressing a specific level of analysis:

- **Demo-site's KPI** (or **high level KPIs):** Selection of 12 top KPIs referred to areas of performance or evaluations that are common to all demonstration cases. These indicators will be applied to almost all demonstration cases and will help to analyse the overall performance of SunHorizon project and to address in each specific context the benefits achieved by the adoption of the different systems (TPs). It is important to mention that, some demonstrations KPIs (e.g. self-consumption) are only applied for a given demo case, depending on their particularities and boundary conditions. A list of KPIs for each of the eight demonstration cases can be found in section 3.6 (See Table 33)
- **Performance Indicators** (by technology): PIs will serve to evaluate technically each technology and, some indicators, will help to detect malfunctioning (WP4/WP5). These indicators can operate at a lower level, at different APIs or modules, to compute alarms, events or to show them in a Building Management System (BMS) to a facility manager.
- **Supporting indicators**: Other indicators and data are used to support the calculation of KPIs and PIs. It can also help to look in further detail some indicator.

Among the high level KPIs, performance domains are split into four categories:

- KPIs measuring Energy Performance aspects, such as energy consumption, RES generation ratio, percentage of self-consumption, etc

[1]CESBA MED project. D3.1.1. Transnational Indicators and Assessment Methods for Buildings and Urban areas
[2] CITyFiED project. KPIs Monitoring update.
[3] inteGRIDy project. D1.4 Evaluation metrics KPIs
[4] RESILIENTproject. D5.1 – Pilots observability – initial specifications
[5] SHIP2FAIR project. D2.3 Key Performance Indicators to evaluate the integration of solar heating in industrial processes
[6] CELSIUS project. D4.1 Report on KPI values
[7] ReUseHeat project. D4.1 Evaluation procedure.

- KPIs measuring Economic Performance, e.g., operational cost avoidance, return of investment, levelized cost of heat, etc
- Environmental Performance to evaluate the greenhouse gases reduction of a TP
- Comfort performance, to evaluate degree of users' satisfaction from SunHorizon deployment

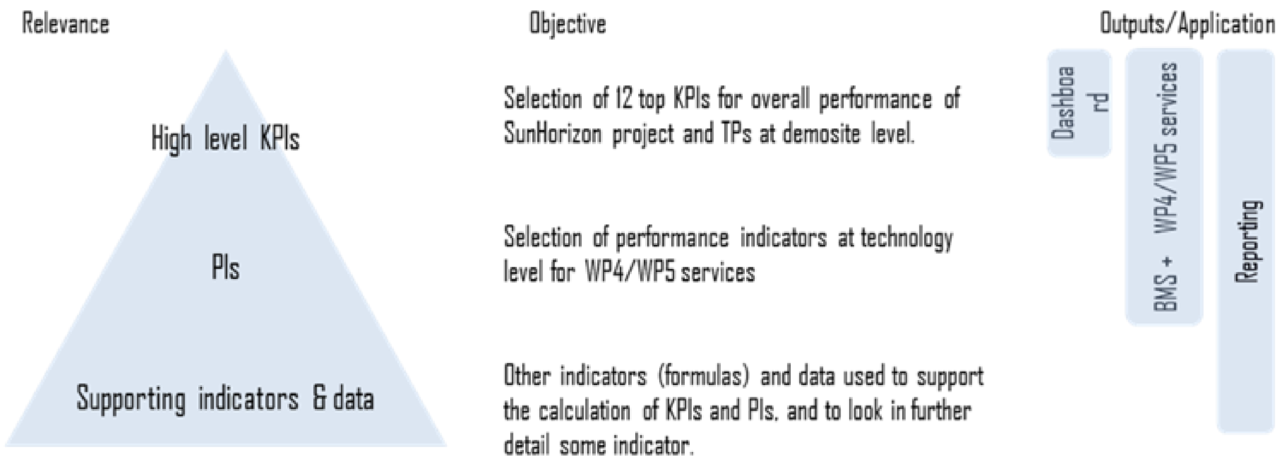


Figure 1 – Relevance and application of each indicator category.

When possible, each KPI is described by characteristics listed hereafter.

- KPI code (i.e. Reference), title, description and definition.
- Unit: indicator unit is specified. In case of normalization, some indicators can be expressed by square meter or volume of the demo-sites building structure (e.g. energy savings per square meter of surface that is conditioned).
- Required data source are set, in order to know which input data is needed. The unit system used in these inputs should be verified in order to assure the validation of the calculations.
- Calculation method followed is explained. Formula and specified variables are explained.
- Reference period: an indicator or an input is levelled over a representative period. Characteristic time can be less than one hour up to one year after integration of shorter periods.
- KPI threshold within SunHorizon project

The proposed planning followed during the project is listed hereafter and illustrated in Figure 2 with a Gantt chart.

Date	Month	Title	Milestone (*at the end of each month)
Nov.-18	M2	KPIs definition from shortcomings of other H2020 projects and previous experience	Preliminary draft of KPIs
Apr.-19	M7	Specific sessions with Consortium experts: TPs (WP3), demosites (link with T2.4), and WP4	
May to June 19	M8-M9	Revision period of KPIs draft and integration of inputs from all consortium experts	First complete definition of KPIs (in line with WP4 planning). + ToC of D2.4
July-19	M10	15 days to receive new inputs and feedback Integration of updates from T2.4, feedback inputs and/or WP4 monitoring constraints Definition of KPI-based methodology (how to use the KPIs) Develop a scale of relevance for KPIs according to Demo Site characteristics	2nd version of KPIs integrating new inputs from TPs and demosites
Aug.-19	M11	15 days to receive new inputs and feedback	-
Sep.-19	**M12**	**Deliverable submission**	**Deliverable final version**

Table 1 – Task 2.3 plan

T.2.3		jan	feb	mar	apr	may	jun	jul	ago	sep
		2019								
		M4	M5	M6	M7	M8	M9	M10	M11	M12
TASKs:	**Milestone:**									
Specific sessions with Consortium expert					Ask TPs and Demo Responsible their KPIs requirements					
First complete definitions of KPIs (link WP4)	List of KPIs variables for control requirements						List of KPIs variables for control requirements			
	List of KPIs, scale of relevance of KPIs and ToC of D2.4						List of KPIs, scale of relevance of KPIs and ToC of D2.4			
Integration of updates from T.2.4 and/or WP4 monitoring constraints Definition of KPI-based methodology (how to use the KPIs)	2nd version of list of KPIs First draft of D2.4								REVIEWED VERSION of the list First draft D2.4	
integrate new inputs and feedback + Deliverable 2.4	Deliverable submission					ToC				**D2.5**

Figure 2 – Gantt chart for T2.3

2.1 Relation to other tasks and deliverables

In order to define the list of KPIs, information from other tasks will be used (See Figure 3). Demosite information collected in T2.1 is used to define KPIs at demo-site level. The solar mapping and business models obtained in T2.2 will be used for the definition of appropriate KPIs for its evaluation. KPI's list will be considered in T2.4 for the simulation results. The information obtained from WP3 will support to KPI for what it concerns performance monitoring and instrumentation at technology package level.

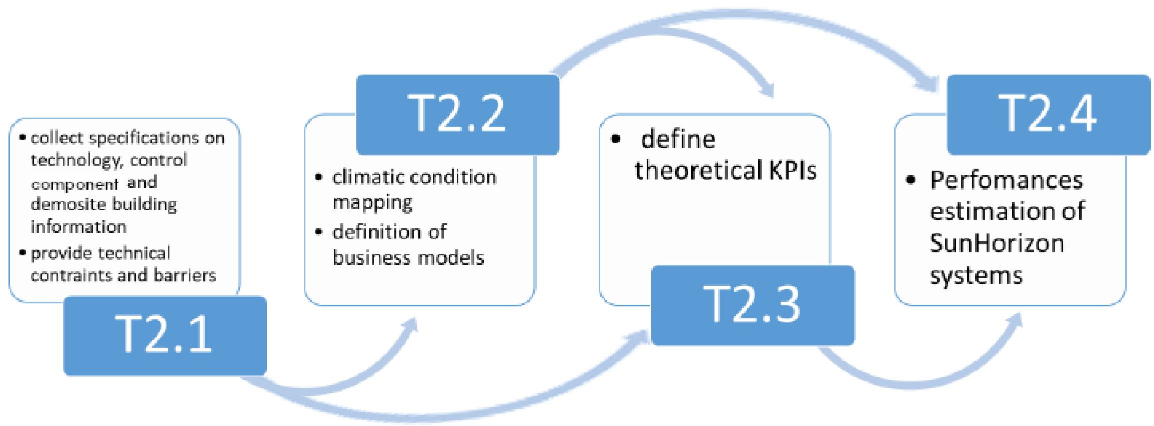


Figure 3 – Information/results exchange between WP2 tasks

Figure 4 shows the relationships of KPIs with WP4 and WP5. Monitored data will be collected in SE cloud platform to be exploited "as data mine" and will be fed for KPIs calculation (through different interfaces and APIs) for different WP4 and WP5 services. In particular, KPIs will be fed into the optimization processes in T4.3. The integration of analytics (based on the definition and evaluation of KPIs and other metrics) for surveillance and fault detection (T5.5) will help reliability-centred maintenance (RCM) practices of the involved energy systems in order to detect critical components and provide support for re-design of relevant facilities. Also, KPIs will be selected and implemented in the future monitoring system, what will be an additional input for decision-making strategies (T5.4) and will help to maintenance planning (T4.2).

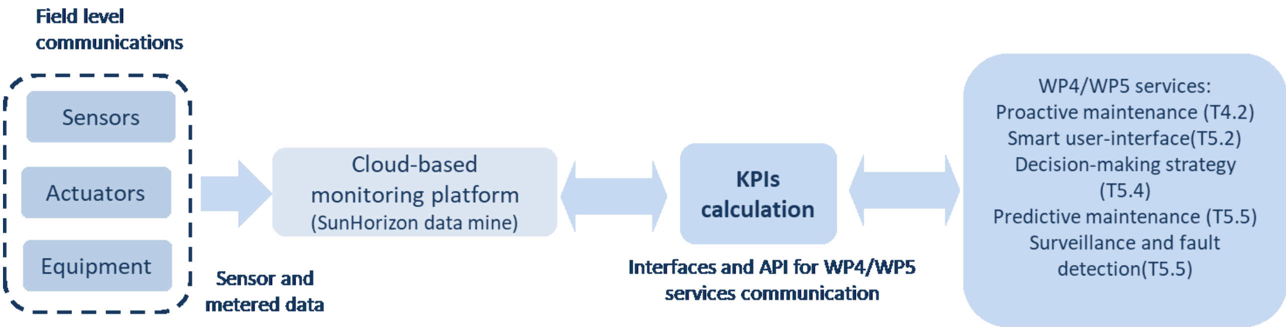


Figure 4 – KPI driven control strategy

At the demonstration campaign and monitoring (T6.4), KPIs will be regularly check at the monitoring database and evaluated to get insights and lessons learnt from the different demonstration cases (T6.5). Following the methodology definition in WP2, the assessment of the TPs deployed in the demo sites will come from the estimate of the energy baseline for each demo site and the analysis of the KPIs during the monitoring period. This work will also report specific guidelines for the TPs derived from the experience during the monitoring period.

As it can be seen, KPIs will be used throughout the project. Therefore, this document will continually evolve as to build on the results of the related Work Packages. Thus, this deliverable should be considered as a living document.

3 KPIs definition and data requirements

3.1 Nomenclature

The following table present the most common terms that are used in this document and to be used within the SunHorizon (SH) project. Some nomenclature and definitions are based on Task IEA SHC Task 60 in order to increase project dissemination and increase the impact of the project through different communication channels.

Term	Description
Q	Energy in the form of heat
E	Energy in the form of electricity
C	A negative amount of heat ("cold"). C=-Q
G	Global solar irradiation. With a subscript "h", denotes the irradiation on a horizontal surface and subscript "col" for irradiation on the collector plane
$\dot{Q}$, $\dot{E}$, $\dot{C}$, …	Energy flow rates: quantities representing a thermal or an electric power
A	Area. With a subscript "col", denotes the area of the solar collector. With a superscript "gross" denotes the gross solar collector area (it may be denoted to a different reference area: effective area, etc.)
AC	Subscript AC can be used to refer the electrical energy that is distributed as alternating current
DC	Subscript DC can be used to refer the electrical energy that is distributed as direct current
STC	Standard testing conditions, which are usually found in product datasheets
Sys	Subscript sys can be used to bundle all system components. It denotes that the energy is used within the system boundary
h	Subscript "h" can be used to denote useful energy used for heating purposes. Also SH, space heating, and DHW, domestic hot water, can be used
c	Subscript "c" can be used to denote useful energy used for cooling purposes
f	Subscript "f" can be used to denote final energy coming from fossil fuels (e.g. natural gas, GLP, etc.)
DS	Subscript DS can be used to refer to Dual Sun's technology, i.e. their hybrid solar and photovoltaic panels (also known as PVT panels)
FAHR	Subscript FAHR can be used to refer to FAHRENHEIT's technology, i.e. their adsorption chiller
BH	Subscript BH can be used to refer to BOOSTHEAT's technology, i.e. their natural gas heat pump
BDR	Subscript BDR can be used to refer to BDR Thermea's technology, i.e. their air-water heat pump(AWHP), or brine-water heat pump(BWHP), or flat plate collectors (FPC), or photovoltaic collectors (PV)
RT	Subscript RT can be used to refer to RATIOTHERM's technology, i.e. their adsorption chiller
TVP	Subscript TVP can be used to refer to TVP Solar SA's technology i.e. their high vacuum solar thermal technology (HVFPC)

Table 2 – Terms and description used within SunHorizon project

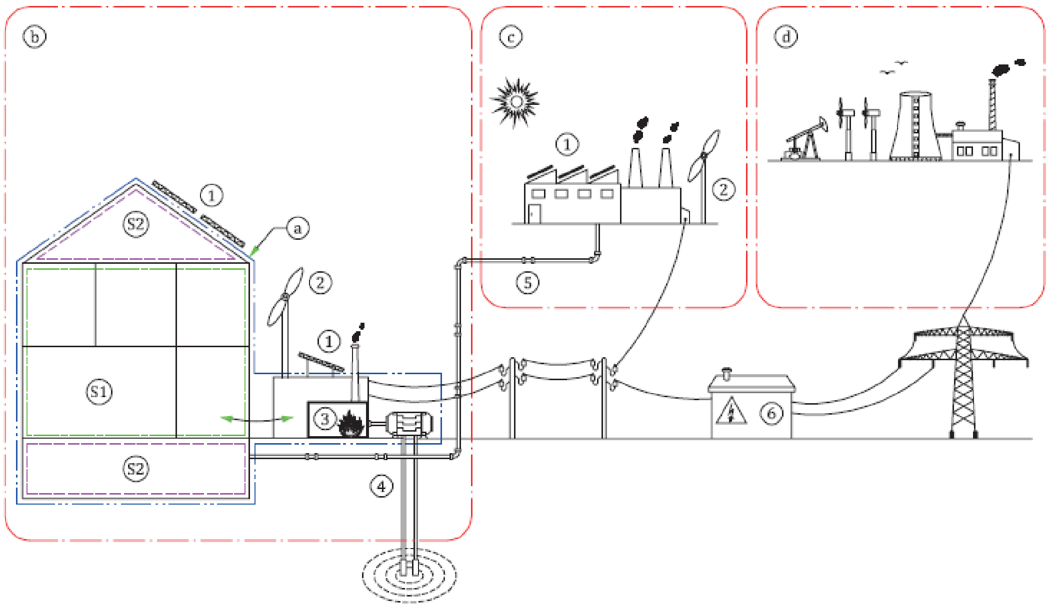
Energy quantities can be represented as absolute values (kWh) or per square meters (area within the assessment boundary, i.e. without considering spaces that are not thermal conditioned).

When a quantity of heat, cold or electricity that flows from a component A to a component B can be denoted by: $Q_{A,B}$, $C_{A,B}$(=-$Q_{B,A}$) or $E_{A,B}$. An asterisk means the sum of all heat or electrical energy that flows away from a component $Q_{A,*}$ or that is consumed by a component $Q_{*,A}$. Asterisk can be omitted if the context permits it, e.g., all electrical energy consumed by a heat pump: $E_{*,HP}$ or E_{HP} (IEA SHC Task 60, 2019).

3.2 Boundaries

The assessment boundary, for all demo-sites, is the one containing the thermally conditioned spaces and on-site SunHorizon's generation systems (See Figure 5, the assessment boundary is referred to "b" perimeter: on-site).

For the primary energy values, all losses in the whole chain are considered (the assessment boundary is referred to "d" perimeter: on-site + nearby + distant), using country-specific primary energy factors. As net metering is going to be applied in most of the demo-sites, the benefits of exporting energy are considered by applying the associated primary energy factor of the electrical grid of the country. This way the avoided grid electricity production will be evaluated, as a result of the exported PV production which reduces the primary energy consumption of the grid generators.



Key

a	assessment boundary (use energy balance)	1	PV, solar
b	perimeter: on-site	2	wind
c	perimeter: nearby	3	boiler room
d	perimeter: distant	4	heat pump
S1	thermally conditioned space	5	district heating/cooling
S2	space outside thermal envelope	6	substation (low/medium voltage and possible storage)

Figure 5 – Assessment Boundaries (figure obtained from ISO52000-2)

In Technology Packages where PV (from BDR) or PVT (from DS) is applied, there will be PV production. The aim of applying PV production is reducing the primary energy consumption (from outside the boundaries) and increasing the renewable energy share and self-consumption values. To assess that, electricity is measured at the perimeter "on-site", thus: accounting not only the electricity consumed by the SunHorizon's equipment but also the building's electricity consumption. In all cases, thermal energy that is not supplied by SunHorizon's equipment is out of the scope. For each demo, a definition of the boundaries will be made in section 3.6. Table 3 summarizes the different boundaries considered.

In case of thermal needs, domestic hot water and space heating are usually covered. Energy needs are consireded as the heat delivered or extracted by emitters (heat exchangers, radiators, fancoils, etc.) to maintain the intended space temperature conditions or to raise the domestic hot water from the cold network temperature to the prefixed delivered temperature. These thermal needs are usually lower than the thermal energy input to be delivered by the generation systems (See AUX 01 and AUX 02 in Annex 1), commonly known as "thermal energy use" or "thermal demand" (ISO52000-2). Usually, the thermal energy use is measured at the heat exchangers between the generation systems and the distribution systems. Thermal energy not supplied by the SunHorizon system (e.g. an individual air conditioner) is out of the scope assessment, unless the electricity of the building is intended to be covered.

