TRI-HP PROJECT | Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

Technical, economic and environmental performance KPIs definition

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CONTENTS

EXECUTIVE SUMMARY

In this deliverable, the Key Performance Indicators (KPIs) for the assessment of the different systems that will be developed along the project are described. Technical, economic and environmental KPIs have been defined, taking into account relevant European and international norms, as well as other recognized references.

The purpose is to set a basis for evaluating different attributes, which set the technical performance, economic profitability and environmental performance of the systems which will be designed and demonstrated in TRI-HP project. The KPIs can be used as well for comparison of the developed systems in TRI-HP with reference cases. In that way, the compliance with the objective values can be evaluated.

List of Acronyms

a	Previous year until recovering the initial outlay
b	Sum of discounted cash flows until the end of period "a"
C_n	Net cash inflow during the period of analysis
COP	Coefficient of performance
C_{RSP}	Costs associated with the refence study period
d	Discount rate
DC	Total disposal costs
DHW	Domestic hot water
DR	Dimension rate
E_{annual}	Yearly energy consumption
EC	Total costs of energy consumed during the use by the equipment or system
EER	Energy Efficiency Ratio
$El_{cool,sys}$	Total used electricity for providing cooling
El_{exp}	Electricity exported to the grid
El_{grid}	Electricity purchased from the grid
El_h	Electricity consumed in the households
$El_{heat,sys}$	Total used electricity for providing heating
El_{PV}	Electricity provided by the photovoltaic field
El_{sys}	Electricity used for the system operation
El_{used}	Total used electricity
E_{RES}	Energy from renewable sources for a heat pump
EV	Exported Energy value
f	Weighting factors to primary energy
FF	Flexibility factor
F_t	Discounted cash flow values of the year in which the investment is recovered.
FV	Final value or residual value
GWP	Global Warming Potential
I	Total initial investment costs
IRR	Internal Rate of Return
KPI	Key Performance Indicator
L	The leakage rate
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
m	Refrigerant charge
m_i	Gas charge in the insulation system
n	Number of years between the base date and the project service life
NET_E	Net Exported Energy
NPC	Net Present Cost
NPV	Net Present Value
nren	Non renewable
O&M	Operation and maintenance costs

PB	Dynamic Payback
P_{bat}	Power sent to the battery or incoming from the battery
PE	Primary energy
$P_{el,\Sigma hp}$	Electricity consumption during the high price periods
$P_{el,\Sigma lp}$	Electricity consumption during the low price periods
PE_{nren}	Non-Renewable Primary Energy
PE_{ren}	Renewable Primary Energy
PE_{tot}	Total Primary Energy
PPV	On-site (photovoltaic) generation power
Pused	Power load
PV	Photovoltaic
Q_{DHW}	Domestic hot water demands
Q_{SC}	Space cooling demands
Q_{SH}	Space heating demands
Q_{usable}	Total usable heat delivered by the heat pump over a period of time
RC	Replacement costs
RER	Renewable Energy Ratio
RES	Renewable Energy Sources
R_{grid}	Grid Purchase Ratio
ROI	Return on Investment
$R_{PV,gen}$	PV Generation Ratio
RSP	Reference study period
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
sl	Service life
SPF	Seasonal Performance Factor
TEWI	Total Equivalent Warming Impact
tot	Total
α_i	Rate of gas recovered from the insulation at the end of life
$\alpha_{recovery}$	Recovery/recycling factor
β	CO_2-emission factor
η	Ratio between total gross production of electricity and the primary energy consumption
η_{el}	Electrical performance factor
Y_{load}	Load cover factor
Y_{supply}	Supply cover factor

1. INTRODUCTION

In this document, key performance indicators (KPIs) describing the performance of the TRI-HP system and its main components, as well as the evaluation of the benefit of the proposed system compared to a reference scenario are defined. These KPIs provide the basis TRI-HP system evaluation of the technical, economic and environmental aspects. They will be used to assess the systems experimentally tested in Task 7.3[1] and simulated in Tasks 7.5[2] and 7.6[3].

The technical performance of the solutions will be assessed through specific indicators, such as the Coefficient of Performance (COP) or Energy Efficiency Ratio (EER) of the heat pump under certain conditions. The methodology for assessment of technical performance will follow equipment-specific standards (e.g. EN 14825 [9] & EN 14511 [8] for heat pumps, Figure 1), as well as other indicators for overall system efficiency. The seasonal performance factor of the different systems SPF_{sys}, will be calculated based on each particularities.

The economic performance of the solutions will be calculated taking into account a life cycle perspective, which considers initial costs, energy and other operational costs, maintenances, substitution, etc. The methodology for the assessment will follow standards such as ISO 15686-5:2017 [12] and EN 16627:2015 [11]. This task will consider different aspects like prospective energy prices, valuation of demand response, etc. KPIs from standards will be used and additional indicators for the performance of the developed solutions will be defined.

