meta build

D3.1 – Technologies for enabling electrification and business models, 1st technology release

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Powering the METAmorphosis of BUILDings towards a decarbonised and sustainable energy system

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Preface

The overall vision is to operationalise energy efficiency first principle in the practical context of buildings, towards the decarbonisation of the EU building stock, through: Electrified low-carbon technologies such as heat pumps for the electrification of the building thermal energy demand; Integration of RES & storage; Building digitalisation and intelligence with smart energy management systems. To achieve the 'META BUILD of the building sector', we will develop and demonstrate at TRL 6-8 highly cost-effective, integrated, and replicable solutions (i.e. Heat Pumps coupled with RES and ES systems) for electrifying thermal energy demand in buildings. Social acceptance and strict adherence to energy efficiency measures will be ensured to promote a sustainable, efficient energy use and an affordable pathway to decarbonise the building-sector heating. A holistic approach addresses challenges throughout the building life cycle, including product manufacturing, energy solution design and engineering, construction, renovation, operation, and maintenance.

META BUILD will deliver:

- KPI-driven assessment methodology & LCA analysis on building electrification.
- Decarbonisation as a service decision support tool; sound Business Models combined with energy efficiency and electrification.
- Advanced HP technologies, PVTs & other RES solutions, thermal & second-life battery storage systems.
- Interoperable framework for electrified ready buildings; Energy management services for RT-monitoring & performance analytics.
- Demand response, grid interaction & flexibility planning tools.
- Pro-active maintenance & controls services.
- Digital Twins for maintaining / enhancing the buildings' performance; Blueprints & policy recommendations for replication & scalability.

Focus will be given on both construction and renovation phases of a building, while META BUILD solutions will be demonstrated and replicated in different types of buildings including 6 Front Runners and 7 Replication Multipliers.

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TUD	TECHNISCHE UNIVERSITAET DRESDEN	DE		UNIZAG	SVEUCILISTE U ZAGREBU, FAKULTET STROJARSTVA I BRODOGRADNJE	HR	
CER	CIRKULARNI ENERGETSKI RESURSI DOO ZA PROJEKTIRANJE I IZGRADNJU ENERGETSKIH POSTROJENJA	HR		HEPT	HEP-TOPLINARSTVO D.O.O.	HR	
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Executive Summary

This deliverable presents the work carried out in META BUILD project's WP3 – "Technologies Enabling Electrification". The main goal of the report is to describe META BUILD's electrification-enabling technologies, regulatory frameworks for the technologies, potential market structures, and business models.

Before delving into the technologies, the deliverable presents a detailed analysis of the legislative and regulatory framework for heating systems in the countries with pilot sites. This mainly includes planning and sizing rules for heat pumps and the safety requirements for each country.

Then, the deliverable introduces the proposed technologies in META BUILD that allow the electrification of the built environment. These technologies include six heat pumps, two photovoltaic thermal collectors, and one second-life battery, which are being developed with the effort of the consortium partners. The deliverable provides detailed insight into each technology, including its starting status, core innovation, current status, and short-term and long-term future plans.

In addition to the technologies, the deliverable presents the methodology for creating a solution database, which will be used for replication purposes. Finally, the deliverable ends with a discussion of the novel market structures and suitable business models for the exploitation of the presented electrifying technologies.

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List of abbreviations

BESS	Battery energy storage system
BMS	Battery management system
BW	Brine-Water
COP	Coefficient of Performance
DHW	Domestic Hot Water
DSHP	Dual Source heat pump
DSHX	Dual-Source Heat Exchanger
EER	Energy Efficiency Ratio
EV	Electric vehicle
HMI	Human machine interface
HP	Heat Pump
HX	Heat Exchangers
IAQ	Indoor Air Quality
KPI	Key Performance Indicator
OCV	Open circuit voltage
PCB	Printed circuit board
PV	Photovoltaic
RES	Renewable Energy Sources
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
SOC	State of charge
SOH	State of health
WP	Work Package
xS yP	x battery cells in series, y cells in parallel

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1 Introduction

1.1 Scope of the document

The main scope of deliverable D3.1 – "Technologies for enabling electrification and business models, 1st technology release" is to present the progress of electrification technology development proposed in Work Package (WP) 3 – "Technologies enabling electrification". It also addresses the necessary legislative and regulatory conditions for the heating systems in the countries with pilot sites where the technology will be deployed and demonstrated in the field. Further, the document introduces the methodology to create novel market structures and business models for the exploitation of the developed technologies.