BOUNDARIES	
Berlin	Only SH equipment, electricity regarding building's consumption is out of the scope/assessment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Berlin DHW and space heating are covered.
Nürnberg	Building's electricity + SH equipment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Nürnberg DHW and space heating are covered.
Sant Cugat	Only SH equipment, electricity regarding building's consumption is out of the scope/assessment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Sant Cugat only space heating and space cooling are covered. There is not DHW demand.
Madrid	Building's electricity + SH equipment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Madrid DHW, space cooling and space heating are covered.
San Lorenzo	Building's electricity + SH equipment. Thermal energy that is not supplied by SH is out of the scope/assessment. In San Lorenzo DHW, space cooling and space heating are covered.
Verviers Sport Centre	Only SH equipment, electricity regarding building's consumption is out of the scope/assessment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Verviers Sport Centre DHW and space heating are covered.
Verviers Swimming Pool	Building's electricity + SH equipment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Verviers Swimming Pool only the swimming pool heating is covered.
Riga	Building's electricity + SH equipment. Thermal energy that is not supplied by SH is out of the scope/assessment. In Riga DHW and space heating are covered.

Table 3 – Summary of the SunHorizon's boundaries.

3.3 Overall assessment methodology

SunHorizon project results will be evaluated comparing the baseline and post-retrofit situations according to the definition of assessment boundaries. Therefore, KPIs will be calculated and compared for different years (and conditions). To make a proper evaluation and depending on the availability of monitored data and/or bills of the pilots, the following calculation pathways can be taken:

- When monitored data and/or bills are missing, a simulation model for the system/s involved in the project will be used to create the baseline scenario. As this model cannot be validated with data, it cannot represent directly the baseline conditions. This can be solved by calibrating the models thanks to the monitoring data from the monitoring campaign of SunHorizon, and then remove the intervention of SH equipment to estimate the theoretical performance of the situation without the intervention (the methodology is based on option D of the IPMVP procedure[8]). In order to establish a clear definition of the baseline situation, all system specifications, occupation schedules, existing control specifications and characteristics of the demo will be considered.
- When there is data available, monitored data and/or bills will be used as baseline period definition. The baseline period will be extrapolated and projected over time assuming same behaviour but adjusting to the different weather conditions (in order to make baseline and post-retrofit consumptions and performance comparable). Thus, the baseline energy use data can be regressed against the coincident weather conditions to obtain the representative baseline regression coefficients and forecast the traditional situation (Doty & Turner, 2004).

"Once the model is calibrated for the baseline and post-retrofit situation, the KPIs are calculated for the baseline period and during the monitoring phase for each demosite, accordingly to the project monitoring campaign (T6.4) and lessons learnt task (T6.5)."

[8] Option D of the International Performance Measurement & Verification Protocol (IMPVP) uses a calibrated computer simulation models of component or whole-building energy consumption to determine energy savings

3.4 KPIs at demo-site level

3.4.1 Energy Performance

In this section, KPIs to assess the energy performance of the entire system are defined.

3.4.1.1 Non-renewable primary energy savings

Description

Non-renewable primary energy savings are defined as the difference between the non-renewable primary energy during the baseline period and the non-renewable primary energy during the post-retrofit period (i.e. after SunHorizon has been applied). Primary energy is defined by Article 2(5) of the Energy Performance of Buildings Directive 6 as *'the energy that has not undergone any conversion in the transformation process, calculated by energy carrier using a primary energy factor'*. It allows accounting all the losses of the whole energy chain, including those located outside the system boundary.

KPI's objective

The objective of this KPI is to evaluate the primary energy savings triggered by the project, assuming that the demo-sites' consumption would have behave following the same trend as in the baseline scenario. Baseline scenario will be obtained based on historical data, energy statistics or "enough-accurate" simulations of the demo-site in the absence of SunHorizon project. Appropriate adjustments of the baseline scenario has been explained in section 3.3.

Assessment method

In order to evaluate the reduction of fossil fuels and the amount of the associated energy that is saved, only non-renewable primary energy is considered in the assessment.

The amount of non-renewable primary energy (PE_{nren}, net primary energy) of the system is calculated as the weighed delivered energy to the building summed over all non-renewable energy carriers; less weighed exported energy summed over all energy carriers, as follows:

$$PE_{nren} = \sum Energy\ Delivered(kWh)_{energy\ carrier} \cdot PEF_{nren,energy\ carrier} - \sum Energy\ Exported(kWh)_{energy\ carrier} \cdot PEF_{nren,energy\ carrier} = E_{grid,sys} \cdot PEF_{nren,grid} + Q_f \cdot PEF_f - E_{PV,ex} \cdot PEF_{nren,grid} + \ldots^{9}$$

Eq. 1

Where:

Energy delivered is the amount of energy coming from outside the assessment boundaries (i.e. amount of electric energy from the grid, or gas consumption) that is delivered to the pilot.

Energy exported is the amount of energy used outside the assessment boundaries (i.e. amount of electric energy injected into the grid, etc.)

$E_{grid,sys}$ is the amount of energy coming from the grid, measured in the building's electrical meters

Q_f is the amount of energy contained in the fuel used (See Annex I, AUX03).

$E_{PV,ex}$ is the amount of energy injected into the grid (See Annex I, AUX19).

PEF_{nren} is the non-renewable primary energy factor (Perimeter: onsite, nearby, distant) (See Annex I, AUX24). For each demosite and energy carrier different primary energy factor should be used, depending on country-specific indicators[10]. The primary energy factor for PV exported will be something like the grid electricity values.

[9] Equation differs from case to case (depending on the energy carriers).

[10] Reference: ISO52000. *Primary energy factor: The system boundary shall encompass the primary energy required to extract and transport the energy carried to the building, as well as any other associated operations.*

Derived from Eq. 1, the difference between the baseline period (denoted with the subscript “bs”) and the post-retrofit period (once SH is applied, denoted with the subscript “pr”) is:

$$PES_{nren} = PE_{nren,bs} - PE_{nren,pr} \qquad \text{Eq. 2}$$

The periodicity of this calculation may be adapted to fit the application of the KPI and the goal pursued to compute the metric. For instance, for reporting a period equal to the length of project may be useful for evaluating the total non-renewable primary energy savings within the project. For simulation-optimization, a period equal to one day could be useful to find the scenario that optimizes this KPI. Besides that, PE_{nren} could be calculated and disaggregated into the different demands: PE_{nren} for DHW covering, PE_{nren} of space heating and space cooling, etc.

KPI EN01 can be also expressed in relative values:

$$f_{sav,PE} = 1 - \frac{\sum PE_{nren,pr}}{\sum PE_{nren,bs}} \qquad \text{Eq. 3}$$

To summarize:

Table 4 – Summary of KPI EN01 Non-renewable Primary Energy Savings

	REF	Notation	Description	Formula	Units	Category
1	EN01	PES_{nren}	Non-renewable Primary energy Savings (Net Balance)	$PES_{nren} = PE_{nren,bs} - PE_{nren,pr}$	kWh	Energy

Data requirement

Based on the formula aforementioned, the following data requirements are set for the KPI computation:

- natural gas (or any other energy carrier, e.g. biomass, LPG, etc.) volumetric flow rate (consumed) in a time interval. The LHV (Low Heating Value) should be provided by the gas company. Depending on the demo this data is necessary or not.
- final energy consumed from the electric grid in a time interval. Depending on the demo only SH equipment or both, SH equipment and building’s electricity consumption, will be considered.
- useful energy produced by the PV panels (or PVT in case of DS), i.e. energy measured at the AC output of the inverter. Depending on the demo this data is necessary or not.

In WP4, these requirements are sent in order to define the monitoring architecture. Technology providers and demo-site responsible are interviewed in order to know if the data is already being measured (by the PLC of the TPs or by the existing monitoring on-site, if there is any).

KPI Threshold

SH TPs are aimed to achieve a KPI EN01 value from 50 to 70% (EN01 expressed in relative values). Variation of the KPI depends on the different demands to be covered, size of the equipment and technologies involved (PV, PVT or only thermal). Objectives per demosite will be defined as soon as the size of the technologies and simulation results are obtained.

3.4.1.2 Renewable energy ratio

Description

Renewable energy is known as the total energy produced from renewable energy sources(RES), such as wind, solar, aerothermal, geothermal, hydrothermal, and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases (ISO, 2017). Thermal and Electricity renewable energy production is reported separately.

Renewable energy ratio is the amount of renewable primary energy that is used within the system's boundaries out of the total primary energy used. It expresses how much renewable energy has been used by the building, including energy from renewable sources produced on-site or delivered by nearby RES production plants. Primary energy factors are used to make the transformation. The exported renewable energy has been accounted for in the entrance and therefore the RER can be higher than 100 %.

KPI's objective

The objective of this KPI is to quantify how much energy is coming from RES, which can help during the control strategies (WP5 link) to maximize the energy coming from renewables and cut of CO_2 emissions.

Assessment method

In order to evaluate the energy coming from RES, non-renewable and renewable primary energy is considered in the assessment. The perimeter of the boundary takes into account net energy which is used to consider the "benefit" of reducing the total primary energy requirement of the grid generators (outside the limits) thanks to the exported energy (produced on-site by RES). This net energy (PEtot, AUX06), is calculated as the summed of non-RES primary energy (AUX07) and RES primary energy (AUX08). For the calculation of the primary energy derived from RES in post-retrofit period (AUX08), the renewable energy factors of the energy carriers are considered for the delivered energy and a factor of 1 is used for the on-site RES production. The ratio will be calculated as follows:

$$RER = \frac{PE_{ren}}{PE_{tot}} \quad \text{Eq. 4}$$

Where, PEren and PEtot can be calculated as explained in Annex 1 (See AUX08 and AUX06, respectively). The periodicity of Eq. 4 depends on the objective of the metrics, and it can be calculated daily, weekly, etc. KPI EN02 can be expressed in relative or absolute values.

Considering in the assessment the energy exported to the grid can lead to RER higher than 1 (or more than 100), as it can happen that there is a high amount of exported energy and the weighting factor for the delivered energy is lower than the weighting factor of the corresponding exported energy, therefore RER results in values higher than 1. Besides that, RER could be calculated for only electricity, in order to assess the electrical covering out of the total electricity consumption (from grid and from the PV/DS panels). RER could also be disaggregated into the different demands: RER for DHW covering, RER of space heating and space cooling, etc.

To summarize:

Table 5 – Summary of KPI EN02 Renewable Energy Ratio

	REF	Notation	Description	Formula	Units	Category
2	EN02	RER	Renewable Energy Ratio	$RER = \frac{PE_{ren}}{PE_{tot}}$	Ratio Or %	Energy

Data requirement

Based on the formula aforementioned, the following data requirements are set for the KPI computation:

- natural gas (or any other energy carrier, e.g. biomass, LPG, etc.) volumetric flow rate (consumed) in a time interval. The LHV (Low Heating Value) should be provided by the gas company or the owner. Depending on the demo this data is necessary or not.
- final energy consumed from the electric grid in a time interval. Depending on the demo only SH equipment or both, SH equipment and building's electricity consumption, will be considered.

- useful energy produced by the PV panels (or PVT in case of DS), i.e. energy measured at the AC output of the inverter. Depending on the demo this data is necessary or not.
- useful energy produced by the solar thermal panels (PVT in case of DS or HVFPC in case of TVP) i.e. energy at the panel output measured with heat meters or by measuring flow rate and temperatures.

In WP4, these requirements are sent in order to define the monitoring architecture. Technology providers and demo-site responsible are interviewed in order to know if the data is already being measured (by the PLC of the TPs or by the existing monitoring on-site, if there is any).

KPI Threshold

SH TPs are aimed to achieve a KPI EN02 value from 40 to 70% (EN02 expressed in relative values). Variation of the KPI depends on the different demands to be covered, size of the equipment and technologies involved (PV, PVT or only thermal). Objectives per demosite will be defined as soon as the size of the technologies and simulation results are obtained.

3.4.1.3 Electricity self-consumption fraction

Description

Electricity self-consumption fraction expresses the amount of energy (in relative or absolute values) that is used within the assessment boundaries out of the total PV production on-site.

KPI's objective

The indicator assesses the amount of electricity consumed on site that comes from solar PV, which helps to quantify the reduction of fossil fuel dependency and cut of CO_2 emissions. In combination with the KPI EN02, helps to understand how much RES electrical energy benefits directly the building (or, by extent the demo) and how much RES energy benefits beyond that.

Assessment method

As no battery is applied on SunHorizon's demosite and PV production and demand can happen at different time intervals, electric energy self-consumed on site ($E_{PV,sys}$) should be calculated as the summed of all the energy that is used in the building and comes from the energy produced on-site at the same calculation interval t (See AUX 05). The total PV production ($E_{PV,*}$) is the already useful energy measured at the inverter's output (AUX 20). The ratio, between $E_{PV,sys}$ and $E_{PV,*}$ is set as:

$$f_{self,el} = \frac{E_{PV,sys}}{E_{PV,*}} \quad \text{Eq. 5}$$

Where

$E_{PV,*}$ is the electric energy produced by PV panels on-site (Measured) can be calculated as explained in Annex 1 (See AUX 20).

$E_{PV,sys}$ is the electric energy self-consumed on-site, can be calculated as explained in Annex 1 (See AUX 05).

To summarize:

Table 6 – Summary of KPI EN03 Self Consumption fraction

	REF	Notation	Description	Formula	Units	Category
3	EN03	$f_{self,el}$	Electricity self-consumption fraction	$f_{self,el} = \frac{E_{PV,sys}}{E_{PV,*}}$	Ratio Or %	Energy

Data requirement

Based on the formula aforementioned, the following data requirements are set for the KPI computation:

- useful energy at the inverter's output, measured with a wattmeter (obtained directly from sensor of technology providers: DS or BDR)
- final energy consumed from the electric grid in a time interval. Depending on the demo only SH equipment or both, SH equipment and building's electricity consumption, will be considered.

KPI Threshold

For each demosite where PV or PVT technologies are applied, SH TPs are aimed to achieve a value of KPI EN03 up to 80%. Objectives per demosite will be defined as soon as the size of the technologies and simulation results are obtained.

3.4.2 Environmental Performance

Definition of KPIs to assess Environmental Performance of the entire system

3.4.2.1 GHG emissions reduction

Description

Greenhouse gases emissions reports the total CO_2-eq emissions of greenhouse gases emitted for all energy carriers associated with the primary energy use in the facility. The emissions factor (relating GHG and primary energy use) depends on country to country and energy carrier. GHG emissions reduction expresses the environmental impact difference before and after retrofitting, in absolute or relative total GHG emissions reduction associated with the net primary energy consumption of the facility.

KPI's objective

SunHorizon applies sun coupled innovative heat pumps that are more efficient, uses less primary energy and also demand is covered partially by renewable energy sources. It results, in principle, in less GHG emissions than the existing facility. The objective of this KPI is to measure the greenhouse gases emissions reduction as a result of applying SunHorizon technologies in a demosite.

Assessment method

Greenhouse gas emissions are calculated considering the net primary energy delivered in the building summed over all non-renewable energy carriers, multiplied by conversion factors for each energy carrier (See Annex I, AUX09).

Conversion factors are expressed in kg of CO_2 equivalent per kWh, are country-specific and may also include the equivalent emissions of other greenhouse gas emissions like methane, water vapour etc. When country specific values are missing, default conversion factors found in ISO52000 Table B16 (See Annex I) should be used. The conversion factors shall be coherent with the choice of referring to gross calorific value or net calorific value.

The difference between absolute total GHG emissions reduction before and after retrofitting is calculated as follows:

$$GHG_{sav} = \sum GHG_{bs} - \sum GHG_{pr} \qquad \text{Eq. 6}$$

It can be also expressed in relative values:

$$f_{sav,GHG} = 1 - \frac{\sum GHG_{pr}}{\sum GHG_{bs}} \qquad \text{Eq. 7}$$

Where the subscripts "bs" refers to baseline period and "pr" post-retrofit period

Table 7 – Summary of KPI ENV01 Self Consumption fraction

	REF	Notation	Description	Formula	Units	Category
4	ENV01	GHG_{sav}	GHG emissions reduction	$GHG_{sav} = \sum GHG_{bs} - \sum GHG_{pr}$	kg or tonCO2eq saved	Environmental

Data requirement

Based on Eq. 1, the same data requirements as KPI EN01 are used.

KPI Threshold

SH TPs are aimed to achieve a KPI ENV01 value from 40 to 60% (ENV01 expressed in relative values), depending on the different demands to be covered, size of the equipment and technologies involved (PV, PVT or only thermal). Objectives per demosite will be defined as soon as the size of the technologies and simulation results are obtained.

3.4.3 Economic Performance

Definition of KPIs to assess Economic Performance of the entire system

3.4.3.1 Costumer's bills reduction

Description

Costumer's bills reduction expresses the costs savings that are avoided by applying SunHorizon TPs. In order to be able to compare the different scenarios, costs are weighted considering the different energy needs covered before and after the SH's application (See section 3.6, to see the assessment boundaries). It represents the savings in the bills (electricity, gas, etc.) as a result of applying SunHorizon TPs.

KPI's objective

The objective of this KPI is being able to compare bill's reduction for the consumers and be able to assess the reduction in local energy bills (one of the objectives of the project). It is very similar to LCoE and LCoH but more intuitive for the consumer.

Assessment method

The reduction is calculated as the difference between the costs at the baseline period multiplied by a weighting factor, and the costs after the retrofit.

The KPI is defined as follows:

$$CBR = (C_f + C_E)_{bs} \cdot w_{bs/pr} - (C_f + C_E)_{pr} \quad \text{Eq. 8}$$

It can be also expressed in relative values:

$$f_{CBR} = 1 - \frac{(C_f + C_E)_{pr}}{(C_f + C_E)_{bs} \cdot w_{bs/pr}} \quad \text{Eq. 9}$$

Where the subscripts "bs" refers to baseline period and "pr" post-retrofit period; C_f are the summed of all fuel costs (gas, oil, etc.) of a facility (AUX10); C_E are the summed of all electricity costs (AUX11); and $w_{bs/pr}$ is the weighting factor, calculated as the % of costs associated to the same energy that is covered (assessed) in the post-retrofit period.

This KPI only considers the costs of electricity and fuels for a consumer. In public facilities or commercial buildings where the user has to pay for maintenance costs of their equipment, then the "Operational Costs Avoidance (OCA)" KPI (See Annex I, AUX16) could be used instead which is calculated by the total costs difference (OPEX weighted difference). Operational costs (OPEX) include not only the costs of electricity and fuels that are obtained from the bills, but also the maintenance costs and financing costs of their facility, and it is explained in KPI EC05.

Table 8 – Summary of KPI EC01 Specific energy savings

	REF	Notation	Description	Formula	Units	Category
5	EC01	CBR	Costumer's bills reduction	$CBR = (C_f + C_E)_{bs} \cdot w_{bs/pr} - (C_f + C_E)_{pr}$	€ saved	Economic

Data requirement

Cost breakdown from bills of the demo owners.