Environmental performance evaluation will also follow the life cycle approach, accounting for all products and flows through the whole life-time of the system: equipment production and installation, operation including energy use, maintenance and replacement, and end of life. This approach is particularly appropriate to evaluate environmental impacts of the electricity use, as it considers an integrated perspective of the electricity generation, transport and distribution. The methodology for the assessment and key indicators will be taken mainly from standards such as EN 15978:2011[21] and EN 378-1 [19].

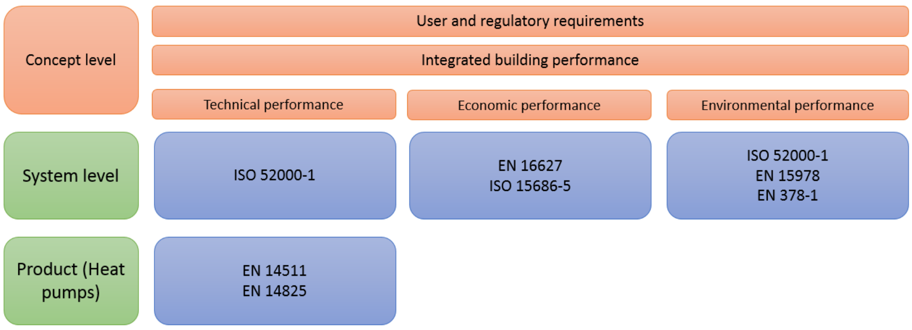

Figure 1. Considered European and international standards for KPIs definition.

Figure 1 shows an overview of the Standards, which have been taken into account for the different KPI types (technical, economic and environmental), at system and product (heat pump) level.

[1] Task 7.3 Building and assembling the systems to be tested.

[2] Task 7.5 Experimental assessment of AEM cost-efficiency benefits.

[3] Task 7.6 Model calibration and yearly simulation assessment.

In the following schemes (Figure 2 and Figure 3) the boundaries considered for technical, economic and environmental KPI calculation are shown, for the two systems developed in TRI-HP project. Inputs and outputs of energy from the system are represented, and the corresponding nomenclature is included in the graphs.

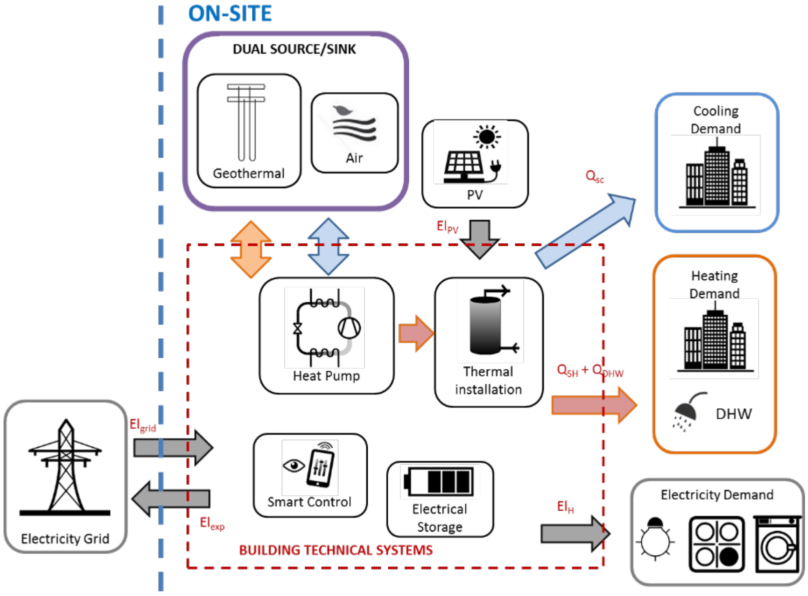

Figure 2. Dual-source heat pump system and its boundary for technical, economic and environmental KPI definition. Note: for economic KPI calculation, the cost of the boreholes, PV and their installation should be included in the boundary.

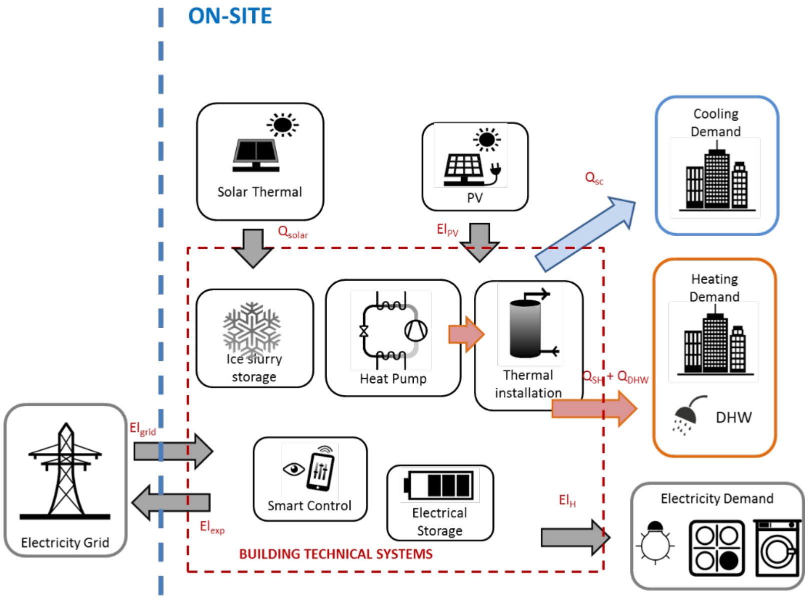

Figure 3. Ice-slurry heat pump system and its boundary for technical, economic and environmental KPI definition. Note: for economic KPI calculation, the cost of the solar systems and their installation should be included.