1.2 Connection with other Work Packages

The deliverable is developed under WP3, in which the leading technologies related to the electrification of the built environment are being developed. WP3 is explicitly or implicitly connected to WP2 – "Electrified thermal energy demand integrated solutions & demonstration strategy", WP4 – "Open modular energy management services", WP5 – "Deployment & demonstration in real cases", and WP6 – "Solutions adoption, replication, scalability & exploitation". The WP2 – "Electrified thermal energy demand integrated solutions & demonstration strategy" contains specific activities for modelling and simulation of the technologies under development in WP3 – "Technologies enabling electrification". The WP4 – "Open modular energy management services" utilises the developed technologies in WP3 – "Technologies enabling electrification" to build open and modular energy management services. Finally, it is heavily connected with WP5 – "Deployment & demonstration in real cases" and WP6 – "Solutions adoption, replication, scalability & exploitation", which are responsible for the deployment and demonstration activities in META BUILD Front Runners and Replication Multipliers, respectively.

1.3 Structure of the document

The rest of the deliverable is divided into the 5 following sections.

Section 2 presents the analysis of legislative and regulatory conditions for heating systems in the countries with Front Runners.

Section 3 includes detailed insight into each heat pump technology, including its starting status, core innovation, current status, and short-term and long-term future plans.

Section 4 includes detailed insight into each technology for integrating renewable energy sources (RES) and storage, including its starting status, core innovation, current status, and short-term and long-term future plans.

Section 5 outlines the structure and initial steps to build a solution database for replication of META BUILD technologies.

Section 6 presents the methodology for creating novel market structures and developing business models for META BUILD technologies.

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2 Legislation and Regulations on Heating and Cooling Systems in the Reference Markets

The purpose of this section is to analyse the legislative conditions and regulatory framework in the countries with pilot sites to ensure that the technical developments align with regulations and facilitate market entry at the project end.

2.1 Front Runner 1 – Austrian framework

2.1.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal equipment system design in Austria are the following:

1. ONorm (H 7500-1:2015, H 7500-2, H 5151-1, H 5055-5059, H 6040, EN 12831-1, EN 15450, EN 15255, EN ISO 13791, S 5021, B 5019, B 8110-5, B 8110-6)
2. OAL Guideline (6/18)

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.1.2 Planning and Sizing Rules

2.1.2.1 Conditions

THERMAL COMFORT

In Austria, indoor air temperatures must be matched according to the type of usage of the rooms. The minimum indoor air temperatures required by ONorm H 7500-1:2015 are shown in Table 1. However, in general a higher indoor temperature of 22°C is usually agreed with tenants since higher are considered as more comfortable and wanted. Regarding humidity, a value of 30 to 45% relative humidity should be aimed for.

Table 1 Austrian Standard room temperatures

Room type	Standard indoor temperature in °C
Living rooms and bedrooms	20+
Kitchen	20+
Bathrooms	24+
Toilets	15+
Lobby, hallway, etc.	15+
Stairwells	15+

ACOUSTIC COMFORT

For permanently installed heat pumps (HP) or retrofitted systems, the sound emissions of 45 dB(A) for residential areas and 50 dB(A) in mixed areas must be maintained between 21:00 and 07:00 o'clock. The requirements for noise protection of rooms used by people (e.g. living rooms, bedrooms, offices) have higher requirements of 30 dB(A) and 25 dB(A), between 22:00 and 06:00. The requirements stated above are

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minimum noise emission standards for heat pumps. These may differ depending on the zoning plan and the prevailing ambient noise situation and can be found in OAL Guideline 6/18 or ONorm S 5021.

Outdoors, directly in front of a residential area, there are no legal limits for noise pollution/noise emissions. As a general rule, however, the noise of a technical system must not stand out from the local background noise during quiet hours. A guideline value that applies in many rural residential areas during the night hours from 10:00 p.m. to 6:00 a.m. is 30 dB(A) sound pressure level at the neighbours' property line.