KPI Threshold

Demosites, where demonstration of SunHorizon controller is going to be fully deployed, are aimed to achieve a KPI EC01 up to 60%. For the other demosites, SunHorizon TPs are aimed to achieve a bill's reduction of 10 to 15%. These objectives will be better defined as soon as the technology and simulation will be performed in detail.

3.4.3.2 LCoH

Description

The Levelized Cost of Heat (LCoH) evaluates the cost of heat produced by the system over their life time. This enables the comparison of different designs and technical solutions. This is the combination of CAPEX and OPEX over the expected and actual lifetime of the plant. It assesses the costs reduction along the value chain (production to decommissioning) and system performance improvements.

KPI's objective

Helps to inform stakeholders on investing in a technology to pursue a project, as it measures lifetime costs divided by energy production over an assumed lifetime, allowing to compare different technologies of unequal life spans, project size, different capital cost, risk, return, and capacities (Office of Indian Energy (U.S. Department of Energy), 2019).

Assessment method

The most common calculation in literature is the Levelized Cost of Energy (LCoE). LCoE is not considered as KPI as the priority within the project is to supply space cooling and heating and DHW demands. Thus, LCoH is applied in this case, as it only evaluated the cost of heating (or cooling). The LCoH is given in €/kWh and it is defined as

$$LCoH = \frac{I_0 - S_0 + \sum_{i=1}^{T} \frac{OPEX_{year,i}}{(1+r)^i}}{\sum_{i=1}^{T} \frac{Energy_{year\ i}}{(1+r)^i}} \quad \text{Eq. 10}$$

Where

I_0 is the initial investment cost (or CAPEX) of the facility. (KPI EC04)
S_0 is part of the investment cost that is subsided (if any)
$OPEX_{year,i}$ operational expenditure of year I, calculated as the summed of all operating costs of the facility (KPI EC05).
$Energy_{year\ i}$ summed of final energy demands (AUX03 + AUX 04)
Some assumptions are needed for the value of "r" (interest rate).

It is important to mention that, not in all demos there is PV production and when there is, the technology (DS) also provides heat (only in San Lorenzo is a pure PV system). In the case of DS technology, the same technology provides two services and the cost will be influenced by two energy terms. Therefore, a correction factor for DS technology should be made in order to calculate the LCoE (instead of LCoH) associated to provide both, electricity and heating demand.

To summarize:

Table 9 – Summary of KPI EC02 LCoH

	REF	Notation	Description	Formula	Units	Category
6	EC02	$LCoH$	Levelized costs of heat	$LCoH = \frac{I_0 - S_0 + \sum_{i=1}^{T} \frac{OPEX_{year,i}}{(1+r)^t}}{\sum_{i=1}^{T} \frac{Energy_{year\ i}}{(1+r)^t}}$	€/kWh or cts€/kWh...	Economic

Data requirement

Based on Eq. 1, the same data requirements as KPI EN01 are used, and also investments costs and operational costs (cost breakdown from bills of the demo owners) are needed.

KPIs Threshold

SH TPs are aimed to achieve a KPI EC02 value from 2 to 4 cts€/kWh depending on the technology and demand covered. Objectives per demosite will be better defined as soon as the technology and simulation will be performed in detail.

3.4.3.3 Simple Pay Back

Description

Pay back is a conventional economic indicator to determine when profit generation starts. It is determinate by filling a cumulated cash flow table established year per year. Cash flow is negative the first year of investment; when it becomes positive, payback period has been reached. Simple payback can be calculated if the earnings are considered constant. In this case, the costs savings (AUX16) – as a result of applying SunHorizon - are the profits for the facility.

KPI's objective

Estimates the year of SH TP profit starts.

Assessment method

Simple Pay Back can be calculated as the ratio between the total capital expenditure (CAPEX, KPI EC04) of a facility and the earnings, which are the operating costs avoidance (OCA), calculated in Annex I, AUX 14. CAPEX is expressed in € and OCA is expressed in €/year. It can be defined as follows:

$$PB = \frac{CAPEX}{OCA} \qquad \text{Eq. 11}$$

Table 10 – Summary of KPI EC03 PB

	REF	Notation	Description	Formula	Units	Category
7	EC03	PB	Simple Pay Back	$PB = \frac{CAPEX}{OCA}$	years	Economic

Data requirement

Initial investment of the TPs and costs' breakdown of the facility provided by each demo owner.

KPIs Threshold

SH TPs are aimed to achieve a KPI EC03 maximum of 10 years for the demosites where the full demonstration of the SunHorizon controller is applied. Objectives per demosite will be better defined as soon as the technology and simulation will be performed in detail.

3.4.3.4 CAPEX

Description

Capital expenditure (CAPEX) is the total net initial investment for SunHorizon TP deployment.

KPI's objective

It is the investment cost of a Technology Package. When compared to a traditional gas-fired system, it provides valuable information of the CAPEX reduction.

Assessment method

The investment cost of a Technology Package is calculated as the summed of the individual investment costs of each technology and its associated components and hydraulics (pumps, valves, etc.). Each technology investment costs is provided directly by each technology provider. If subsidies are considered, the investment cost is calculated as the project cost less the part of the project cost that is subsidized. The subscript “tech” refers to technology, and “comp” to components.

$$CAPEX = \sum I_{tech,1} + \cdots + I_{tech,N} + \sum I_{comp,1} + \cdots + I_{comp,N} = I_0 \quad \text{Eq. 12}$$

When compared to a traditional gas-fired system, in relative values, the CAPEX reduction will be:

$$f_{CAPEX} = 1 - \frac{CAPEX_{SunHorizon}}{CAPEX_{traditional}} \quad \text{Eq. 13}$$

Table 11 – Summary of KPI EC03 PB

	REF	Notation	Description	Formula	Units	Category
8	EC04	$CAPEX$	Capital Expenditure	$CAPEX = I_0$	€	Economic

Data requirement

Initial investment breakdown of the TPs.

KPIs Threshold

SH TPs are aimed to achieve a reduction from 5 to 10% of the CAPEX per technology package. Objectives per TP will be better defined as soon as the technology and simulation will be performed in detail.

3.4.3.5 OPEX

Description

Operational expenditure (OPEX) is the sum of total operational costs expenditures on site, planned O&M and unscheduled maintenance.

KPI's objective

It should represent the operational costs of the Technology Packages. When compared to a traditional gas-fired system, it provides valuable information of the OPEX reduction.

Assessment method

OPEX is calculated as the sum of each operational cost: cost of fuel, cost of electricity, cost of maintenance of each technology (within the TP), costs of financing costs (if any), etc. If expressed in specific terms (€/kW), it is proposed to divide the OPEX by the total installed heating (or cooling) capacity of each TP.

$$OPEX = C_f + C_E + C_{maint} + C_{fin} \quad \text{Eq. 14}$$

When compared to a traditional gas-fired system, in relative values, the OPEX reduction will be:

$$f_{CAPEX} = 1 - \frac{OPEX_{SunHorizon}}{OPEX_{traditional}} \quad \text{Eq. 15}$$

Table 12 – Summary of KPI EC03 PB

	REF	Notation	Description	Formula	Units	Category
9	EC05	OPEX	OPEX (Operational Expenditure)	$OPEX = C_f + C_E + C_{maint} + C_{fin}$	€	Economic

Data requirement

Operational costs' breakdown of the facilities.

KPIs Threshold

SH TPs are aimed to achieve a reduction from 10 to 20% of the OPEX per technology package. Objectives per TP will be better defined as soon as the technology and simulation will be performed in detail.

3.4.4 Comfort Performance

Definition of KPIs to assess Comfort Performance of the entire system

Thermal comfort can be defined as the condition of mind which expresses people's satisfaction with their thermal environment. Traditional approaches relies on consolidated Fanger's theory, and take into account influencing variables like ambient air and radiant temperatures, relative humidity, air velocity as well as clothing and activity factors. If rigorously applied, the monitoring of these variables and computation of common comfort indexes such as PMV or PPD becomes challenging. However, in practice, most of the abovementioned variables either remain quite stable or are not influenced by the applied heating and cooling solutions, so they do not have substantial effects on the thermal perception. In this sense, indoor ambient temperature is by far the most relevant comfort variable, being used in the vast majority of buildings and HVAC control systems as the main KPI to evaluate comfort performance. Next, two temperature-based indicators are proposed to evaluate SunHorizon solutions in terms of thermal comfort provision during a given period of time.

3.4.4.1 Heating comfort Index

Description

The Heating Comfort Index (HCI) represents a measure of the discomfort level during heating operation periods linked to the inability of the heating system to provide enough high temperature conditions. This could be calculated based on the number of occupancy hours below the established acceptable comfort range; however, in order to account for how severe the discomfort level is, HCI weighs those discomfort hours in terms of the distance between the current indoor temperature and the lower comfort temperature limit.

KPI's objective

Identification and quantification of low SunHorizon comfort performance linked to the provision of too cold thermal conditions during heating operation

Assessment method

According to the previous definition, the HCI is calculated as the cumulated sum of hourly values for the product of discomfort hours and the temperature difference between the lower comfort limit and the current real ambient temperature. Therefore, it is expressed in ºC·h. It can be defined as follows:

$$HCI = \sum \left(T_{comf,min} - T\right) \cdot \Delta t \,, \qquad if\ T < T_{comf,min} \qquad \text{Eq. 16}$$

It should be noted that only discomfort hours during the occupancy schedule contribute to the cumulated sum.

Table 13 – Summary of KPI COM01 - HCI

	REF	Notation	Description	Formula	Units	Category
10	COM01	HCI	Heating Comfort Index	$HCI = \sum \left(T_{comf,min} - T\right) \cdot \Delta t \,, \quad if\ T < T_{comf,min}$	ºC·h	Comfort

Data requirement

Only indoor ambient temperature should be measured. However, the occupancy schedule should be taken into account in order to disregard discomfort conditions out of this period.

KPIs Threshold

A reasonable threshold for HCI has been estimated on a weekly value of 7 ºC·h based on the assumption of average 10h/day occupancy schedule (including weekends for residential bulidings) and an assumable 10% of the time in which the heating setpoint may not be met (with +/- 1ºC average deviation). This is substantially more restrictive than traditional PPD<10% targets. In case of tertiary buildings, comfort requirements should be less restrictive, thus a 15 ºC·h can be assumed as threshold. Objectives per demosite will be better defined as soon as the technology and simulation will be performed in detail.

3.4.4.2 Cooling comfort Index

Description

The Cooling Comfort Index (CCI) represents a measure of the discomfort level during cooling operation periods linked to the inability of the cooling system to sufficiently reduce the temperature conditions. This could be calculated based on the number of occupancy hours above the established acceptable comfort range; however, in order to account for how severe the discomfort level is, CCI weighs those discomfort hours in terms of the distance between the upper comfort temperature limit and the current indoor temperature.

KPI's objective

Identification and quantification of low SunHorizon comfort performance linked to the provision of too hot thermal conditions during cooling operation

Assessment method

According to the previous definition, the CCI is calculated as the cumulated sum of the hourly values for the product of discomfort hours and temperature difference between the lower comfort limit and the current real ambient temperature and the upper limit of the considered comfort range. Therefore, it is expressed in ºC·h.

$$CCI = \sum \left(T - T_{comf,max}\right) \cdot \Delta t \,, \qquad if\ T > T_{comf,max} \qquad \text{Eq. 17}$$

It should be noted that only discomfort hours during the occupancy schedule contribute to the cumulated sum.

Table 14 — Summary of KPI COM02 CCI

	REF	Notation	Description	Formula	Units	Category
11	COM02	CCI	Cooling Comfort Index	$CCI = \sum \left(T - T_{comf,max}\right) \cdot \Delta t \,, \quad if\ T > T_{comf,max}$	ºC·h	Comfort

Data requirement

Only indoor ambient temperature should be measured. However, the occupancy schedule should be accounted for in order to disregard discomfort conditions out of this period.

KPIs Threshold

Similarly to HCI, a reasonable threshold for CCI has been estimated on a weekly value of 7ºC·h based on the assumption of average 10h/day occupancy schedule (including weekends for residential buildings) and an assumable 10% of the time in which the cooling set-point may not bemet (with +/- 1ºC average deviation). This is substantially more restrictive than traditional PPD < 10% targets. In case of tertiary buildings, comfort requirements should be less restrictive, so 15 ºC·h can be assumed as threshold. Objectives per demosite will be better defined as soon as the technology and simulation will be performed in detail.

3.4.4.3 Costumer's satisfaction rate

Description

Customer Satisfaction Score (CSAT) measures an average value of costumer comfort level in the building. The users give their opinion in a range from 1 to 5 (liker scale). The user-interface implemented on-site is a tablet PC on a mount making it accessible. An average value of the costumer's satisfaction rate is obtained as the mean value of all user opinions recollected daily. It is not applicable for all demo sites, as this user-interface is only implemented to the demo-site that are public buildings (Verviers).

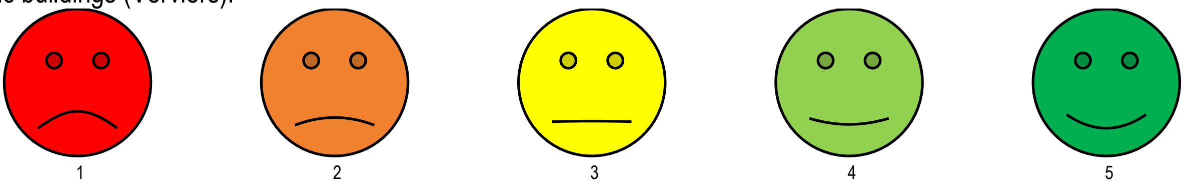


Figure 6 – graphic of the liker scale (answer for each question)

KPI's objective

The objective of this KPI is to obtain the user behaviour and in this way, feed the learning algorithms in T5.3. SH scope is not aimed to achieve a specific value of CSAT score, it aims to learn from the user to achieve better cooling and heating comfort indexes.

Assessment method

For this purpose, several questions will allow the users to provide their feedback with the aim of learning from them (comfort levels and habits). The question will be the following:

- *How would you describe the comfort level of the indoor temperature here today?*
- *How would you describe the comfort level of the indoor air humidity here today?*
- *This facility has been equipped with a X that has reduces greenhouse gas emissions by _ kg CO_2eq (annual CO_2eq per person and year in the EU is _ kg) during the last month. How does this information affect your experience here today?*
- *This facility has been equipped with a Y that has reduces greenhouse gas emissions by _ kg CO_2eq (annual CO_2eq per person and year in the EU is _ kg) during the last month. How does this information affect your experience here today?*
- *This facility has been equipped with a Z that has reduces greenhouse gas emissions by _ kg CO_2eq (annual CO_2eq per person and year in the EU is _ kg) during the last month. How does this information affect your experience here today?*

Where X, Y, Z would be equipment installed by SunHorizon technology provider partners (different depending on the demosite). Therefore, the overall feedback could be obtained by weighting the answer in the following way:

$$CSAT\ score = \left(\frac{\sum scores\ on\ the\ questions}{number\ of\ answers\ on\ the\ question}\right) / \ 5 \qquad \text{Eq. 18}$$

The CSAT score will be gathered each time a user gives their feedback. Several users could give their opinion in the same hour, resulting in several CSAT scores for certain outdoor and indoor conditions. For learning algorithms, it would be interesting to have an average CSAT score for hourly values in order to learn from them in that specific hour (with specific indoor and outdoor conditions). Average daily values of CSAT score could be used for knowing the overall comfort.

Table 15 – Summary of KPI COM3 - CSAT

	REF	Notation	Description	Formula	Units	Category
12	COM3	$CSAT$	Costumer's satisfaction rate	$CSAT\ score = \left(\frac{\sum scores\ on\ the\ questions}{number\ of\ answers\ on\ the\ question}\right) / \ 5$	0 to 1 Or %	Comfort

Data requirement

Scores from the questions provided by the user interface, number of answers per user and number of users per hour that have answered the questions.

3.5 PIs at technology level

3.5.1 Performance indicators

3.5.1.1 TVP

TVP technology has MT-Power High Vacuum Solar Thermal technology with a transparent insulating material that can reach up to 180ºC. Starting from this experience, TVP will optimize and demonstrate a lower temperature high efficiency solar thermal system dedicated to space heating and DHW services. In order to assess the performance to be achieved within SH project, the following PIs are defined for TVP technology:

- Instantaneous thermal efficiency
- Solar thermal fraction

PIs Threshold

TVP aims to achieve an instantaneous solar thermal efficiency of 70% (at 90ºC). Furthermore, TVP aims to achieve an energy output increase of 20% (compared to traditional flat plate solar thermal collectors), resulting in better solar thermal fractions (PI TPV02) compared to traditional solar fields. As the solar fraction depends on the overall system's consumption, a value will be given once the size of all technologies and simulations results are obtained. Regarding economic values, TVP targets a CAPEX of 500€/m^2 and an OPEX of 59% less in comparison with average gas prices for typical households at EU-28 level.

Instantaneous thermal efficiency:

The panel is tested by ISO standard 9806 to determine the collector performance in standard conditions and energy production (Q in watts) of the panel depending on solar radiation and ambient temperature data (Chamsa-ard, Sukchai, Sonsaree, & Sirisamphanwong, 2014). In real-time conditions, the efficiency is calculated as the ratio between the useful energy output ($\dot{Q}_{TVP,*}$) and solar irradiance received in the titled surface of the panel. Therefore, the efficiency is stated as follows:

$$\eta_{TVP,at\,T_{supply}}^{gross} = \frac{\dot{Q}_{TVP,*}}{G_{col} \cdot A_{TVP}^{gross}} \qquad \text{Eq. 19}$$

Where

- $Q_{TVP,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22)
- G_{col} is the solar irradiation on the collector plane
- A is the solar gross surface area (specified by technology provider). Also efficiencies may also be related to different reference area (effective area, absorber area, etc.).

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation (or computation of the average value) will allow calculating daily, weekly, monthly and yearly KPI values. Figure 7 shows the main TVP variables to calculate TVP's KPIs. The following data is required to compute the calculation:

- To determine the useful energy output ($\dot{Q}_{TVP,*}$) either a heat meter is used or by measuring the flow ($\dot{m}_{TVP}$) and the temperature difference in/out of the panel ($T_{out,TVP} - T_{in,TVP}$)
- The irradiance (G_{col}) can be obtained from a weather station (measured or estimated irradiance) or by a weather service
- In order to consider the temperature at which the solar technology is supplying heat, for instantaneous efficiencies the collector mean fluid temperature is $T_m = \frac{T_{in}+T_{out}}{2}$, and for seasonal values the following indicator to calculate the average operating temperature could be used:

$$T_m^{char} = \int_0^T \frac{T_m dt}{T} \qquad \text{Eq. 20}$$

Superscript *char* refers to characteristic temperature.