The KPIs at component level are defined for the heat pumps to be developed during TRI-HP project. The boundary in that case is the heat pump itself, being the energy input the electricity consumed, and the output the thermal energy delivered for heating + cooling, as shown in Figure 4.

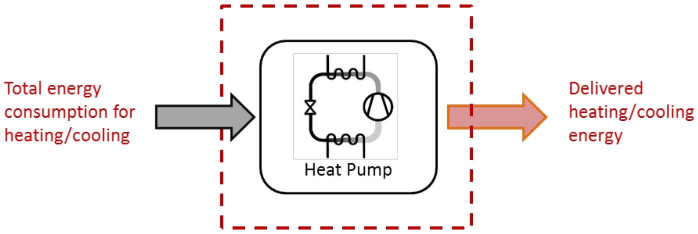

Figure 4. Boundary at component level (heat pump).

2. TECHNICAL KPIS

According to the scope of the project, technical KPIs are set both at energy supply unit (heat pump) level and system (multi-family building) level.

The following KPIs are set at system level:

- Seasonal performance factor (SPF)
- Electrical Performance factor (η_{el})
- Grid purchase ratio (R_{grid})
- PV generation ratio ($R_{PV,gen}$)
- Load Cover Factor (γ_{load})
- Supply Cover Factor (γ_{supply})
- Net Exported Energy (Net_E)
- Flexiblity Factor (FF)

The following KPIs are set at heat pump level:

- Coefficient of performance (COP)
- Energy efficiency ratio (EER)
- Seasonal coefficient of performance (SCOP)
- Seasonal energy efficiency ratio (SEER)
- Energy from renewable sources for a heat pump (E_{RES})

2.1 SEASONAL PERFORMANCE FACTOR (SPF)

Definition	The seasonal performance factor represents the ratio of total energy demand (taking into account heating, cooling and domestic hot water demand), to the total energy (electrical energy) used to heat or cool the system, over time period (day, month, year, etc.). It is assumed that all auxiliary or back-up energy is provided by electricity, i.e. there is no fuel-based supply.
Input Parameters & Calculation	Three different KPIs are defined, one referred to heating energy demands, another one referred to cooling energy demands, and a global one.

	Seasonal Performance Factor, heating: $$\mathrm{SPF}_{heating} = \frac{Q_{SH}+Q_{DHW}}{El_{heat,sys}} \quad (1)$$ Seasonal Performance Factor, cooling: $$\mathrm{SPF}_{cooling} = \frac{Q_{SC}}{El_{cool,sys}} \quad (2)$$ Seasonal Performance Factor, global: $$\mathrm{SPF}_{global} = \frac{Q_{SH}+Q_{SC}+Q_{DHW}}{El_{used}} = \frac{Q_{SH}+Q_{SC}+Q_{DHW}}{El_{sys}} \quad (3)$$ Where: Q_{SH} = Space heating demands (kWh/y) Q_{SC} = Space cooling demands (kWh/y) Q_{DHW} = Domestic hot water demands (kWh/y) $El_{heat,sys}$ = Total used electricity for providing heating (kWh/y) $El_{cool,sys}$ = Total used electricity for providing cooling (kWh/y) El_{sys} = Total used electricity ($El_{heat,sys}$ + $El_{cool,sys}$) (kWh/y)
Unit	Dimensionless number (kWh/kWh)
References	CTE - Código Técnico de la Edificación [1] RITE - Reglamento de Instalaciones Térmicas de edificios [2] IPMVP – International Performance Measurement & Verification Protocol [3] AZEB project. https://azeb.eu/ [4] ISO 52000-1 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

2.2 Electrical Performance Factor (η_{el})

Definition	The electrical performance factor represents the ratio of total electricity demand and the total energy delivered to the building technical systems, both from the PV system and from the grid.