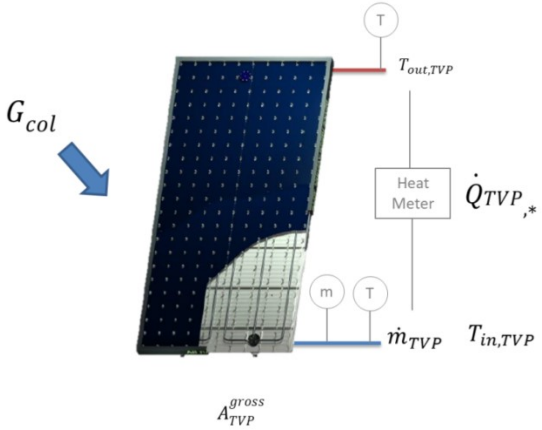


Figure 7 – TVP illustration (Variables and data requirements)

To summarize:

Table 16 – Summary of PI TVP01 Instantaneous thermal efficiency

REF	Notation	Description	Formula	Units
TVP01	$\eta^{gross}_{TVP,at\ T_{supply}}$	Instantaneous thermal efficiency	$\eta^{gross}_{TVP,at\ T_{supply}} = \frac{\dot{Q}_{TVP,*}}{G_{col} \cdot A^{gross}_{TVP}}$	% or ratio

Solar thermal fraction

The **solar thermal fraction** expresses how much heat input into the system is provided by solar thermal energy. It can be defined as:

$$f_{sol,th} = \frac{Q_{TVP,*}}{Q_{*,sys}} \quad \text{Eq. 21}$$

Where:

$Q_{TVP,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22). If TVP supplies the evaporator of a heat pump, only the part that is directly provided to cover heating and DHW needs should be considered.

$Q_{*,sys}$ is thermal energy output from other technologies (e.g. summed of all other energy inputs to RT)

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements.

The following data is required to compute the calculation:

- To determine the sum of all heat inputs to the system, useful energy outputs or energy inputs to the main tank (RT tank in most cases) should be measured either by a heat meter or by means of measuring the flow and the temperature difference in/out.

Table 17 – Summary of PI TVPV02 Solar Thermal Fraction

REF	Notation	Description	Formula	Units
TVP02	$f_{sol,th}$	Solar Thermal Fraction	$f_{sol,th} = \frac{Q_{TVP,*}}{Q_{*,sys}}$	ratio

3.5.1.2 BH

BoostHeat (BH) is a gas driven heat pump technology that combines the best of heat pump and condensing boiler technologies to achieve unmatched efficiency. It consists of a single thermodynamic module with one or more thermal compressors in parallel, a heating head, a low-NO_x burner, an exchanger, CO_2 heat pump circuit, and a control system. In order to assess the performance to be achieved within SH project, the following PIs are defined for BH technology:

- Seasonal Gas Utilization Efficiency
- Seasonal Performance Factor

PIs Threshold

BH aims to achieve up to 200% of SGUE values (PI BH01). The Seasonal Performance Factor depends on the overall installation, thus it will be calculated in detailed during simulations. Regarding economic values, BH aims to achieve an OPEX reduction of 20% compared with traditional gas-fired systems.

Seasonal Gas Utilization Efficiency

Seasonal Gas Utilization Efficiency (SGUE) means the gas utilization efficiency to provide a useful output, which can be calculated as the ratio of the overall heating energy to the overall gas consumption:

$$SGUE = \frac{\int \dot{Q}_{BH,h,*}\, dt}{\int \dot{Q}_f\, dt} \qquad \text{Eq. 22}$$

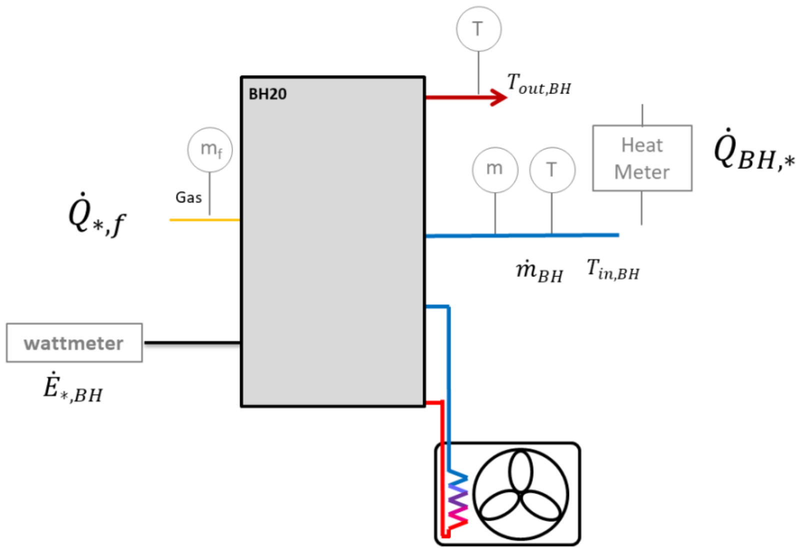


Figure 8 – BH illustration (variables and possible data requirements)

Figure 8 shows the main BH variables to calculate BH's KPIs. Heat flows and electricity consumption will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. The following data is required to compute the calculation:

- $\dot{Q}_{BH,h,*}$ is the thermal energy output (heating) from the boost heat unit obtained from AUX 22(See Annex I), or directly measured by heatmeter.
- $\dot{Q}_f$ is the final energy consumption (gas) in kWh obtained from AUX 03 (See Annex I), or directly measured by heatmeter or gas flowmeter m^3. In the latter case, a transformation to kWh is needed.

Table 18 – Summary of PI BH 01 Seasonal Gas Utilization Efficiency

REF	Notation	Description	Formula	Units
BH01	$SGUE$	Seasonal Gas Utilization Efficiency	$SGUE = \frac{\int \dot{Q}_{BH,h,*}\,dt}{\int \dot{Q}_f\,dt}$	ratio

Seasonal Performance Factor

Seasonal Performance Factor (SPF) is the efficiency factor of the unit in primary energy terms. It considers the total amount of primary energy used to produce a useful output, including electricity associated to pumps, auxiliaries, etc. of the BH unit, and the gas consumption. It allows to compare different type of heat pumps. It can be calculated as the ratio of the overall heating energy to the total primary energy consumed, as follows:

$$SPF_{BH} = \frac{\int \dot{Q}_{BH,h,*}\,dt}{\left(\int \dot{E}_{*,BH}\,dt\right)PEF_{tot,cr} + \left(\int \dot{Q}_{*,BH}\,dt\right)PEF_{tot,cr}} \quad \text{Eq. 23}$$

Besides the previous data required for compute PI BH01 computation, the amount of $\dot{E}_{*,BH}$ electrical energy consumption in kWh is also required, and it can be obtained from AUX04 (See Annex I) or directly measured by wattmeters. As the compressor is thermal driven, the electricity consumption of the BH unit is very low and associated with the auxiliaries and pumps' consumption.

Table 19 – Summary of PI BH02 Seasonal performance factor

REF	Notation	Description	Formula	Units
BH02	SPF_{BH}	Seasonal Performance Factor	$SPF_{BH} = \frac{\int \dot{Q}_{BH,h,*}\,dt}{\left(\int \dot{E}_{*,BH}\,dt\right)PEF_{tot,cr} + \left(\int \dot{Q}_{*,BH}\,dt\right)PEF_{tot,cr}}$	% or ratio

3.5.1.3 FAHR

FAHR technology is a hybrid sorption/compression chiller that uses low GWP and ODP refrigerants and combines the energy efficiency of adsorption technology with the precision and power of compression cooling. Silica gel is used as an adsorbent in the current models but Zeolites adsorbents for the sorption technology and alternative refrigerants for the compression part will be studied. The current available models have a total cooling capacity ranging between 45 to 90 kW. In order to assess the performance to be achieved within SH project, the following PIs are defined for FAHR technology:

- Seasonal electric EER (cooling)
- Seasonal Performance Factor of FAHR unit

PIs Threshold for FAHR

FAHR aims to achieve an increase of COP of 20-30% and an OPEX reduction of 10-15% compared to the state of the art of vapour compression systems. The Seasonal Performance Factor depends on the overall installation; thus it will be calculated in detailed during simulations. Regarding economic values, FAHR aims to achieve a CAPEX reduction of 20% compared to the current thermally driven chiller prices.

Seasonal electric EER (cooling)

Electric Efficiency Ratio (EER) is the energy efficiency ratio of a heat pump, air conditioner or comfort chiller, in cooling mode calculated as the cooling demand divided by the associated energy consumption to provide that cooling demand throughout a specific time period. Heating mode of the FAHR technolgy is out of the scope of SunHorizon (it will only cover space cooling needs)

$$(S)EER = \frac{\int \dot{Q}_{FAHR,c,*}\, dt}{\int \dot{E}_{*,FAHR}\, dt} \qquad \text{Eq. 24}$$

Heat flows and electricity consumption will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. If the computation is made for a year, it is representative for the cooling season, and it is widely known as Seasonal electric EER (cooling mode).

Figure 9 shows the main FAHR variables to compute the FAHR KPIs. The following data is required to compute the calculation:

- $\dot{Q}_{FAHR,c,*}$ is the thermal energy output (cooling) from the FAHR unit obtained from AUX 22(See Annex I), or directly measured by heatmeter or by measuring the flow ($\dot{m}_{FAHR}$) and the temperature difference in/out of the unit ($T_{out,FAHR} - T_{in,FAHR}$).
- $E_{*,FAHR}$ electric energy consumption measured at the FAHR unit obtained from AUX 23 (See Annex I). All auxiliaries, pumps, etc. and compressor's energy consumption are included

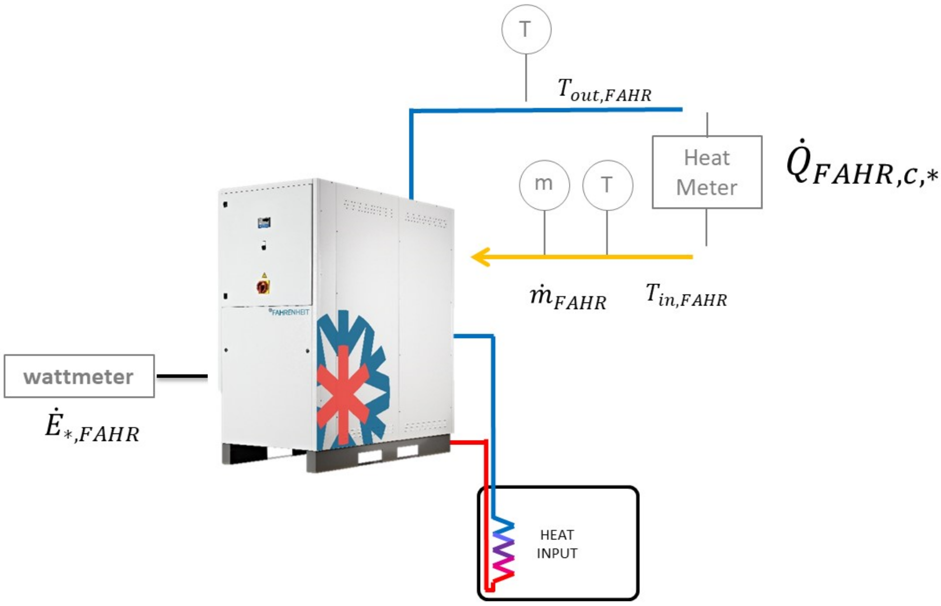


Figure 9 – FAHR illustration (variables and possible data requirements)

Table 20 – Summary of PI FAHR 01 Seasonal electric EER (cooling)

REF	Notation	Description	Formula	Units
FAHR01	$(S)EER$	Seasonal electric EER (cooling)	$(S)EER = \frac{\int \dot{Q}_{FAHR,c,*}\,dt}{\int \dot{E}_{*,FAHR}\,dt}$	ratio

Seasonal Performance Factor of FAHR unit

Seasonal Performance Factor (SPF) is the efficiency factor of the unit in primary energy terms. It considers the total amount of primary energy used to produce a useful output, including electricity associated to pumps, auxiliaries, etc. of the FAHR unit and other energy carrier's consumption (if there is any). It can be calculated as the ratio of the overall heating energy to the total primary energy consumed, as follows:

$$SPF_{FAHR} = \frac{\int \dot{Q}_{FAHR,c,*}\,dt}{\left(\int \dot{E}_{*,FAHR}\,dt\right)PEF_{tot,cr} + \left(\int \dot{Q}_{*,FAHR}\,dt\right)PEF_{tot,cr}} \quad \text{Eq. 25}$$

Table 21 – Summary of PI FAHR 02 Seasonal Performance Factor

REF	Notation	Description	Formula	Units
FAHR02	SPF_{FAHR}	Seasonal Performance Factor of FAHR unit	$SPF_{FAHR} = \frac{\int \dot{Q}_{FAHR,c,*}\,dt}{\left(\int \dot{E}_{*,FAHR}\,dt\right)PEF_{tot,cr} + \left(\int \dot{Q}_{*,FAHR}\,dt\right)PEF_{tot,cr}}$	% or ratio

Besides the previous data required for compute PI FAHR01 computation, the amount of $\dot{Q}_{*,FAHR}$ heating energy consumption in kWh is also required, and it can be obtained from AUX01 (See Annex I) or directly measured by heatmeters (in case of Sant Cugat demosite, TP3, this heating energy comes from solar thermal energy and the PEFtot factor is 1, being entirely from a renewable energy source).

3.5.1.4 BDR

BDR has three technologies to be applied within the project:

- An electrical heat pump to be combined with solar thermal. The heat pump heating power range is, for residential heating, from 4kW to 27kW. PIs defined are: Seasonal electric COP (heating), seasonal electric EER (cooling), and Seasonal Performance Factor (SPF)
- Flat plate solar thermal collector. PIs defined are: Instantaneous thermal efficiency and solar thermal fraction
- PV solar panel. PI defined is solar electric efficiency.

BDR is going to develop and demonstrate (also thanks to SunHorizon tool) an optimally sized and managed “Solar hybrid HP” package. Considering weather forecast, consumption profile and energy storage capacity, making it predictable and manageable, it will enhance the matching of supply/demand and the locally use of the solar energy self-produced.

PIs Thresholds for BDR

BDR will apply different technologies in SunHorizon. BDR aims to increase the COP of the systems in 15% thanks to the optimal integration of the PV or PVT panels with the heat pump, compared to traditional vapour compression systems. It will result in 15% electricity savings and 20% of OPEX reduction.

3.5.1.4.1 BDR heat pump

Seasonal electric COP (heating)

Coefficient of performance (COP) is the energy efficiency ratio of a heat pump, air conditioner or comfort chiller, in heating mode calculated as the heating demand divided by the associated energy consumption to provide that demand, calculated throughout a specific time period.

$$(S)COP_{BDR} = \frac{\int \dot{Q}_{BDR,h,*}\, dt}{\int \dot{E}_{*,BDR}\, dt} \qquad \text{Eq. 26}$$

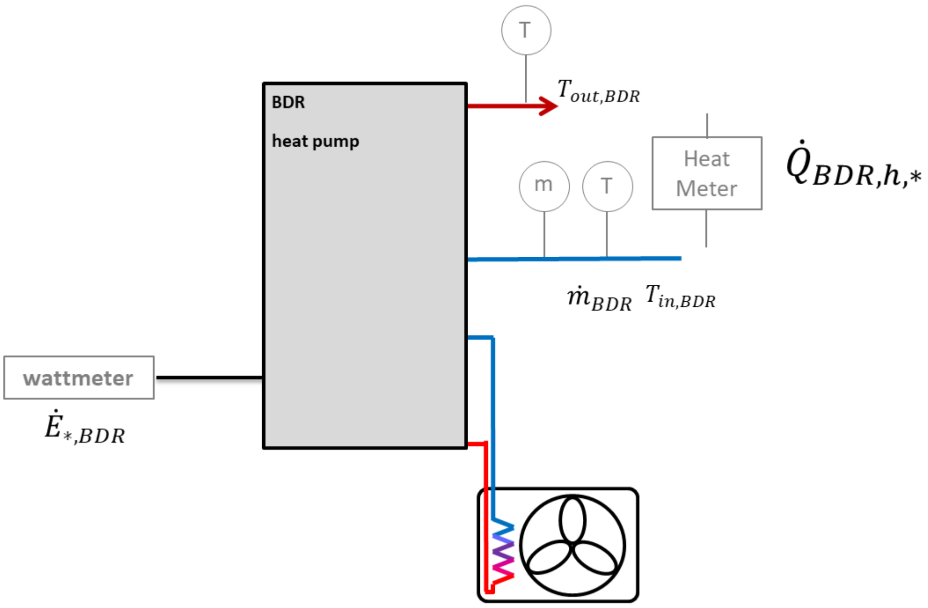


Figure 10 – BDR’s heat pump illustration in heating mode (variables and possible data requirements)

Heat flows and electricity consumption will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. If the computation is made for a year, it is representative for the heating season, and it is widely known as Seasonal Coefficient of Performance (heating mode, SCOP). Figure 10 shows the BDR’s heat pump in heating mode, and it shows the main variables to calculate BDR’s HP KPIs (heating mode). The following data are required to compute the calculation:

- $\dot{Q}_{BDR,h,*}$ is the thermal energy output (heating) from the BDR heat pump obtained from AUX 22(See Annex I), directly measured by heatmeter or by measuring the flow $(\dot{m}_{BDR})$ and the temperature difference in/out of the unit $(T_{out,BDR} - T_{in,BDR})$.
- $E_{*,BDR}$ electric energy consumption measured at the BDR heat pump obtained from AUX 23 (See Annex I). All auxiliaries, pumps, etc. and compressor's energy consumption are included

Table 22 – Summary of PI BDR 01 Seasonal electric COP (heating)

REF	Notation	Description	Formula	Units
BDR01	$(S)COP_{BDR}$	Seasonal electric COP (heating)	$(S)COP_{BDR} = \frac{\int \dot{Q}_{BDR,h,*}\,dt}{\int \dot{E}_{*,BDR}\,dt}$	ratio

Seasonal electric EER (cooling)

Electric Efficiency Ratio (EER) is the energy efficiency ratio of a heat pump, air conditioner or comfort chiller, in cooling mode calculated as the cooling demand divided by the associated energy consumption to provide that cooling demand calculated throughout a specific time period.

$$(S)EER_{BDR} = \frac{\int \dot{Q}_{BDR,c,*}\,dt}{\int \dot{E}_{*,BDR}\,dt} \quad \text{Eq. 27}$$

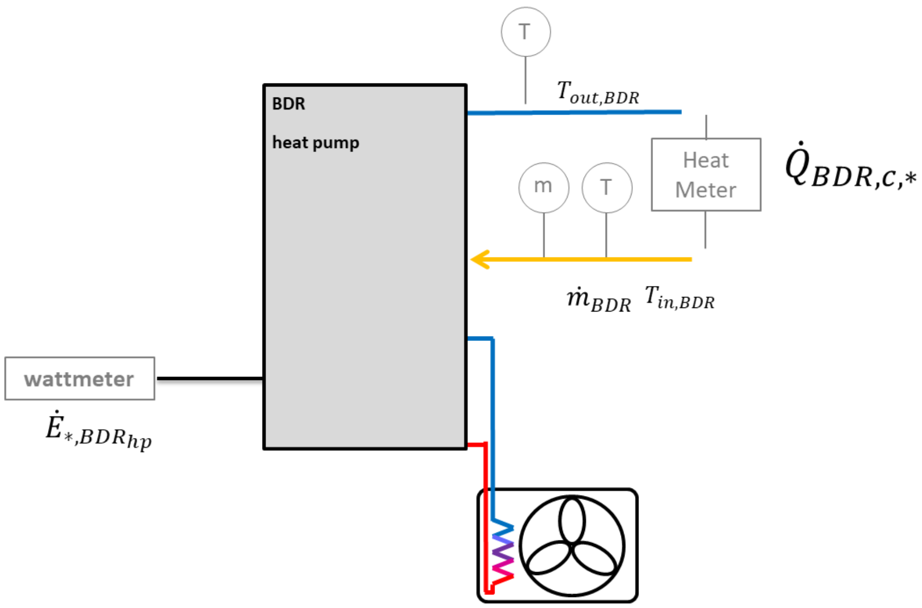


Figure 11 – BDR's heat pump illustration in cooling mode (variables and possible data requirements)

Heat flows and electricity consumption will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. If the computation is made for a year, it is representative for the heating season, and it is widely known as Seasonal electric EER (cooling mode, SEER). Figure 11 shows the BDR's heat pump in cooling mode, and it shows the main variables to calculate BDR's HP KPIs (cooling mode). The following data are required to compute the calculation:

- $\dot{Q}_{BDR,c,*}$ is the thermal energy output (cooling) from the BDR heat pump obtained from AUX 22(See Annex I), or directly measured by heatmeter or by measuring the flow $(\dot{m}_{BDR})$ and the temperature difference in/out of the unit $(T_{in,BDR} - T_{out,BDR})$.
- $E_{*,BDR}$ electric energy consumption measured at the BDR heat pump obtained from AUX 23 (See Annex I). All auxiliaries, pumps, etc. and compressor's energy consumption are included

Table 23 – Summary of PI BDR 02 Seasonal electric EER (cooling)

REF	Notation	Description	Formula	Units
BDR02	$(S)EER_{BDR}$	Seasonal electric EER (cooling)	$(S)EER_{BDR} = \frac{\int \dot{Q}_{BDR,c,*}\, dt}{\int \dot{E}_{*,BDR}\, dt}$	ratio

Seasonal Performance Factor of BDR's unit

Seasonal Performance Factor (SPF) is the efficiency factor of the unit in primary energy terms. It considers the total amount of primary energy used to produce a useful output, including electricity associated to pumps, auxiliaries, etc. of the BDR unit and other energy carrier's consumption (if there is any). It can be calculated as the ratio of the overall heating energy to the total primary energy consumed, as follows:

$$SPF_{BDR} = \frac{Q_{BDR,*}}{(E_{*,BDR})PEF_{tot} + (Q_{*,BDR})PEF_{tot}}$$

Eq. 28

Table 24 – Summary of PI BDR 03 Seasonal Performance Factor

REF	Notation	Description	Formula	Units
BDR03	SPF_{BDR}	Seasonal Performance Factor of BDR unit	$SPF_{BDR} = \frac{Q_{BDR,*}}{(E_{*,BDR})PEF_{tot} + (Q_{*,BDR})PEF_{tot}}$	% or ratio

Besides the previous data required for PI BDR01 and BDR02 computation, the amount of $\dot{Q}_{*,BDR}$ (energy consumption in kWh in the condenser in cooling mode, and evaporator in heating mode) is also required. It can be obtained from AUX01 (See Annex I) or directly measured by heatmeters. In any case, either if the heating energy comes from solar thermal energy or the environment the PEFtot factor is 1, being entirely from a renewable energy source.

3.5.1.4.2 BDR Solar thermal panels

Instantaneous thermal efficiency:

The panel is tested by ISO standard 9806 to determine the collector performance in standard conditions and energy production (Q in watts) of the panel depending on solar radiation and ambient temperature data (Chamsa-ard, Sukchai, Sonsaree, & Sirisamphanwong, 2014). In practice, the efficiency is calculated as the ratio between the useful energy output ($\dot{Q}_{BDRcol,*}$) and solar irradiance received in the titled surface of the panel. Therefore, the efficiency is stated as follows:

$$\eta_{BDRcol,th}^{gross} = \frac{\dot{Q}_{BDRcol,*}}{G_{col} \cdot A_{BDRcol}^{gross}}$$

Eq. 29

Where

- $Q_{BDRcol,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22)
- G_{col} is the solar irradiation on the collector plane
- A is the solar gross surface area (provided by technology provider)

Also efficiencies may also be related to different reference area (effective area, absorber area, etc.).

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation (or computation of the average value) will allow calculating daily, weekly, monthly and yearly KPI values.

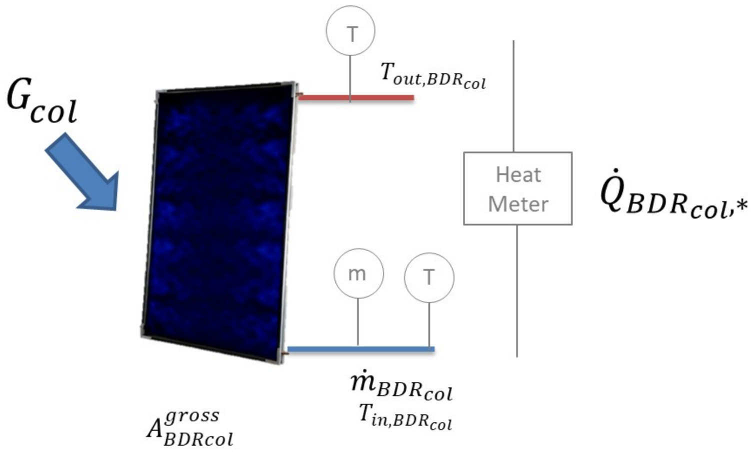


Figure 12 – BDR's solar collector illustration (variables and possible data requirements)

Figure 12 shows the main variables to compute the BDR's solar collector KPI computation, where:

- To determine the useful energy output ($\dot{Q}_{BDRcol,*}$) either a heat meter is used or by measuring the flow ($\dot{m}_{BDRcol}$) and the temperature difference in/out of the panel($T_{out,BDRcol} - T_{in,BDRcol}$).
- The irradiance can be obtained from a weather station (measured or estimated irradiance) or by a weather service.

In order to consider the temperature at which the solar technology is supplying heat, for instantaneous efficiencies the collector mean fluid temperature is $T_m = \frac{T_{in}+T_{out}}{2}$, and for seasonal values the following indicator to calculate the average operating temperature could be used:

$$T_m^{char} = \int_0^T \frac{T_m dt}{T} \quad \text{Eq. 30}$$

Superscript *char* refers to characteristic temperature. To summarize:

Table 25 – Summary of PI BDR04 Instantaneous thermal efficiency:

REF	Notation	Description	Formula	Units
BDR04	$\eta^{gross}_{BDRcol,th}$	Instantaneous thermal efficiency	$\eta^{gross}_{BDRcol,th} = \frac{\dot{Q}_{BDRcol,*}}{G_{col} \cdot A^{gross}_{BDRcol}}$	% or ratio

Solar thermal fraction

The **solar thermal fraction** expresses how much heat input into the system is provided by solar thermal energy. It can be defined as

$$f_{sol,th} = \frac{Q_{BDRcol,*}}{Q_{*,sys}} \quad \text{Eq. 31}$$

Where

- $Q_{BDRcol,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22). If BDR's collector supplies the evaporator of a heat pump, only the part that is directly provided to cover heating and DHW needs should be considered.
- $Q_{*,sys}$ is thermal energy output from other technologies (e.g. summed of all other energy inputs to RT)

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

The following data is required to compute the calculation:

- To determine the sum of all heat inputs to the system, useful energy outputs or energy inputs to the main tank (RT tank in Madrid case and BDR tank in San Lorenzo's case) should be measured either by a heat meter or by means of measuring the flow and the temperature difference in/out.

Table 26 – Summary of PI BDR 05 Solar thermal fraction

REF	Notation	Description	Formula	Units
BDR05	$f_{sol,th}$	Solar thermal fraction	$f_{sol,th} = \frac{Q_{BDRcol,*}}{Q_{*,sys}}$	% or ratio

3.5.1.4.3 BDR PV panels

Solar Electric efficiency

Solar electric efficiency quantifies how much sunlight (irradiance) is converted into useful power output. The higher is the efficiency the higher is the amount of power produced by the PV panel. Efficiency is not constant over time; it varies depending on the temperature, optical properties (presence of dust, etc.) and other electric parameters. The instantaneous efficiency can be defined as follows:

$$\eta_{BDRcol,el}^{gross} = \frac{\dot{E}_{BDRPV,*}}{G_{col} \cdot A_{BDRPV}^{gross}} \quad \text{Eq. 32}$$

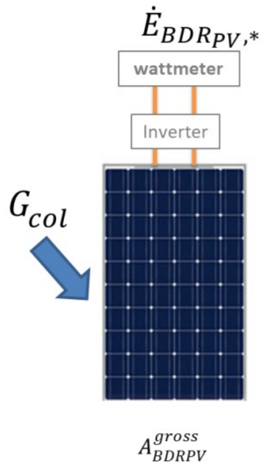


Figure 13 – BDR's PV panel illustration (variables and possible data requirements)

Figure 13 shows the main variables of the BDR's PV panel, where:

- $E_{BDRPV,*}$ is the instantaneous power output. It can be aggregated over a specific time (i.e. electric energy production. See Annex I, AUX21). The useful power output is measured at the output of the inverter by means of a wattmeter.
- G_{col} is the solar irradiation on the collector plane. The irradiance can be obtained from a weather station (measured or estimated irradiance) or by a weather service

A is the solar gross surface area (provided by technology provider). Also efficiencies may also be related to different reference area (effective area, absorber area, etc.). Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily, weekly, monthly and yearly KPI values.

Table 27 – Summary of PI BDR06 Solar Electric efficiency

REF	Notation	Description	Formula	Units
BDR06	$\eta_{BDRcol,el}^{gross}$	Solar Electric efficiency	$\eta_{BDRcol,el}^{gross} = \frac{\dot{E}_{BDRPV,*}}{G_{col} \cdot A_{BDRPV}^{gross}}$	% or ratio

3.5.1.5 DS

The DualSun module is 1677x990mm² black hybrid module (can be insulated or non-insulated) that has an electrical part of 280Wp photovoltaic module with 60 monocrystalline cells and can provide 1055Wth at standard conditions (for applications of 20ºC). In order to assess the performance to be achieved within SH project, the following PIs are defined for DS technology:

- Instantaneous thermal efficiency
- Solar thermal fraction
- Solar Electric efficiency
- Thermal-Electric Ratio

PIs Thresholds for DS

DS aims to achieve an increase of 25% the instantaneous efficiency for low temperature applications and an increase of 60% for DHW preparation. Regarding economic indicators, DS aims to reduce the CAPEX in 10%.

Instantaneous thermal efficiency:

The panel is tested by ISO standard 9806 to determine the collector performance in standard conditions and energy production (Q in watts) of the panel depending on solar radiation and ambient temperature data (Chamsa-ard, Sukchai, Sonsaree, & Sirisamphanwong, 2014). In practice, the efficiency is calculated as the ratio between the useful energy output ($\dot{Q}_{TVP,*}$) and solar irradiance received in the titled surface of the panel. Therefore, the efficiency is stated as follows:

$$\eta_{DS,th}^{gross} = \frac{\dot{Q}_{DS,*}}{G_{col} \cdot A_{DS}^{gross}} \qquad \textit{Eq. 33}$$

Where

- $Q_{DS,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22)
- G_{col} is the solar irradiation on the collector plane
- A is the solar gross surface area (provided by technology provider)

Also efficiencies may also be related to different reference area (effective are, absorber area, etc.).

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation (or computation of the average value) will allow calculating daily, weekly, monthly and yearly KPI values. Figure 14 shows the main variable for DS's KPI computation, where the following data is required:

- To determine the useful energy output ($\dot{Q}_{DS,*}$) either a heat meter is used or by measuring the flow ($\dot{m}_{DS}$) and the temperature difference in/out of the panel($T_{out,DS} - T_{in,DS}$).
- The irradiance can be obtained from a weather station (measured or estimated irradiance) or by a weather service

In order to consider the temperature at which the solar technology is supplying heat, for instantaneous efficiencies the collector mean fluid temperature is $T_m = \frac{T_{in}+T_{out}}{2}$, and for seasonal values the following indicator to calculate the average operating temperature could be used:

$$T_m^{char} = \int_0^T \frac{T_m dt}{T} \qquad \textit{Eq. 34}$$

Superscript *char* refers to characteristic temperature.

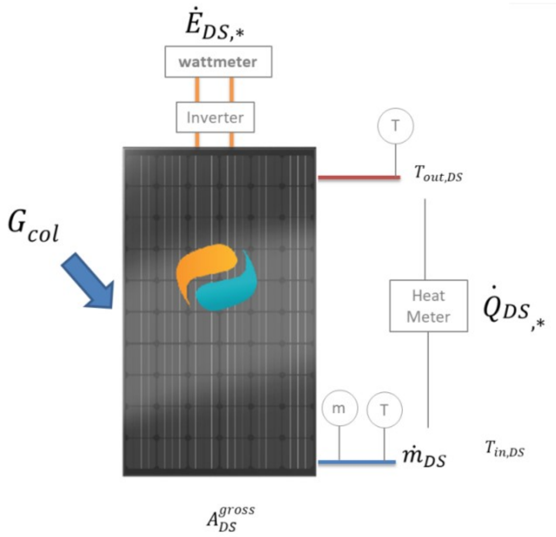


Figure 14 – DS illustration (Variables and data requirements)

To summarize:

Table 28 – Summary of PI DS 01 Instantaneous thermal efficiency:

REF	Notation	Description	Formula	Units
DS01	$\eta_{DS,th}^{gross}$	Instantaneous thermal efficiency:	$\eta_{DS,th}^{gross} = \frac{\dot{Q}_{DS,*}}{G_{col} \cdot A_{DS}^{gross}}$	% or ratio

Solar thermal fraction

The **solar thermal fraction** expresses how much heat input into the system is provided by solar thermal energy. It can be defined as

$$f_{sol,th} = \frac{Q_{DS,*}}{Q_{*,sys}} \quad \text{Eq. 35}$$

Where

- $Q_{DS,*}$ is the instantaneous thermal power output. It can be aggregated over a specific time (i.e. thermal energy output. See Annex I, AUX22). If DS supplies the evaporator of a heat pump, only the part that is directly provided to cover heating and DHW needs should be considered.
- $Q_{*,sys}$ is thermal energy output from other technologies (e.g. summed of all other energy inputs to RT)

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements. To determine the sum of all heat inputs to the system, useful energy outputs or energy inputs to the main tank (RT tank in most cases) should be measured either by a heat meter or by means of measuring the flow and the temperature difference in/out.

Table 29 – Summary of PI DS02 Solar thermal fraction

REF	Notation	Description	Formula	Units
DS02	$f_{sol,th}$	Solar thermal fraction	$f_{sol,th} = \frac{Q_{DS,*}}{Q_{*,sys}}$	% or ratio

Solar Electric efficiency

Solar electric efficiency quantifies how much sunlight (irradiance) is converted into useful power output. The higher is the efficiency the higher is the amount of power produced by the PV panel. Efficiency is not constant over time, it varies depending on the temperature, optical properties (presence of dust, etc.) and other electric parameters. The instantaneous efficiency can be defined as follows:

$$\eta_{DS,el}^{gross} = \frac{\dot{E}_{DS,*}}{G_{col} \cdot A_{DS}^{gross}}$$ *Eq. 36*

Where

- $\dot{E}_{DS,*}$ is the instantaneous power output. It can be aggregated over a specific time (i.e. electric energy production. See Annex I, AUX21). The useful power output is measured at the output of the inverter by means of a wattmeter.
- G_{col} is the solar irradiation on the collector plane (same variable as in PI DS01)
- A is the solar gross surface area (same as in PI DS01)

Heat flows in the solar collectors will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily, weekly, monthly and yearly KPI values.

Table 30 – Summary of PI DS03 Solar Electric efficiency

REF	Notation	Description	Formula	Units
DS03	$\eta_{DS,el}^{gross}$	Solar Electric efficiency	$\eta_{DS,el}^{gross} = \frac{\dot{E}_{DS,*}}{G_{col} \cdot A_{DS}^{gross}}$	% or ratio

Thermal-Electric Ratio

Thermal-electric ratio is the ratio between the amount of heating solar output and power output of a hybrid solar collector. It allows identifying instantaneously if the solar collector is producing more heat or more electricity. In a hybrid solar collector, the more heating power is provided, the less electricity is possible to be produced as temperature get higher, as the higher the temperatures of the panel, lower electrical efficiencies are obtained and thus, less power production (Cuce, Oztekin, & Cuce, 2018).

The ratio is defined as follows:

$$TER = \frac{Q_{DS,*}}{E_{DS,*}}$$ *Eq. 37*

It can be computed using above-mentioned variables, and it is usually obtained instantaneously, but an aggregated value could be useful as well. Aggregation will allow calculating daily, weekly, monthly and yearly KPI values.

To summarize:

Table 31 – Summary of PI DS04 Thermal electric ratio

REF	Notation	Description	Formula	Units
DS04	TER	Thermal-electric Ratio	$TER = \frac{Q_{DS,*}}{E_{DS,*}}$	% or ratio

3.5.1.6 RT

Ratiotherm storage is based in the principle of injection known as of the “cane of stratification” which allows energy distribution by natural convection. More precisely, the fluid goes up inside a tube thermo-syphon (stratification canes) with bored holes for the injection of fluid in the tank. By the difference in density, the fluid circulates in the cane of stratification until reaching the height of the of the same layer temperature.

In order to calculate the stratification efficiency of the tank, the difference between the top and bottom temperature of the unit could be measured, meaning that the higher the value the more stratification is obtained. Other temperature measurements could be made (at different heights), in order to measure the difference among the layers (if required).

$$dT = T_{top,tank} - T_{bottom,tank} \quad \text{Eq. 38}$$

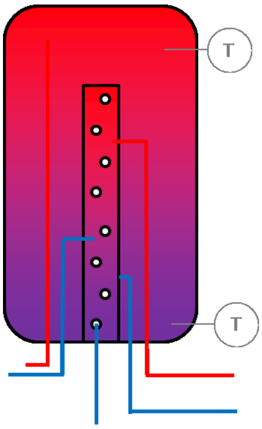


Figure 15 – RT illustration (Variables and data requirements)

The minimum data to compute the calculation will be the top (measured at the highest point) and bottom temperature (measured at the lowest point of the tank).