Input Parameters & Calculation	Electrical Performance: $$\eta_{el} = \frac{El_{sys}+El_h}{El_{PV}+El_{grid}-El_{exp}} \quad (4)$$ Where: El_{grid} = Electricity purchased from the grid (kWh) El_{exp} = Electricity exported to the grid (kWh) El_{PV} = Electricity provided by the photovoltaic field (kWh) El_{sys} = Electricity used for the operation of the heating/cooling system (kWh) El_h = Electricity consumed in the households (kWh)
Unit	Dimensionless number (kWh/kWh)
References	CTE - Código Técnico de la Edificación [1] RITE - Reglamento de Instalaciones Térmicas de edificios [2] IPMVP – International Performance Measurement & Verification Protocol [3] AZEB project. https://azeb.eu/ [4] ISO 520001 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

2.3 Grid Purchase Ratio (R_{grid})

Definition	The grid purchase ratio represents the ratio of energy (electrical energy) purchased from the grid to the total energy (electrical energy) used by the system, over a time period.
Input Parameters & Calculation	Grid Purchase Ratio: $$R_{grid} = \frac{El_{grid}}{El_{used}} = \frac{El_{grid}}{El_{sys}+El_h} \quad (5)$$ Where: El_{grid} = Electricity purchased from the grid (kWh/y) El_{used} = Total used electricity (kWh/y) El_{sys} = Electricity used for the system operation (kWh/y) El_h = Electricity consumed in the households (kWh/y)
Unit	%

References	R. Haberl et. al. Hardware-in-the-Loop Tests on Complete Systems with Heat Pumps and PV for the Supply of Heat and Electricity. EuroSun 2018. ISES Conference Proceedings (2018) [6]

2.4 PV GENERATION RATIO ($R_{PV,GEN}$)

Definition	The PV generation ratio represents the total electricity provided by the photovoltaic field to the total electricity consumption of the system, over a time period.
Input Parameters & Calculation	PV Generation Ratio: $$R_{PV,gen} = \frac{El_{PV}}{El_{used}} = \frac{El_{PV}}{El_{sys}+El_h} \quad (6)$$ Where: El_{PV} = Electricity provided by the photovoltaic field (kWh/y) El_{used} = Total used electricity (kWh/y) El_{sys} = Electricity used for the operation of the heating and cooling system (kWh/y) El_h= Electricity consumed in the households (kWh/y)
Unit	%
References	R. Haberl et. al. Hardware-in-the-Loop Tests on Complete Systems with Heat Pumps and PV for the Supply of Heat and Electricity. EuroSun 2018. ISES Conference Proceedings (2018) [6]

2.5 LOAD COVER FACTOR (γ_{load})

Definition	The load cover factor is the relation between the electric energy produced on-site and directly used and the total electric energy use.
Input Parameters & Calculation	Load Cover Factor: $$\gamma_{load} = \frac{\int min\,[P_{PV}(t)-P_{bat}(t), P_{used}(t)]\,dt}{\int P_{used}(t)\,dt} \quad (7)$$ Where: P_{PV} = On-site (photovoltaic) generation power (kW) P_{used} = Power load (kW) P_{bat} = is the power sent to the battery (positive if charging) or incoming from the battery (negative if discharging) during the interval of time of evaluation (kW)

	The Load cover factor is identical to the Renewable Energy fraction (REF) defined by REHVA (see below) and similar to the Use matching fraction defined in ISO52000-1, in case of renewable on-site production and considering all energy needs.
Unit	%
References	Jaume Salom et al., Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data, Applied Energy, Volume 136, 2014, pp. 119-131, https://doi.org/10.1016/j.apenergy.2014.09.018 [7] REHVA Report nº 4, "REHVA nZEB technical definition and system boundaries for nearly zero energy buildings," Jarek Kurnitski (Editor), www.rehva.eu, 2013 [8] ISO 520001 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

2.6 SUPPLY COVER FACTOR (γ_{supply})

Definition	The supply cover factor is the relation between the electric energy produced on-site and directly used and the total renewable electric energy produced on-site.
Input Parameters & Calculation	Supply Cover Factor: $$\gamma_{supply} = \frac{\int min\,[P_{PV}(t), P_{used}(t)+P_{bat}(t)]\,dt}{\int P_{PV}(t)\,dt} \quad (8)$$ Where: P_{PV} = On-site (photovoltaic) generation power (kW) P_{used} = Power load (kW) P_{bat} = is the power sent to the battery (positive if charging) or from the battery (negative if discharging) during the interval of time of evaluation (kW) The Load cover factor is identical to the Renewable Energy fraction (REF) defined by REHVA and similar to the Use matching fraction defined in ISO52000-1, in case of renewable on-site production and considering all energy needs
Unit	%
References	Jaume Salom et al., Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data, Applied Energy, Volume 136, 2014, pp. 119-131, https://doi.org/10.1016/j.apenergy.2014.09.018 [7] REHVA Report nº 4, "REHVA nZEB technical definition and system boundaries for nearly zero energy buildings," Jarek Kurnitski (Editor), www.rehva.eu, 2013 [8] ISO 520001 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