Table 32 – Summary of PI RT 01 Stratification Efficiency

REF	Notation	Description	Formula	Units
RT01	dT	Stratification Efficiency	$dT = T_{top,tank} - T_{bottom,tank}$	ºC

PIs Thresholds for RT

RT aims to achieve an increase of annual efficiency of solar energy up to 20%, thanks to the stratification efficiency. Furthermore, RT aims to reduce the OPEX up to 15%.

3.6 KPIs Assessment at demo-site level

3.6.1 Definition for each demo-site

A table summarizing the identified general KPIs on energetic, environmental, economic and comfort aspects and the relative specific cases for which they are relevant is reported below. The following KPI will be mainly used for control strategies as well as to inform the user.

KPIs			DEMONSTRATION CASES							
Nº	REF	Notation	Berlin	Nürnberg	Sant Cugat	Madrid	San Lorenzo	Verviers Sport Centre	Verviers Swimming Pool	Riga
1	EN01	PESnren	X	X	X	X	X	X	X	X
2	EN02	RER	X	X	X	X	X	X	X	X
3	EN03	SCR		X		X	X		X	X
4	ENV01	GHG_{sav}	X	X	X	X	X	X	X	X
5	EC01	CBR		X		X	X		X	X
6	EC02	LCoH	X	X	X	X	X	X	X	X
7	EC03	SPB	X	X	X	X	X	X	X	X
8	EC04	CAPEX	X	X	X	X	X	X	X	X
9	EC05	OPEX	X	X	X	X	X	X	X	X
10	COM01	HCI[11]	X	X	X	X	X	X	X	X
11	COM02	CCI			X	X	X			
12	COM03	CSAT[2]	X	X	X	X	X	X	X	X

Table 33 – High level KPIs for each of the eight demonstration cases.

PIs are related to technology packages and therefore they are also applied differently at each demo-site. A table summarizing which technology is applied in each demo-site helps to understand where and which PIs will be used at demo-site level for WP4/WP5 services.

Technologies		DEMONSTRATION CASES							
Technology provider	Technology	Berlin	Nürnberg	Sant Cugat	Madrid	San Lorenzo	Verviers Sport Centre	Verviers Swimming Pool	Riga
TVP	Solar Thermal	X		X			X		
DS	Solar PV		X		X			X	X
BDR	Solar Thermal					X			
BDR	Solar PV					X			
BDR	Heat Pump				X	X			
BH	Thermal Driven HP	X	X				X	X	X
FAHR	Adsorption HP			X					
RT	Ratiotherm tank	X	X	X	X		X	X	X

[11] Depending the energy uses that SUNHORIZON addresses
[2] Depending where the SUNHORIZON user-interface is implemented

Table 34 –PIs applicability for each of the eight demonstration cases.

In the following schematics, the assessment boundary for KPIs calculation of each demosite, as well as an illustration of the connections' components[12] to show the energy flows and storage are defined. The schematics are based on the square view proposed from IEA (Frank, Haller, Herkel, & Ruschenburg, 2010).

3.6.1.1 TP1: BERLIN AND SPORT CENTRE (VERVIERS) DEMO CASE

Berlin's demosite consists of 2 small residential houses in the town centre of Berlin. The current energy system – based on boilers and one house with 3m^2 of flat plate solar thermal panels – will be installed in parallel with the technology package 1 (TP1) that consists of a parallel integration of solar thermal (TVP) for space heating and DHW purposes with a gas driven HP (BoostHEAT) to cover non solar periods.

The Hall Moray demosite is a public sport centre located in the city of Verviers. The sport centre is currently heated by two large gas-fired boilers and one separate boiler for DHW purposes. The TP1 SH system will be integrated in parallel to cover partially both demands (pre-heating or partial flows) and reduce the gas-fired boiler consumption.

As there is not on-site electricity production by SH system, electricity regarding building's consumption is out of the scope/assessment. Only electricity consumed by the SH equipment is considered for the evaluation. Thermal energy need's assessment will be the entire system (space heating + DHW needs).

IEA's square view is shown in Figure 16. Electricity from the grid to cover SH system, sun's irradiation on the TVP panels and natural gas to cover the BH-Gas heat pump will be the final energy considered in the assessment (which will be converted to primary energy).

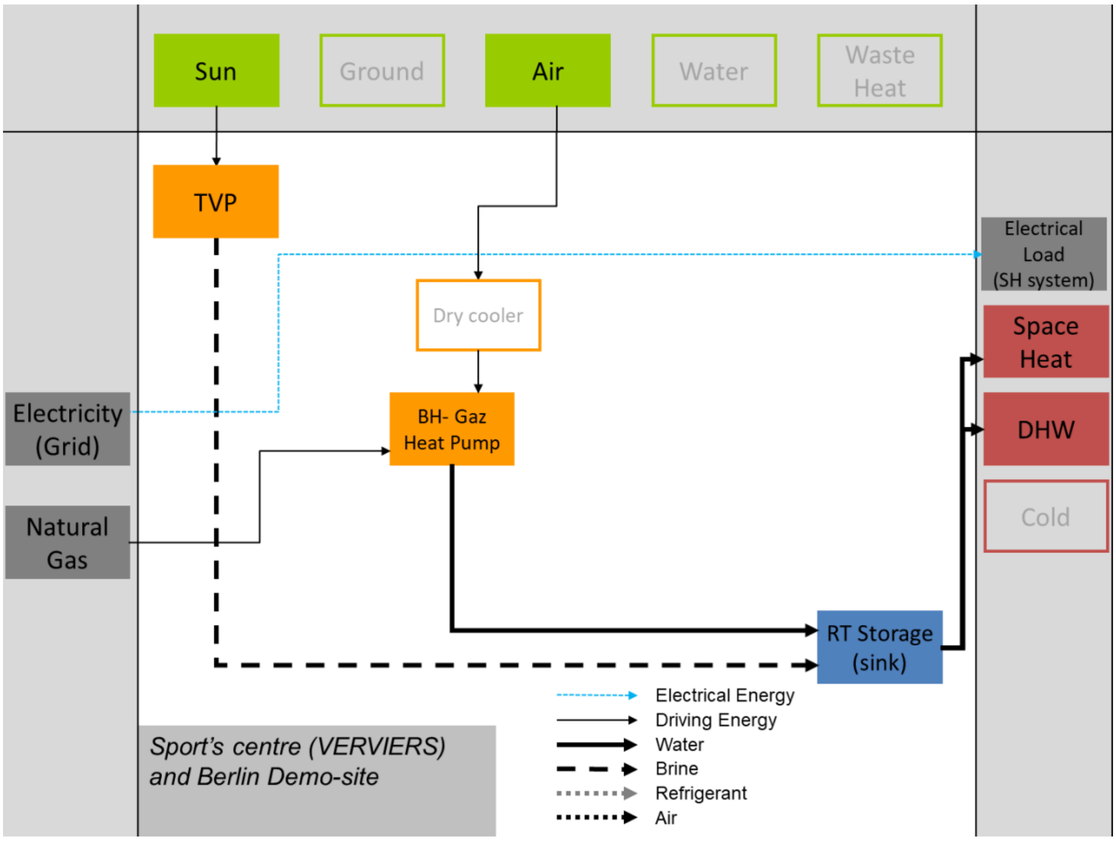


Figure 16 – IEA's schematics for Berlin and Hall Moray's Demo-site

[12] Please note that, this document has been elaborated before the schematics of the demosite are closed and it might differ from the final schematics that will be installed. An updated document will be elaborated once the technologies are installed and the schematics and real conditions are known.

3.6.1.2 TP2: NÜRNBERG, RIGA AND SWIMMING POOL (VERVIERS) DEMO CASE

The Nürnberg demo site comprises four residential apartments. Their existing system (oil-fired back-up heating) will be removed and substituted by Technology package 2 (TP2), to replace the existing heat sources that serve individual apartments, providing a centralised system that serves the space heating and domestic hot water needs of the occupants.

Riga's demosite comprises two single-family residential detached houses, in Imanta and Sunisi. In the case of Imanta gas-fired boilers cover space heating and DHW needs. In the case of Sunisi, a gas-fired boiler cover space heating and dHW needs, and an air-to-air heat pump covers cooling needs in summer. TP2 will be installed in parallel.

Swimming Pool's demosite is a sports-building with a large pool, a smaller pool and additional amenities such as gymnasium, weightlifting, rooms, toilets and changing rooms. The energy needs are very high and covered by large gas-fired boilers and air handling units. TP2 will be installed in parallel.

TP2 consists of DS panels to cover the evaporator needs of the BH unit, and the BH unit covers the demands: space heating and DHW in two demosites and swimming pool's demand in Verviers. The SH system will cover all needs in the case of Nürnberg and Riga, thus the assessment is the entire system's energy consumption. In case of Verviers demosite, only the small swimming pool's demand will be covered. Therefore, in the latter case, only this thermal load will be considered for the assessment. Besides that, in all demos electricity will also be covered by DS panels, and therefore the electricity consumptions of the building and SH system will be assessed.

IEA's square view is shown in Figure 17 for Riga and Nunberg's case, and Figure 18 shows the Vervier's case. Electricity from the grid (pumps, auxiliaries, building's consumption, etc.) and to the grid (from DS panels), sun's irradiation on the DS panels (and the useful outputs) and natural gas to cover the BH-Gaz heat pump will be the final energy considered in the assessment (which will be converted to primary energy).

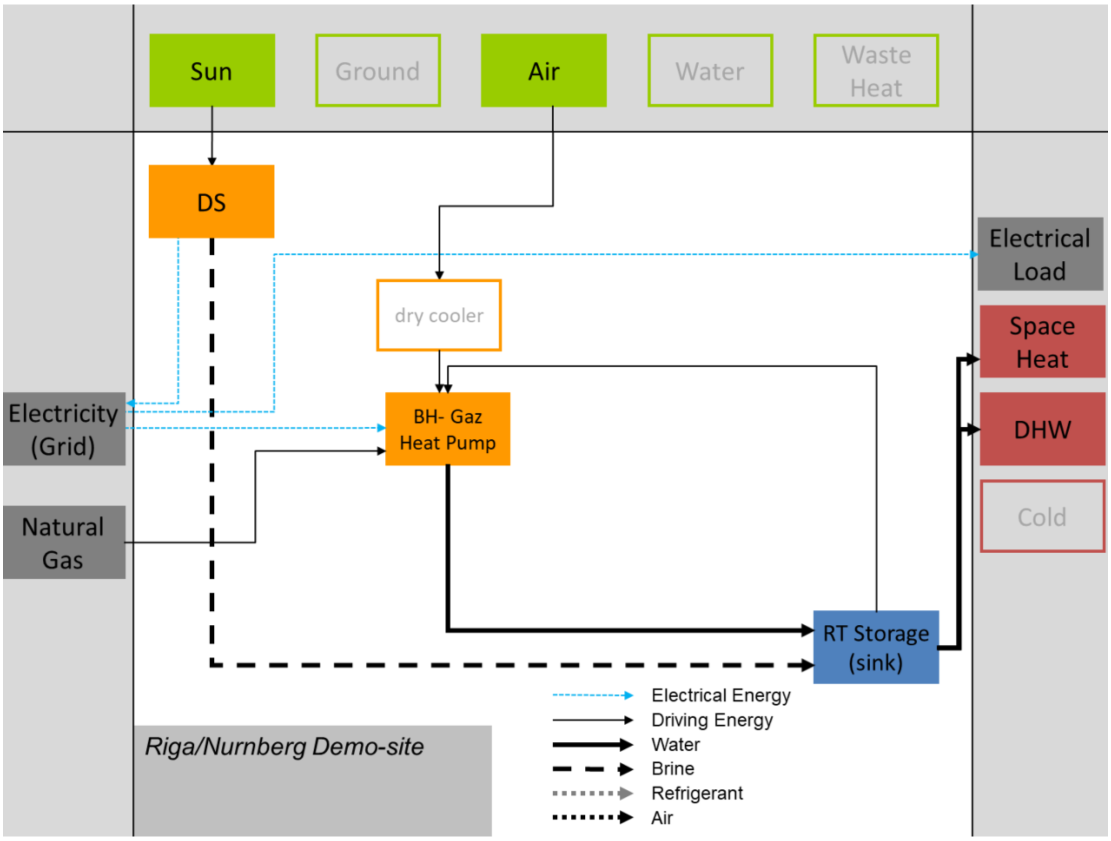


Figure 17 – IEA's schematics for Riga and Nunberg's Demo-site

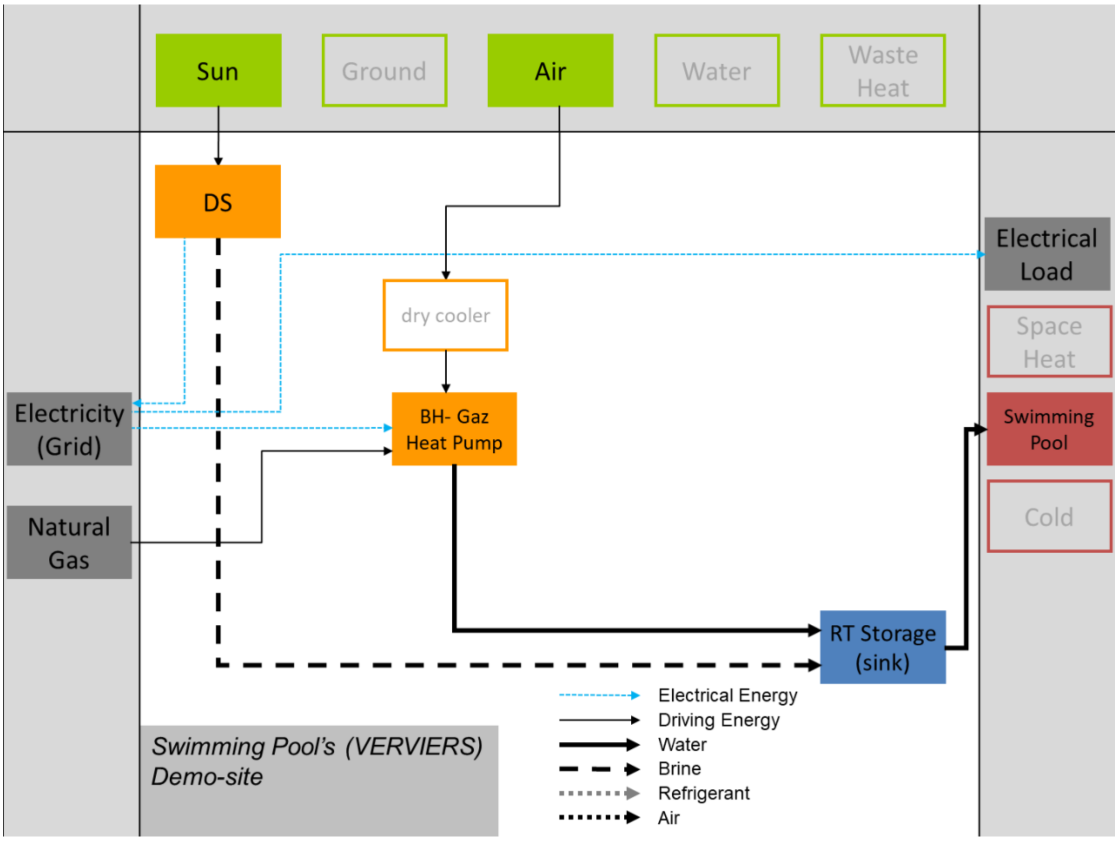


Figure 18 – IEA's schematics for Swimming Pool Verviers's Demo-site

3.6.1.3 TP3: SANT CUGAT DEMO CASE

Sant Cugat demosite is a civic centre and all space heating, cooling and domestic hot water needs are served by electric appliances (air handling unit). The technology demonstration deployed as part of the SunHorizon installation will partially serve the space heating and cooling needs of the civic centre by means of Technology Package 3 (TP3). TP3 consists of TVP technology for space heating and DHW, and in summer, for driving a thermal compressor of an adsorption chiller (FAHR technology).

As there is not on-site electricity production by SH system, electricity regarding building's consumption is out of the scope/assessment. Only electricity consumed by the SH equipment is considered for the evaluation. Thermal energy need's assessment will be the entire system (space heating + space cooling + DHW needs).

IEA's square view is shown in Figure 19. Electricity from the grid to cover SH system and sun's irradiation on the TVP will be the final energy considered in the assessment (which will be converted to primary energy).

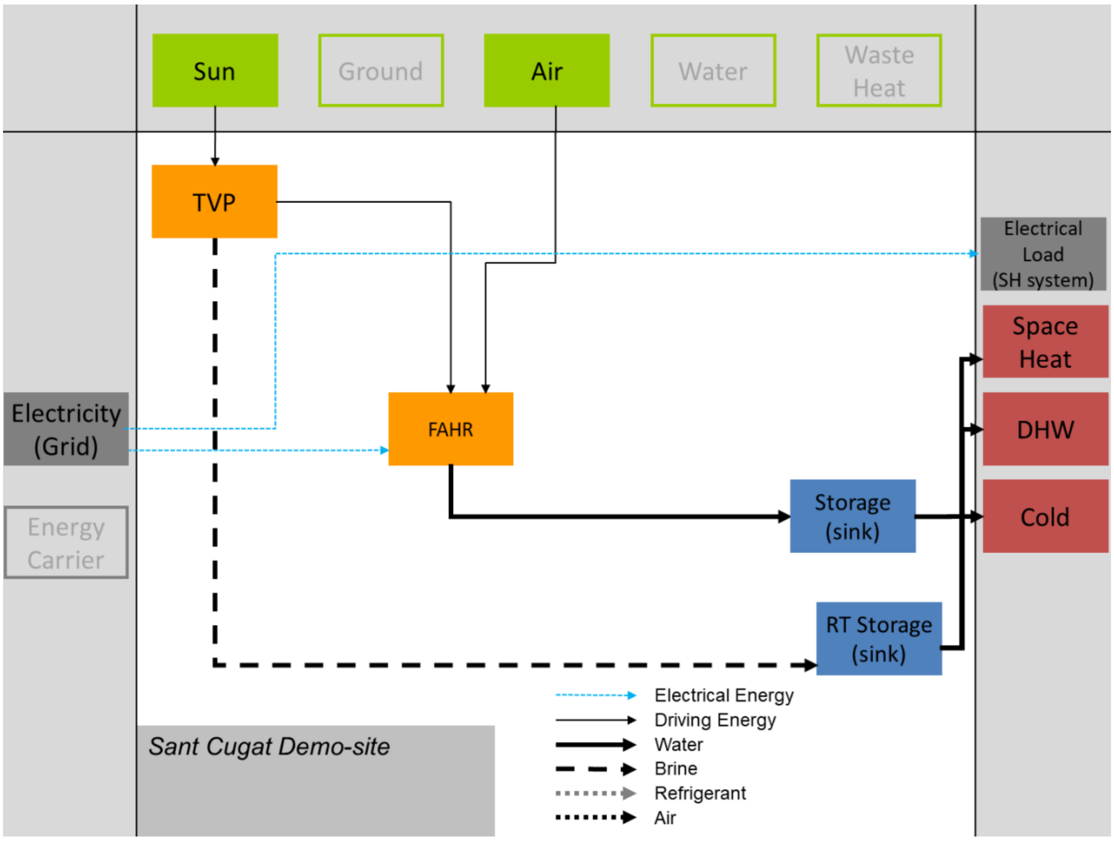


Figure 19 – IEA's schematics for Sant Cugat's Demo-site

3.6.1.4 TP4: MADRID AND SAN LORENZO DEMO CASE

Madrid democase consists of a 9 apartment building with individual gas-fired boilers to cover DHW and space heating. The building is going to be refurbished and the system will be change to a centralized system with fancoils for each dwelling and a centralized DHW supply. The fancoils will be supplied by SunHorizon system covering space cooling and heating, as well as DHW needs. Technology Package 4 in Madrid consists of DS panels to cover electricity needs as well as the evaporator of a brine-water heat pump, and BDR heat pumps will cover DHW, and space heating and cooling needs.