2.7 NET EXPORTED ENERGY (NET_E)

Definition	Grid interaction indicators are based on the Net exported energy which represents the electricity interaction between the building and the grid, meaning the balance between exported energy and delivered energy from the grid.
Input Parameters & Calculation	Net exported energy: $$Net_E = El_{exp} - El_{grid} \quad (9)$$ Where: El_{grid} = Electricity purchased from the grid (kWh) El_{exp} = Electricity exported to the grid (kWh) This indicator can be represented by a "curve of duration", where the values of Net_e obtained during a period are ranked (negative values represent that the electrical power of the network is imported, and positive values represent that the Energy is exported). From this representation, interesting information can be extracted, such as: • Percentage of the time when the building is importing energy from the grid • Percentage of the time when the building is exporting energy to the grid • Percentage of time in which the balance between generation and load is close to zero, therefore, there are not energy exchanges with the grid. • Maximum peak of electricity imported energy. • Maximum peak of electricity exported energy • Dimension rate, (DR) which is the maximum of the Net exported energy $DR = \max(Net_E)$ For a proper analysis of grid interaction, subhourly resolution data is required (recommended in the range of 1-5 minutes, as maximum) as there is a relatively high impact due to time averaging effects [9].
Unit	kWh
References	Jaume Salom et al., Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data, Applied Energy, Volume 136, 2014, pp. 119-131, https://doi.org/10.1016/j.apenergy.2014.09.018 [7]

2.8 FLEXIBILITY FACTOR (FF)

Definition	One of the goals of implementing flexibility control strategies consists in the ability to shift system energy consumption towards periods of lower electricity prices (or lower CO_2 emissions) from the grid. The Flexibility Factor is an indicator which measures how the consumption is distributed in the low price or the high price periods.
Input Parameters & Calculation	Flexibility Factor: $$FF = \frac{P_{el,\sum lp} - P_{el,\sum hp}}{P_{el,\sum lp} + P_{el,\sum hp}} \quad (10)$$ Where: $P_{el,\sum lp}$ = Electricity consumption during the low price periods (kWh) $P_{el,\sum hp}$ = Electricity consumption during the high price periods (kWh) The Flexibility Factor varies between -1 (all the electricity use occurs during hours of high price) and 1 (all the electricity use occurs during hours of flow price).
Unit	dimensionless (-)
References	Thibault Péan, Ramon Costa-Castelló, Jaume Salom, Price and carbon-based energy flexibility of residential heating and cooling loads using model predictive control, Sustainable Cities and Society, Volume 50, 2019, https://doi.org/10.1016/j.scs.2019.101579. [10]

2.9 COEFFICIENT OF PERFORMANCE (COP)

Definition	The coefficient of performance represents the efficiency of a heat pump in heating mode. It is defined as the ratio of the heating capacity to the effective power input of the unit.
Input Parameters & Calculation	Coefficient of performance: $$COP = \frac{Heating\ capacity\ (kW)}{Effective\ power\ input\ of\ the\ unit\ (kW)} \quad (11)$$ EN 14511 will be followed when testing the developed heat pumps. COP values will be calculated for each of the testing conditions considered.
Unit	Dimensionless number (kW/kW)
References	EN 14511 – Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. [11]

2.10 Energy Efficiency Ratio (EER)

Definition	The energy efficiency ratio represents the efficiency of a heat pump in cooling mode. It is defined as the ratio of the cooling capacity to the effective power input of the unit.
Input Parameters & Calculation	Coefficient of performance: $$EER = \frac{Cooling\ capacity\ (kW)}{Effective\ power\ input\ of\ the\ unit\ (kW)} \quad (12)$$ EN 14511 will be followed when testing the developed heat pumps.
Unit	Dimensionless number (kW/kW)
References	EN 14511 – Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. [11]

2.11 Seasonal Coefficient of performance (SCOP)

Definition	The seasonal coefficient of performance represents the overall coefficient of performance of the unit, representative for the whole designated heating season. It is calculated as the reference annual heating demand divided by the annual energy consumption for heating.
Input Parameters & Calculation	Seasonal coefficient of performance: $$SCOP = \frac{Annual\ heating\ demand\ (kWh/y)}{Annual\ energy\ consumption\ for\ heating\ (kWh/y)} \quad (13)$$ Values are calculated according to EN 14825 under certain defined boundary conditions.
Unit	Dimensionless number (kWh/kWh)
References	EN 14825 – Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance. [12]

2.12 Seasonal Energy Efficiency Ratio (SEER)

Definition	The seasonal energy efficiency ratio represents the overall energy efficiency ratio of the unit, representative for the whole designated cooling season. It is calculated as the reference annual cooling demand divided by the annual energy consumption for cooling.
Input Parameters & Calculation	Seasonal energy efficiency ratio: $$SEER = \frac{Annual\ cooling\ demand\ (kWh/y)}{Annual\ energy\ consumption\ for\ cooling\ (kWh/y)} \quad (14)$$

	Values are calculated according to EN 14825 under certain defined boundary conditions.
Unit	Dimensionless number (kWh/kWh)
References	EN 14825 – Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance. [12]