San Lorenzo is a single-family detached house, with an electric air-water heat pump for DHW and heating needs with an oil-fired boiler as back-up. The SH system will be installed in parallel. Technology Package 4 in San Lorenzo consists of PV panels to cover electricity needs as well as a parallel connection of flat plate solar thermal collector and a heat pump to cover DHW, space heating and cooling needs.

Therefore, thermal energy need's assessment will be the entire system (space heating + space cooling + DHW needs) for both demosites. Also, electricity production from DS panels will cover SH system and possibly some building's electricity consumption. Thus, SH electricity assessment is the entire building as well (SH system's consumption + building's consumption).

IEA's square view is shown in Figure 20 for Madrid and Figure 21 for San Lorenzo's demosite. Electricity from the grid (pumps, auxiliaries, building's consumption, etc.) and to the grid (from DS panels), and sun's irradiation on the DS panels (and the useful outputs) will be the final energy considered in the assessment (which will be converted to primary energy).

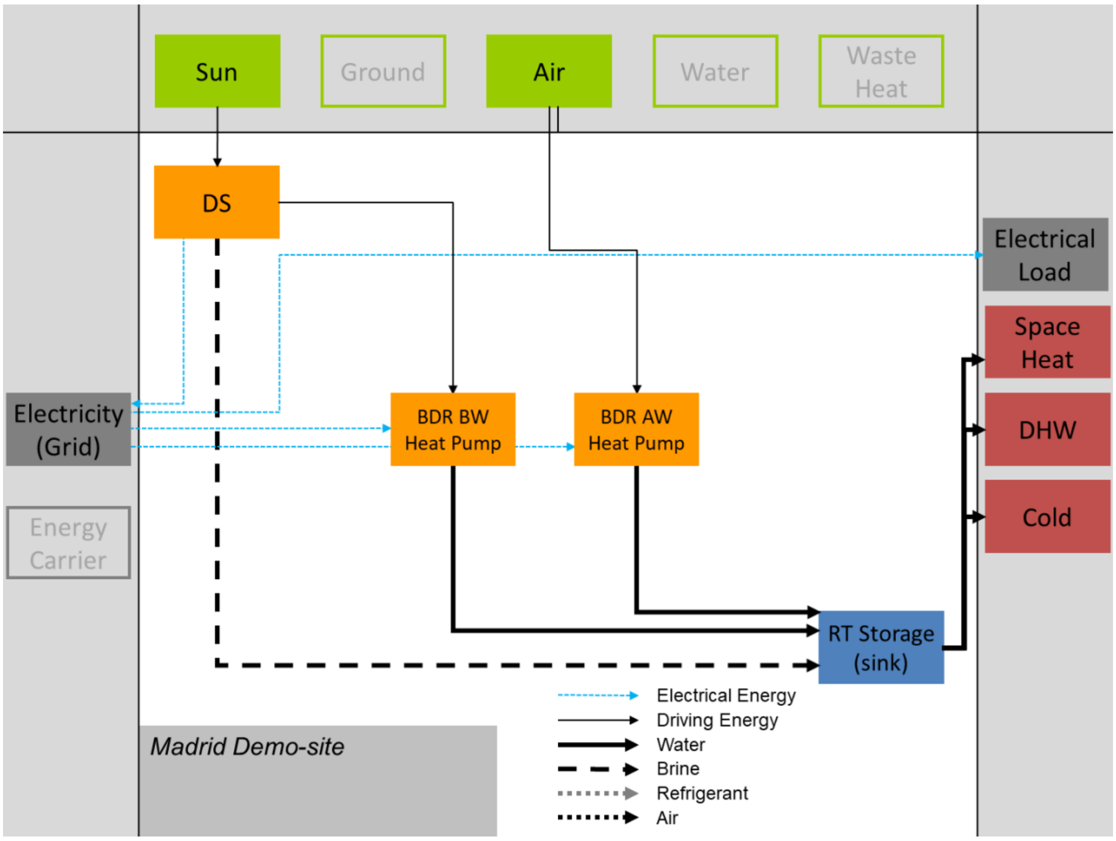


Figure 20 – IEA's schematics for Madrid's Demo-site. (AW=Air Water heat pump; BW= Brine Water heat pump)

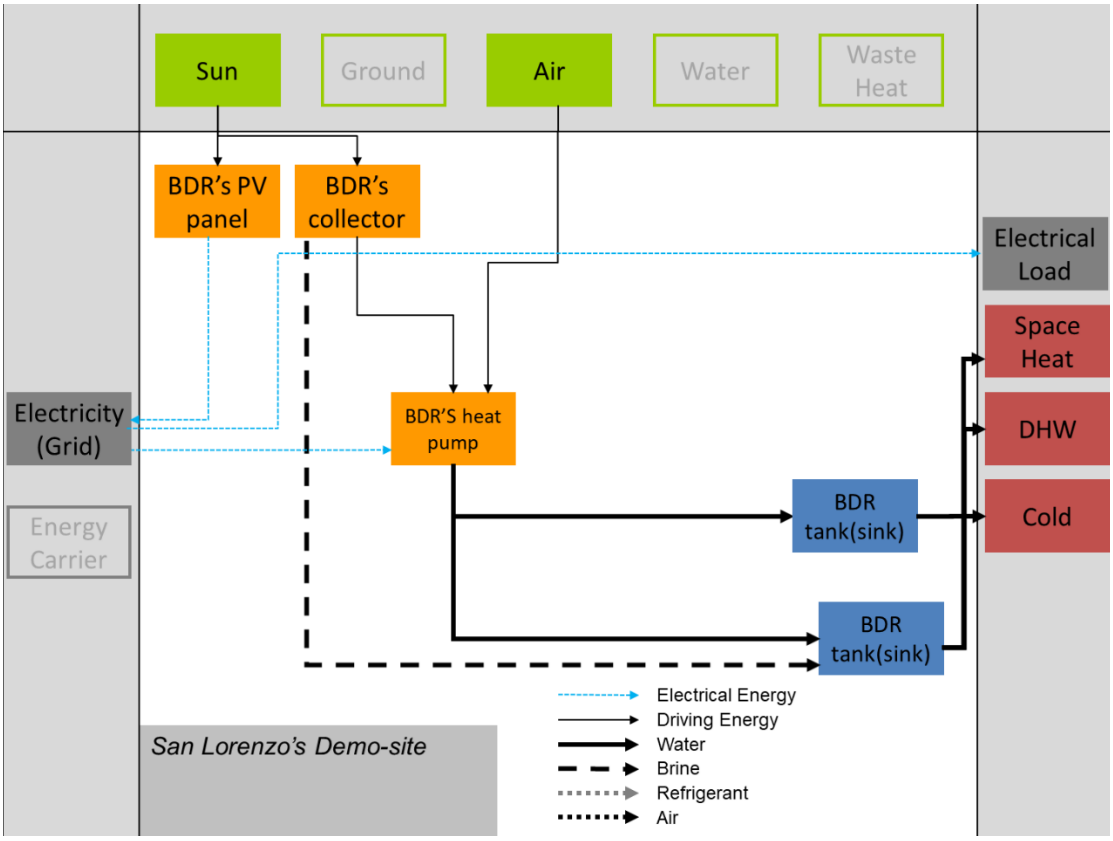


Figure 21 – IEA's schematics for San Lorenzo's Demo-site

3.6.1.5 TP5: VIRTUAL DEMO CASE

The last Technology Package is number 5, which does not comprise any real demosite but it will be virtually modelled and assessed. In this case, TVP is used for space heating and DHW needs, and BH to cover non solar periods. Also in summer, TVP and BH will supply heat to the thermal compressor of the FAHR adsorption chiller. IEA's square view is shown in Figure 22, electricity from the grid to cover SH system, natural gas consumption of the BH unit and sun's irradiation on the TVP will be the final energy considered in the assessment (which will be converted to primary energy).

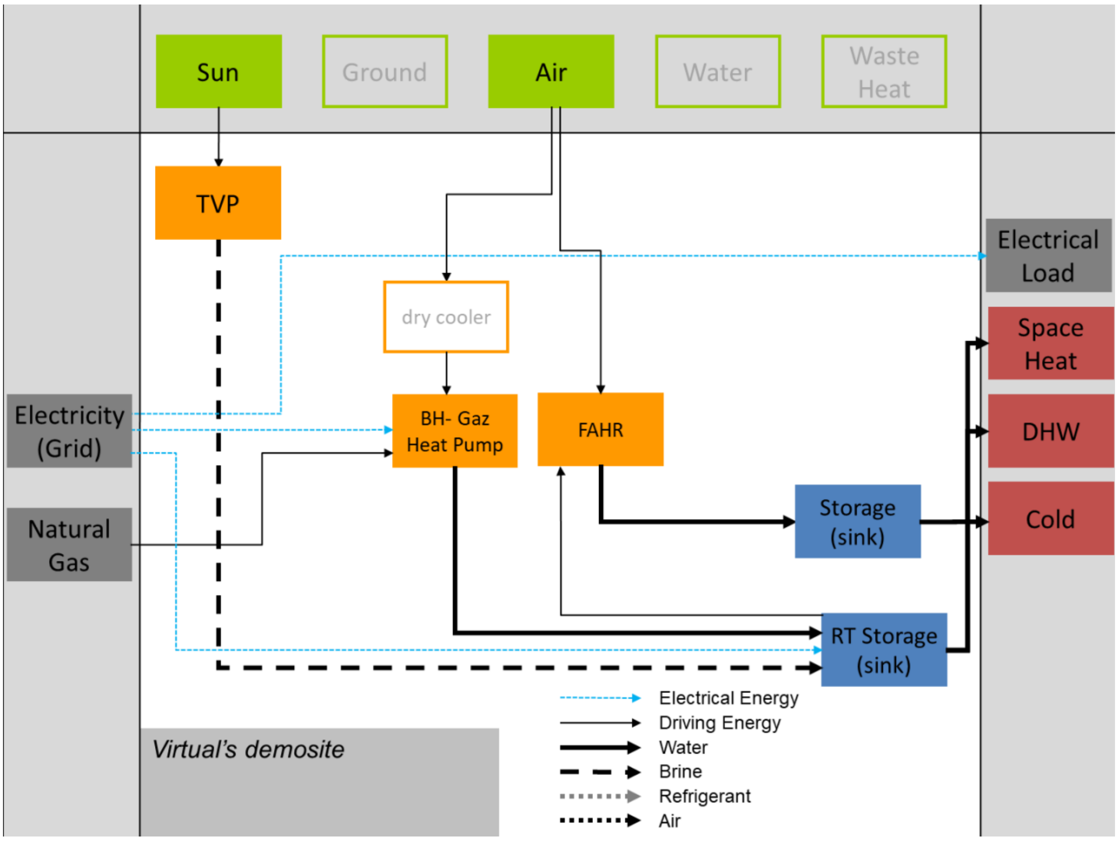


Figure 22 – IEA's schematics for the virtual demo-site

4 Relationship of KPIs with stakeholders

The KPIs selected establish a mechanism for continuous monitoring and control of the demonstration cases, providing useful insight to the stakeholders involved at the different business scenarios.

To further understand the SunHorizon performance framework, KPIs relevance for the different business stakeholders' groups is considered in Table 35 . The most significant KPIs (Base on previous experiences and literature) have been identified but a further analysis could be made once the KPIs are assessed (in the evaluation period) by means of interviews to different stakeholders.

Stakeholders			
Policies Bodies and Governance	ESCOs	Manufacturers	End-users
Policy bodies are interested in data and indicators to evaluate their policy plans. Energy related (KPI EN01 and KPI EN02) and Environmental related KPIs (such as KPI ENV01) can help to measure how far is a country to achieve their policy targets as well as to identify measures and instruments to make more efforts on achieving their objectives. Economic related: payback period and CAPEX KPI's can help to conduct studies on how to improve the values in their countries through economic instruments (funds, feed in tariffs, etc.).	An energy service company (ESCO) is a commercial or non-profit business providing a broad range of energy solutions including designs and implementation of energy savings, therefore the most significant KPIs are related with economic (KPI EC01,and KPI EC02) and energy performances (KPI EN01 and PIs for each technology) . It can help an ESCO to decide between one technology or another and to convince possible investors to invest in a specific technology (or Technology Package) reducing investment risks.	Manufactures are the ones producing the technology and possibly, selling them. Thus, the most significant KPIs are related to efficiency (PIs for each technology) and costs performances (KPI EC02, AUX16). It can help a manufacturer to identify where to invest their resources (e.g. improve efficiency for specific conditions, etc.) or to expand their market-share (reduction of costs, etc.). Regarding KPI for maintenance, it could help a manufacturer to identify malfunctioning equipment.	End-users are more interested in economic-related KPIs rather than technical ones. But also, energy consumption, energy savings or even greenhouse gases emissions' reduction could be interesting for them. Energy related KPIs allows users to be aware of the amount of energy that they are consuming and thanks to KPI ENV01 to understand the environmental impact of their energy system. KPI EC02 can help a consumer to be aware of the specific energy costs and KPI EC01 how much money they are saving by means of their new equipment. In fact the reduction of the energy bill is the main factor driving consumer's choices, consequently a KPI that will endorse consumers to be more active and to be more aware of their choices.

Table 35 - KPI's relationship with stakeholder (SunHorizon performance framework).

5 Conclusions

This document corresponds to the deliverable D2.4 of SunHorizon project. Its purpose is to define how to assess the performance of the project's objectives for the demonstration cases by means of defining a list of indicators and thresholds to be met.

The deliverable has been performed as a guide for practical application of KPI definitions and consistent evaluation methodologies during the rest of the project. Formerly, the document starts introducing the project and the methodology that will be followed throughout the project to define and divide the KPIs analysis. Next, the tasks' objectives, plan and links within the project are described. Later the indicators are defined within 3 categories: high level indicators (KPIs) which are summarize in Table 33 and are applied differently to each of the eight demonstration cases; Performance indicators (PIs) which are explained at technology level (6 technologies) and are applied differently (depending of the TP) in each demosite (See Table 34); and auxiliary indicators that support the overall calculations and could be used during the project for reporting (to give more detail of a specific KPI or PI), showing data in the user-dashboard, etc.

Along with the definition of the list of KPIs, data sources required for KPI calculation are defined, which will help to define the monitoring requirements and data gathering needs (link with WP4 of SH project). KPIs will be used throughout the project for different purposes such as support the control algorithms, maintenance, assessment of demonstrations, and optimization analysis, among others.

An assessment for each demo has been explained in section 3.6. This section gives an overall picture of each demo energy sources and demands, and it completes the methodology to evaluate the benefit of SunHorizon integration in the different cases. To conclude, the relationship of the KPIs with the stakeholders is described, which allows to identify the most significant categories for each stakeholder and to quantify the satisfaction accruing of the project (See Table 35).

It is important to mention that, during the operation of the Technology Packages, monitoring data will feed the KPIs computation and the evaluation outcome will turn out in a series of indicators allowing to measure the different dimensions of the expected Project impact. KPIs thresholds could be modified/changed when the demonstration phase will start, thus this document will continually evolve as to build on the results of the related Work Packages. Thus, this deliverable should be considered as a living document.

To conclude, this document provides a complete overview of the general methodological aspects that dictate how the SunHorizon demonstration actions will be assessed after their implementation in order to analyse all aspects of the project results, regarding not only technical considerations but also economic, environmental and comfort categories. Also, it sets a robust basis on how to assess sun coupled innovative heat pumps and for replication and scalability in future developments that will contribute to a more efficient energy supply and the decarbonisation of heating and cooling applications.

6 ANNEXES

A.1. Auxiliary Indicators

In this section auxiliary indicators are listed in order to assist in the calculation of the KPIs and PIs. Also Auxiliary Indicators could be used for control services (e.g. to show the amount of energy demanded, etc.) or for reporting. On the other hand, other parameters, such as temperatures in the different components, have not been considered as indicators as it is "raw" data. Nevertheless, such parameters could be used in control services and reporting as well.