2.13 ENERGY FROM RENEWABLE SOURCES FOR A HEAT PUMP (E_{RES})

Definition	This value represents the amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps and considered energy from renewable sources for the purposes of Directive
Input Parameters & Calculation	Energy from renewable sources for a heat pump: $$E_{RES} = Q_{usable} \cdot \left(1 - \frac{1}{SPF}\right) \quad (15)$$ Where: Q_{usable} = Total usable heat delivered by the heat pump over a period of time (kWh) SPF = estimated average seasonal performance factor for the heat pump (referred to SCOP) Only heat pumps with SPF > 1.15 * 1/η shall be taken into account. Being η the ratio between total gross production of electricity and the primary energy consumption for the production of electricity and shall be calculated as an EU average based on Eurostat data. By 31st December 2021, the Commission shall adopt delegated acts in accordance with Article 35 to supplement this Directive by establishing a methodology for calculating the quantity of renewable energy used for cooling and district cooling and to amend Annex VII. That methodology shall include minimum seasonal performance factors for heat pumps operating in reverse mode.
Unit	kWh
References	Directive EU 2018/2001of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of renewable energy from renewable sources [13]

The technical KPIs defined above will be calculated in different tasks of the project.

The technical KPIs at heat pump level will be calculated during Task 5.3[4] and Task 5.4[5], when the experimental campaigns to characterize the developed heat pumps are completed.

In Task 1.3[6], when the System Simulation Framework is defined, the technical KPIs calculation at system level will be included, taking into account the definitions that have been made for each of the KPIs, as well as the particularities of each of the systems (solar ice-slurry system and dual-source system). The values of COP and EER of each of the heat pumps developed in the project will be used as an input for global performance calculation. For that reason, these values will be updated in Deliverable 5.6[7] depending on the real measurements and calculations developed during the experimental campaigns for each of the heat pumps (Tasks 5.3[4] and 5.4[5]). Then, when the different systems have been experimentally tested in Task 7.4[8], a new update of the System Simulation Framework will be done, for the correct calculation of the KPIs at system level. And finally, the KPIs at system level will be also calculated in Task 7.7[9] in different cases extrapolated to EU-27.

[4] Task 5.3. Assembly of the prototypes and first experimental campaign

[5] Task 5.4. Heat pump upgrading and second experimental campaign

[6] Task 1.3. System simulation framework

[7] D5.6. Refined heat pump design and results of final testing.

[8] Task 7.4. Whole system test and optimization

[9] Task 7.7. Simulation scale-up, cost assessment and extrapolations to EU-28

3. Economic KPIs

Within the Life Cylce Cost (LCC) studies there are several economic indicators. As in the Life Cycle Assessment (LCA) studies, the economic indicators evaluated depend on the objective of study, the target audience and the level of accuracy of the required results.

Among the main economic indicators, the followings have been highlighted:

- Net Present Cost (NPC)
- Net Present Value (NPV)
- Cost of Energy based on Annuity
- Internal Rate of Return (IRR)
- Dynamic Payback (PB)
- Return On Investment (ROI)

3.1 Net Present Cost (NPC)

Definition	Net Present Cost is defined as the sum of all costs associated with the equipment or system during the study period (outgoing cash flows) discounted at present time.
Input Parameters & Calculation	$$NPC= \Sigma C_{RSP} = I+O\&M+RC+EC+DC-FV-EV \quad (16)$$ Where: C_{RSP} = Costs associated with the reference study period (€/kWh) I = total initial investment costs (€/kWh) O&M = Operation and maintenance costs (€/kWh) RC = Replacement costs (€/kWh) EC = Total costs of energy consumed during the use by the equipment or system (electricity, biomass…) (€/kWh) DC = Total disposal costs (€/kWh) FV = Final value or residual value (€/kWh) EV = Exported Energy value (€/kWh)
Unit	€/kWh delivered
References	EN 16627:2016 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [14] ISO 15686-5:2017 Building and constructed assets-Service life planning-Part 5: Life-cycle costing. [15]

3.2 NET PRESENT VALUE (NPV)

Definition	Net Present Value is the difference between the present value of cash inflows and the present value cash outflows. Net present value is used in capital budget to analyse the profitability of a projected investment or project. A positive NPV indicates that the projected earnings generated by a project or investment exceed the anticipated costs. Generally, an investment with a positive NPV will be a profitable one and, one with negative NPV will result in a net loss. This concept is the basis for the NPV rule, which dictates that the only investments that should be made are those with positive NPV values.
Input Parameters & Calculation	$NPVsl = \sum_{n=1}^{sl} \frac{Cn}{(1+d)^n} - I$ (17) Where: C_n= net cash inflow during the period of analysis I= total initial investment costs d= discount rate n= number of years between the base date and the project service life sl = period of analysis, the service life
Unit	€
References	EN 16627:2016 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [14] ISO 15686-5:2017 Building and constructed assets-Service life planning-Part 5: Life-cycle costing. [15] Bresaer project: Breakthrough Solutions for Adaptable Envelopes in building Refurbishment http://www.bresaer.eu/ [16]

3.3 INTERNAL RATE OF RETURN (IRR)

Definition	The Internal Rate of Return (IRR) is a metric used in capital budgeting to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the Net Present Value (NPV) of all cash flows from project equal to zero. IRR calculations rely on the same formula as NPV does.
Input Parameters & Calculation	$0 = NPVsl = \sum_{n=1}^{sl} \frac{Cn}{(1+d)^n} - I$ (18) Where:

	C_n = net cash inflow during the period of analysis I = total initial investment costs d = discount rate n = number of years between the base date and the project service life sl = period of analysis, the service life
Unit	%
References	EN 16627:2016 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [14] ISO 15686-5:2017 Building and constructed assets-Service life planning-Part 5: Life-cycle costing. [15]

3.4 DYNAMIC PAYBACK PERIOD

Definition	The payback period is the time it takes to cover investment costs. It can be calculated from the number of years elapsed between the initial investment and the time at which cumulative savings offset the investment. Simple payback takes real (non-discounted) values for future cash inflows or outflows. Discounted payback uses present values. Payback in general ignores all costs and savings that occur after payback has been reached. Payback period is usually considered as an additional criterion to assess the investment, especially to assess the risks. Investments with a short payback period are considered safer than those with a longer payback period. As the invested capital flows back slower, the risk that the market changes and the invested capital can only be recovered later or not at all increases. On the other hand, costs and savings that occur after the investment has paid back are not considered. Therefore, sometimes decisions that are based on payback periods are not optimal and it is recommended to also consult other indicators.
Input Parameters & Calculation	$$PB = a + \frac{I-b}{Ft} \quad (19)$$ Where: a = Previous year until recovering the initial outlay I = total initial investment costs b = sum of discounted cash flows until the end of period "a" F_t = discounted cash flow values of the year in which the investment is recovered.
Unit	years
References	EN 16627:2016 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [14] ISO 15686-5:2017 Building and constructed assets-Service life planning-Part 5: Life-cycle costing. [15]

3.5 RETURN ON INVESTMENT

Definition	The return on investment (ROI) is an economic variable that enables the evaluation of the feasibility of an investment or the comparison between different possible investments. To calculate the ROI, the benefit (or return) of an investment is divided by the cost of the investment and the result is expressed as a percentage or a ratio.
Input Parameters & Calculation	$$ROI_{sl} = \frac{NPVsl}{I} x100 \quad (20)$$ Where: sl = period of analysis, the service life NPV_{sl} = Net Present Value of the service life I = total initial investment costs
Unit	%
References	EN 16627:2016 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [14] ISO 15686-5:2017 Building and constructed assets-Service life planning-Part 5: Life-cycle costing. [15]

The calculation method for the economic KPIs will be included in the System Simulation Framework developed in Task 1.3[10].

A first estimation of the inversion cost of the systems will be developed in Task 1.4[11]. The calculated inversion costs will be updated when more information is available about the newly developed systems within the project:

- CO_2-ice heat pump
- R290-ice heat pump
- R290 heat pump with dual-source heat exchanger.

The update and extrapolations for the calculation of the KPIs at system level will be done in Task 7.7[12].

[10] Task 1.3. System simulation framework

[11] Task 1.4. Gathering Economic data of the proposed solutions

[12] Task 7.7. Simulation scale-up, cost assessment and extrapolations to EU-28

Reference values for the electricity cost will be taken from Eurostat [17] for EU-27 countries and from different identified sources in the case of Switzerland [18-20], and Norway [21].

4. Environmental KPIs

Environmental KPIs refer to the whole system, including the heat pumps and the rest of the installation for heating, cooling & DHW generation.

4.1 Total Equivalent Warming Impact (TEWI)

Definition	Assessment of the impact on climate change over the lifetime of a system by combining: 1) Direct contribution of refrigerant emissions to the atmosphere 2) Indirect contributions of the CO_2 resulting from energy to operate the system. TEWI is designed to calculate the total global warming contribution of the use of a refrigerating system. It measures both the direct global warming effect of the refrigerant, if emitted, and the indirect contribution of the energy required to power the unit over its intended operational life. It is only valid for comparing alternative systems or refrigerant options for one application in one location. TEWI is calculated relative to a particular refrigerating system and not only to the refrigerant itself. It varies from one system to another and depends on assumptions made relative to important factors like operating time, service life, conversion factor and efficiency. For a given system or application, the most effective use of TEWI is made by determining the relative importance of the direct and indirect effects.
Input Parameters & Calculation	TEWI is calculated as: TEWI = Impact of leakage losses + Impact of recovery losses + Impact of energy consumption. $TEWI = GWP \times L \times n + [GWP \times m \times (1-\alpha_{recovery})] + n \times E_{annual} \times \beta$ (21) Where: GWP = the global warming potential, CO_2-related L = the leakage rate (kg/y) n = the system operating time (y) m = the refrigerant charge (kg) $\alpha_{recovery}$ = the recovery/recycling factor, 0 to 1 E_{annual} = the yearly energy consumption (kW/y), calculated as the balance between E_{grid} and $E_{exported}$.