AUX01- Useful heating energy demand is defined as the total heating energy demand measured on site (e.g. overall energy demanded to cover domestic hot water and space heating needs). Energy demand will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX01	Q_h	USEFUL energy demand: heating	$Q_{h=} \int \dot{m} C_p (T_{in} - T_{out})\, dt$	kWh	Energy	day week month year	Heat meter or by measuring flow rate and temperatures.	m = mass flow rate cp = specific heat capacity Tin/Tout = inlet/outlet temperature * All variables referred to heat transfer fluid

AUX02- Useful cooling energy demand is defined as the total cooling energy demand measured on site. Energy demand will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX02	Q_c or C_c	USEFUL energy demand: cooling	$Q_{c=} \int \dot{m} C_p (T_{in} - T_{out})\, dt$	kWh	Energy	day week month year	Heat meter or by measuring flow rate and temperatures.	m = mass flow rate cp = specific heat capacity Tin/Tout = inlet/outlet temperature * All variables referred to heat transfer fluid

AUX03 –Final energy demand: fuel, Q_f ,is the amount of energy contained in the fuel used. In the case of natural gas, it can be calculated indirectly from the measured gas consumption in m³ at the gas meter. LHV is the lower heating value, usually provided by the gas company, which subtracts the heat of vaporization of the water from the higher heating value. In case LHV is unknown and the technology condenses the water during the combustion process, a reference value from ISO52000 table B13-B15 can be used. Total final energy demand will be calculated considering the amount of fuel consumed on site (units of flow rate depending on monitoring platform) and the lower heating value of the fuel, during a time period. Flow rate will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX03	Qf	FINAL energy demand: fuel	$Q_f = \int \rho \dot{q} LHV \, dt$	kWh	Energy	day week month year	Calculation from direct measurement of fluid flow meter (e.g. for natural gas)	ρ = density q = volumetric flow rate LHV = fuel Lower Heating Value ity (or HHV, in case is a condensing technology) Δt = time period * All variables referred to the fuel

Fuel	Gross calorific value(kWh/kg)	Fuel	Gross calorific value (kWh/kg)	density (kg/m³)
Anthracite	8.97-9.7	Heating oil, light	12.44	0.84-0.85 kg/L*
Bituminous coal	4.7-6.9	Heating oil, heavy	13.94-11.75	0.96 kg/L *
Charcoal	8.22	Commercial propane (liquid)	13.89	0.51
Coke	7.8-8.6	Natural gas L	9.75-9.78	0.64
Ligite	4.2-8.3	Natural gas H	11.41-11.47	0.61
Peat	3.6-5.6	Methane	11.06-11.08	0.55
Wood (dry)	3.9-4.7	Propane	28.03	1.56
		Butane	37.19	2.09
		Hydrogen	39	0.09
		Biogas	4 to 8 (depending on methane content)	1.2

Table 36 – Gross calorific value of some common fuel (IS052000-2)

AUX04- FINAL energy demand: electricity $E_{*,sys}$. Is the amount of electrical energy demanded by the system within the system's boundary. Depending on the boundaries **$E_{*,sys}$** will account the electrical energy demanded by only SunHorizon system, or by both, SunHorizon system and the building, etc.(see analysis made in section 3.6.1). The subscript * can refer to: grid or PV or be omitted if it refers to the total energy demand of the system depending where is used and where it comes from:

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX04	$E_{*,sys}$	FINAL energy demand: electricity	$E_{*,sys} = \int \dot{E}_{*,sys}\, dt$	kWh	Energy	day week month year	Calculation from direct measurement: Wattmeters	-

From AUX04, $E_{grid,sys}$ is the amount of energy coming from the grid, measured in the building's electrical meters. It will be calculated as the delivered energy to the facility less the energy produced by the PV panels injected to the grid at the same time interval. Also, for each time interval the total result will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

AUX05- PV energy used on-site (within the system boundaries) $E_{PV,sys}$. Is the amount of electrical energy demanded from the grid at the same time that PV is producing electric energy. As the produced electric energy on-site will be directly injected into the grid (net metering), it is necessary to compare instantly when the building requires electric energy from the grid and PV production is injecting into the grid at the same time. When the energy demanded by the system is less than the energy produced by the PV panels, the energy measured at the electrical panel is in fact **$E_{PV,sys}$** at that time step (all consumption is covered by PV panels). Otherwise, if the energy demanded is greater than the energy produced by the PV panels, the energy produced by the PV panels is $E_{PV,sys}$ (all PV production is consumed by the system and partially covered by the grid).

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX05	$E_{PV,sys}$	PV energy used on-site (within the system boundaries)	$E_{PV,sys} = \int \min(\dot{E}_{*,sys}, \dot{E}_{PV,*})\, dt$	kWh	Energy	day week month year	Calculation from direct measurement: Wattmeters	E*,sys = FINAL energy demand: electricity at time step t (AUX04) Epv,* = electric energy produced on-site at time step t (AUX20)

AUX06- Total Primary Energy (Perimeter: onsite, nearby distant) PE_{tot} is the total primary energy consumed at the energy facility. It is calculated as the summed of non-renewable primary energy (AUX07) and renewable primary energy(AUX08).

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX06	PE_{tot}	Total primary energy (Perimeter: onsite, nearby, distant)	$PE_{tot} = PE_{ren} + PE_{nren}$	kWh	Energy	day week month year	Indirect calculation	PEnren (AUX07) PEren (AUX08)

AUX07- Total non-renewable primary energy (Perimeter: onsite, nearby distant) PE_{nren} is the total non-renewable primary energy consumed at the energy facility. It is calculated as the summed of the final energy per energy carrier multiplied by the corresponding primary energy factor (per energy carrier, AUX 24-25). Also, the avoided primary energy as a result of injecting PV to the grid is considered (AUX 25 and AUX 27)

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX07	PEnren	Total non-renewable primary energy	$PE_{nren} = E_{grid,sys} \cdot PEF_{nren,grid} + Q_f \cdot PEF_f - E_{PV,ex} \cdot PEF_{nren,grid} + \cdots$	kWh	Energy	day week month year	Indirect calculation	$E_{grid,sys}$ (AUX04) PEFnren,grid (AUX24) Qf(AUX03) PEFf(AUX24) EPVex (AUX27) …etc

AUX08- PEren is the total renewable primary energy consumed at the energy facility, as the summed of the final energy per energy carrier multiplied by the corresponding primary energy factor (per energy carrier, AUX 24-26). Also, renewables coming from the grid are considered.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX08	PEren	Total renewable primary energy	$PE_{ren} = E_{PV,sys} \cdot PEF_{ren} + Q_{f,ren} \cdot PEF_{ren} + E_{grid,sys} PEF_{ren,grid} \cdots$	kWh	Energy	day week month year	Indirect calculation	$E_{grid,sys}$ (AUX04) PEFren,grid (AUX25) Qfren(AUX03) PEFf(AUX25) EPVex (AUX27) PEFren,grid (AUX25) …etc)

AUX09- Total GHG emissions, GHG_{tot}, reports the total CO2-eq emissions of greenhouse gases emitted for all energy carriers associated with the primary energy use in the facility. The emissions factor (relating GHG and primary energy use) depends on country to country and energy carrier; when country conversion factor is missing, default values from ISO52000 Table B16 can be taken (depending on the energy carrier)

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX09	GHG_{tot}	Total GHG emissions	$GHG_{tot} = \sum PE_{nren,cr} \cdot f_{GHG,cr}$	tonCO2eq/year	Environmental	day week month year	Indirect calculation	fGHG,cr = emissions factor (relating GHG and primary energy use) per energy carrier PEnren,cr = non-renewable primary energy per energy carrier

AUX10- Fuel costs, C_f, are the total costs associated to fuel expenses (non-renewable and renewable fuels, e.g. natural gas, biogas, biomass, etc.). Fuel consumption (Qf) should consider all type of fuels used as inputs for the evaluated process.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX10	C_f	Fuel costs	$C_{fuel} = Q_f \cdot P_f$	€	Economic	month year	Indirect calculation; price from public databases (validated with billing information)	Q_f(AUX03) Pf(price of fuel: provided by demo owner)

AUX11- Electricity costs, C_E, are the total costs associated to electricity expenses.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX11	C_E	Electricity costs	$C_E = E_{grid,sys} \cdot P_{el}$	€	Economic	month year	Indirect calculation; price from public databases (validated with billing information)	Q_E(AUX04) Pel(price of electricity: provided by demo owner)

AUX12- Financing costs, C_{fint}, total financing expenditures, if any.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX12	C_{fin}	Financing costs	C_{fin}	€	Economic	month year	Directly provided by demo partners	-

AUX13- Maintenance costs, C_{maint}, total maintenance expenditures to each technology provider (or demo partners).

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX13	C_{maint}	Maintenance costs	C_{maint}	€	Economic	month year	Directly provided by technology providers (or demo partners)	-

AUX14- OPEX Cost Avoidance, OCA, are the operating costs that are avoided by applying SunHorizon TPs. It is calculated as the difference between the operating costs at the baseline period and the operating costs after the retrofit. It represents the savings in the bills (electricity, gas, etc.) as a result of applying SunHorizon TPs. The baseline period costs are multiplied by a weighting factor ($w_{bs/pr}$) in order to take into account the amount of costs associated to the energy needs assessed by SH system.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX14	OCA	OPEX Cost Avoidance	$OCA = OPEX_{bs} \cdot w_{bs/pr} - OPEX_{pr}$	€	Economic	day week month year	Indirect calculation	OPEXbs =OPEX in the baseline period OPEXpr =OPEX in the post-retrofit period

AUX15- Cashflow, CF, is defined as the total amount of money being transferred into and out of a system, during a reporting period. No incomes are considered as the profits of the installations are measured by the difference between operational costs before and after the retrofit of the demosites (OCA, AUX15). CF summarizes the impact of both the investment and the operation costs along the service life of the installation

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX15	CF	Cash Flow in year i	$CF_{year,i} = OCA_{year_i} - OPEX_{year_i}$	€	Economic	year	Indirect calculation	OCAyear,i (AUX 14) OPEX (KPI EC05) Should be calculated at the end of each year

AUX16-Net Present Value (NPV) is the present value of the entire project benefits including the design, installation and execution phases. It represents the total money profitability of the project.

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX16	NPV	Net Present Value	$NPV_{yearN} = \sum_{i=1}^{N} \frac{CF_{year,i}}{(1+r)^i} - CAPEX_{year_0}$	€	Economic	Day, week month year	Indirect calculation	CFyeari(AUX15) CAPEX (KPI EC04). R= interest rate.

AUX17- Time Outside of Heating comfort (TOH) Percentage of the time out of the range of defined maximum and minimum temperatures during the heating season. It can be disaggregated by uses (heating and DHW). It considers the occupancy schedule in winter time as the total hours that heating is needed

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX17	TOH	Time outside of Heating Comfort (Disaggregated by uses: heating, DHW)	$TOH = \frac{\sum TIME(if\ T < T_{comf,min})}{Th} \cdot 100$	h	Comfort	day week month year	Indirect calculation	T=Indoor temperature $T_{hours,h}$=total hours within the occupancy schedule that heating is needed Tcomf,min= minimum comfort temperature (or heating setpoint)

AUX18- Time outside of Cooling Comfort (TOC) Percentage of the time out of the range of defined maximum and minimum temperatures during the cooling season. It considers the occupancy schedule in summer time as the total hours that cooling is needed

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX18	TOC	Time outside of Cooling Comfort	$TOC = \frac{\sum TIME(if\ T > T_{comf,max})}{T_{hours,c}} \cdot 100$	h	Comfort	day week month year	Indirect calculation	T=Indoor temperature $T_{hours,c}$=total hours within the occupancy schedule that cooling is needed Tcomf,max= maximum comfort temperature (or cooling setpoint)

AUX19-Electrical energy produced by a PV system exported ($E_{PV,ex}$) is the amount of energy injected into the grid. It can be indirectly calculated as the difference between the total energy produced by the PV panels (or PVT panels) and the energy self-consumed by the demo, in the same time period. First, AUX21 and AUX05 will be calculated, and if needed aggregation of measured data (available every 15min/1h) will be done. Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX19	$E_{PV,ex}$	Electrical energy produced by a PV system exported (out of the system boundaries)	$E_{PV,ex} = E_{PV,*} - E_{PV,sys}$	kWh	Energy	day week month year	Indirect calculation	EPV,ex = electrical energy produced by a PV system and exported/inyected to the grid(out of the system's boundary) (AUX19). EPV,* all energy produced by the PV system (AUX 20). EPV,sys energy produced by the PV system and consumed on-site (within the system's boundary) (AUX05)

AUX20- Electricity output from PV ($E_{PV,*}$) is the electric useful output in the solar collectors measured at the inverter (AC output). If the inverter's efficiency is considered, then is measured at the inlet (DC input to the inverter) and outlet of the inverter. Finally the electric useful output will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX20	$E_{PV,*}$	Electricity output from PV	$E_{PV,*} = \int \dot{E}_{PV,*}\, dt$	kWh		day week month year	Directly measured at the PV panels	$\dot{E}_{PV,*}$ instantaneous production

AUX21- Thermal output from technology I ($Q_{i,*}$) is the useful thermal output of a specific technology (e.g. heating energy output from BDR to RT tank). It will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX21	$Q_{i,*}$	Thermal output from technology i	$Q_{i,*} = \int \dot{Q}_{i,*}\, dt$	kWh		day week month year one-off	Directly measured at the heatmeters of each technology	$\dot{Q}_{i,*}$ instantaneous production

AUX22- Electricity consumed by technology I ($E_{i,*}$) is the electric energy consumed by a specific technology, including electricity used for pumps, compressors,.. to run the technology. It will be calculated by aggregation of measured data (available every 15min/1h). Aggregation will allow calculating daily/weekly/monthly/yearly KPI values. Final decision to be taken according to monitoring platform design/requirements

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX22	$E_{*,i}$	Electricity consumed by technology i	$E_{i,*} = \int \dot{E}_{*,i}\, dt$	kWh		day week month year	Directly measured at the wattmeters of each technology	$\dot{E}_{i,*}$ instantaneous production

AUX23- Total primary energy factors PEFtot "*The primary energy factors are the ratio of a given type of primary energy (renewable, non-renewable, total) to the actual energy amount*"(See Figure 24 – Primary Energy Factors calculation based on ISO52000 Figure 24). Thus, the total PEF can be calculated as the summed of the non-renewable primary energy factor (PEF_{nren}) and renewable primary energy factor (PEF_{ren}):

$$\mathrm{PEF_{P,tot}} = \mathrm{PEF_{Pnren}} + \mathrm{PEF_{Pren}} \quad \textit{(Eq. 1)}$$

Primary energy factors are different for each energy carrier and country, thus for each demosite and energy carrier different primary energy factor should be defined on country-specific indicators[13]. It should be consider that PEFs are not based entirely on scientific arguments and clear algorithms (Papaglastra, 2018).

	FRANCE	GERMANY	NETHERLANDS	POLAND	SPAIN	SWEDEN	UK
$\boldsymbol{PEF_{t,grid}}$[14]	2.58	2.6	2.56	3	2.6	2	2.92

Figure 23 – electricity mix PEF for different countries (Molenbroek, Stricker, & Boermans, 2011) in kWh of primary energy /kWh of the actual energy amount

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX23	PEFtot	Total primary energy factor (Perimeter: onsite, nearby, distant)	$PEF_{tot,energy\ carrier}$	kWh of primary energy /kWh of the actual energy amount		-	ISO52000 Or Country specific	-

AUX24- the non-renewable primary energy factor $\boldsymbol{PEF_{nren}}$ (Perimeter: onsite, nearby, distant) is demonstrate how much non-renewable primary energy is used to generate a unit of final energy. Main values of PEFs can be taken from ISO 52000-1:2017 table B.16(See Table 37).

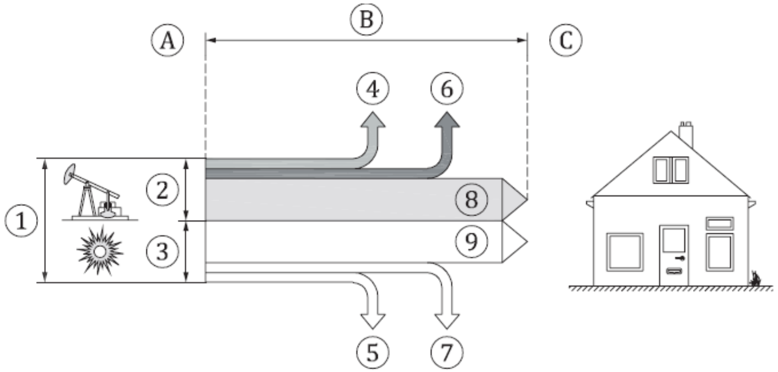
[13] Reference: ISO52000. Primary energy factor: The system boundary shall encompass the primary energy required to extract and transport the energy carried to the building, as well as any other associated operations.

[14] Given the significant changes that lie ahead for electricity supply, the PEF for electricity should be revised regularly and its method of calculation clearly documented and eventually harmonized (Papaglastra, 2018)

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX24	PEF_{nren}	non-renewable primary energy factor	PEF_{nren}	kWh of primary energy /kWh of the actual energy amount	Energy	-	ISO52000 Or Country specific	-

AUX25- the non-renewable primary energy factor PEF_{nren} (Perimeter: onsite, nearby, distant) it demonstrates how much primary energy from renewable sources is used to generate a unit of final energy through the use of consumption indicators. Main values of PEFs can be taken from ISO 52000-1:2017 table B.16(See Table 37).

REF	Notation	Description	Formula	Units	Category	Periodicity	Data source	Variables
AUX25	PEF_{ren}	renewable primary energy factor	PEF_{ren}	kWh of primary energy /kWh of the actual energy amount	Energy	-	ISO52000 Or Country specific	-



$$f_{Ptot} = \frac{①}{⑧+⑨} \quad f_{Pnren} = \frac{②}{⑧+⑨} \quad f_{Pren} = \frac{③}{⑧+⑨}$$

Key

A	energy source	4	non-renewable infrastructure related energy
B	upstream chain of energy supply	5	renewable infrastructure related energy
C	inside the assessment boundary	6	non-renewable energy to extract, refine, convert and transport
1	total primary energy	7	renewable energy to extract, refine, convert and transport
2	non-renewable primary energy	8	delivered non-renewable energy
3	renewable primary energy	9	delivered renewable energy

Figure 24 – Primary Energy Factors calculation based on ISO52000 (ISO, 2017)

	Energy carrier Delivered from distant		f_{Pnren}	f_{Pren}	f_{Ptot}	K_{CO2e} (g/kW h)
1	Fossil fuels	Solid	1,1	0	1,1	360
2		Liquid	1,1	0	1,1	290
3		Gaseous	1,1	0	1,1	220
4	Bio fuels	Solid	0,2	1	1,2	40
5		Liquid	0,5	1	1,5	70
6		Gaseous	0,4	1	1,4	100
7	Electricity [c]		2,3	0,2	2,5	420
	Delivered from nearby					
8	District heating [a]		1,3	0	1,3	260
9	District cooling		1,3	0	1,3	260
	Delivered from on-site					
10	Solar	PV electricity	0	1	1	0
11		Thermal	0	1	1	0
12	Wind		0	1	1	0
13	Environment	Geo-, aero-, hydrothermal	0	1	1	0
	Exported					
14	Electricity [b c]	To the grid	2,3	0,2	2,5	420
15		To non EPB uses	2,3	0,2	2,5	420

[a] Default value based on a natural gas boiler. Specific values are calculated according to M3–8.5.

[b] It is possible to differentiate between different sources of electricity like wind or solar.

[c] These values are established in line with the default coefficient provided in Annex IV of Directive 2012/27/EU. This default coefficient is currently being reviewed and a later amendment of the above factors could be needed.

NOTE 1 Add a column in case of other requirements, e.g., CO_2 requirement.

NOTE 2 Add rows for each relevant energy carrier.

Table 37– Primary Energy Factor (ISO52000 Table B16) (ISO, 2017)

7 References

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