	β = the CO_2-emission factor (kg/kWh) When greenhouse gases may be emitted by insulation or other components in the cooling or heating system the global warming potential of such gases is to be added: $$GWP_i \times m_i \times (1 - \alpha_i) \quad (22)$$ Where: GWP_i = the global warming potential of gas in the insulation, CO_2-related m_i = the gas charge in the insulation system (kg) α_i = the rate of gas recovered from the insulation at the end of life, from 0 to 1 When calculating TEWI it is very important to update GWP CO_2 related and CO_2-emission per kilowatt hour from the latest figures.
Unit	kg CO_2
References	EN 378:2016 Refrigerating Systems and Heat Pumps – Safety and Environmental Requirements. [22] Real Alternatives Project. https://www.realalternatives.eu/ [23]

4.2 Primary Energy Consumption

Definition	The Primary Energy accounts for the energy that has not been subjected to any conversion of transformation process which also receives the name of source energy, The primary energy indicator sums up all delivered and exported energy, for all the energy carriers, into a single indicator with corresponding (national, regional or local) primary energy weighting factors. The weighting factors can be time dependent, particularly for the energy from the grid, but usually constant annual values are used. The Total Primary Energy Consumption of a product is the sum of any primary energy sources (e.g. raw fuels, biomass, solar radiation, geothermal energy, wind energy…) as the non-renewable primary energy is the energy taken from a source which is depleted by extraction (e.g. fossil fuels)
Input Parameters & Calculation	In the case of the TRI-HP project. Non-renewable Primary Energy Balance:

	$$PE_{nren} = \sum_t El_{grid} \cdot f_{grid,nren} - \sum_t El_{exp} \cdot f_{exp,nren} \quad (23)$$ Total Primary Energy Balance: $$PE_{tot} = \sum_t El_{grid} \cdot f_{grid,tot} - \sum_t El_{exp} \cdot f_{exp,tot} \quad (24)$$ Where: El_{grid} = Electricity purchased from the grid (kWh) El_{exp} = Electricity exported to the grid (kWh) f = weighting factors to primary energy (Kwh_{PE}/Kwh_{el}) nren = non-renewable tot = total Primary Energy consumption is used as one of the main indicators for the assessment of the energy balance in the EPBD directives and adopted in most of the countries in Europe. However, ISO 52000-1 which defines the overarching framework and procedures for the EPB assessment, distinguish between non-EPBD uses (appliances and lighting in some cases for residential) and two different forms of the energy balance. The different forms vary in the consideration of the resources avoided by the external grid due to the export of the energy carrier and each EU country can apply other considerations in the energy balance.
Unit	Kwh_{PE}
References	ISO 520001 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

4.3 Renewable Energy Ratio (RER)

Definition	The share of renewable energy is defined by the Renewable Energy Ratio (RER), which is calculated relative to all energy use in the building, in terms of total primary energy and accounting all the energy renewable sources. These include solar thermal, solar electricity, wind and hydroelectricity, renewable energy captured from ambient heat sources by heat pumps and free cooling, renewable fuels.
Input Parameters & Calculation	Renewable Energy Ratio: $$RER = \frac{PE_{ren,RER}}{PE_{tot}} \quad (25)$$ Where:

	$PE_{ren,RER}$= Renewable primary energy (kWh) PE_{tot} = Total primary energy calculated total primary conversion factors (kWh) RER is defined in the ISO 52000-1 and is dependent on the chosen perimeter. So, usually two types of RER can be distinguished. The on-site RER which considers only the energy that is used in the building and the distant RER accounting for the benefit for the external word of exporting energy produced on-site. The renewable primary energy produced on-site have the total primary energy factor of 1.0 and the non-renewable primary energy factor of 0. In the case of TRI-HP project, all energy uses in the building is considered similar to EPBD uses.
Unit	dimensionless (-)
References	REHVA Report nº 4, "REHVA nZEB technical definition and system boundaries for nearly zero energy buildings," Jarek Kurnitski (Editor), www.rehva.eu, 2013 [8] ISO 520001 Energy Performance of Buildings – Overarching EPB Assessment – Part I. General framework and procedures. [5]

References for the primary energy conversion factors and CO_2-equivalent emissions for the calculation of the defined KPIs will be taken from a RITE recognized document in the case of Spain [24] and from ISO 52000-1 for other European locations [5].

In the case of the TEWI calculation, the leakage rate and recovery/recycling factor will be chosen taking into account previous experience from the partners which have direct related experience, such as HEIM and GRVEFC. Some references for TEWI calculation can be found in [25].

TEWI has been selected as a valuable indicator for comparison of systems using very low GWP refrigerants – such as R290 and CO_2, used in TRI-HP project – and systems with conventional refrigerants with much higher GWP. As shown in [26], the direct effect of refrigerant leakage can contribute to around 10% of the total equivalent warming impact in the case of a conventional refrigerant, such as R410A, whereas with R290 its contribution would be negligible. The reference system for that study is a 30 kW air/water heat pump for retrofitting multi-family houses and commercial buildings.

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