2.1.2.2 Energy Efficiency

In Austria, an energy performance certificate must be issued for buildings that are newly constructed or renovated. An energy certificate is also required if you want to sell or rent a building, this is regulated in the federal law EAVG 2012. The energy certificate contains various key figures that are determined using certified or standardised procedures. Among other things, the energy demand for heating, indoor air, cooling, etc. is calculated. The process of determining these key figures is explained in Onorm H 5056 to H 5059.

The energy certificate describes the energetic condition of the building and enables a comparison of buildings with each other regarding their overall energy efficiency. The reference building is defined by the Austrian Institute for Building Technology.

For this purpose, the Austrian Institute for Building Technology published guideline 6. This guideline is updated on a continuing basis. Due to the "guideline-character", it is up to the federal states how they implement the guideline in their state law. The directive was drawn up on the basis of the building directive specified by the EU (Directive 2002/91/EC) and has been replaced by EU Directive 2010/31/EU. In Austria, ONorm H 5055 was created for this purpose, which specifies and describes the content and structure of an energy certificate. ONorm B 8110-5 and 6 are also relevant for the preparation of the energy certificate, as they define the different climate models of Austria and the usage profiles of different building types, which are to be applied for the preparation of the energy certificate.

After the Energy Performance Certificate for the building has been issued and all other agency approvals have been positive, the building's heating and cooling loads are calculated. These loads are considered the basis for the design of the heat source and represent the highest heat demand for space heating in the winter months and the highest cooling energy demand in the summer months, respectively.

The heat load is calculated via ONorm EN 12831-1 and the national supplement ONorm H 7500- 1 and 2. These standards describe and illustrate the calculation principles for the heating load calculation. Furthermore, the indoor temperatures that should be used are given for the different room types. For the heating load calculation, the site-related standard outdoor temperature is also included and determined by the Austrian Institute for Building Technology and published in Guideline 6.

The energy demand, which is needed for hot water preparation, is determined with ONorm H 5151-1. Furthermore, in the guideline, the dimensioning of the piping, the safety valves, the hot water quantity, the hot water storage tank, etc. are described and calculated.

Knowing the energy requirements of the space heating and hot water preparation, the requirement for the heat source (boiler, HP, etc.) can be calculated based on the yearly peak load (coldest day in Austria with the highest space heating load plus. hot water preparation). If an HP is used, the heat source is selected and designed via ONorm EN 15450.

For the calculation of the cooling load, ONorm EN ISO 13791 and ONorm EN 15255 are applied. As a national supplement, ONorm H 6040 was created. In ONorm EN ISO 13791, ONorm EN 15255 and ONorm H 6040,

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the calculation steps, how the cooling load must be calculated, and which site-related reference values are to be assumed are described and presented in more detail.

2.1.2.3 Sizing of components and systems

ONorm EN 15450:2008 describes how to calculate the heat pump capacity based on the heating load and hot water demand. This includes several different reduction factors that take into account the type of heat pump system. In order to reduce the number of starts to a minimum, it must be ensured that the heat output delivered by the heat pump is fully transferred to the heating system. A buffer tank which is connected in parallel to the heat pump can support this and also functions as an aid to hydraulic de-coupling. A guideline for dimensioning the buffer tank volume is 12 l to 35 l per kW of maximum heat pump capacity.

2.1.3 Safety Requirements

ONorm B 5019 - also known as the "Legionella standard" - regulates the hygiene-related planning, execution, monitoring, renovation and operation of central drinking water heating systems.

The specifications in this ONORM are valid under the condition that drinking water is heated centrally, in particular for hospitals and health resorts, care facilities, bathing facilities, accommodation facilities, community facilities as well as public buildings and residential complexes (terraced houses, apartment buildings) with branched distribution networks.

Drinking water heating systems which supply only one dwelling (decentralised solutions or also via dwelling stations), one or two-family houses or facilities in which a growth of Legionella can arise, but which are not to be classified as central drinking water heating systems are not part of this standard.

Summary of the norm:

- The heated drinking water must have a temperature of at least 60°C when entering the distribution system during proper operation. This temperature must be ensured throughout the year.
- Technical measures must be taken to ensure that a minimum temperature of 55 °C is maintained at every point of the water heater (except the cold water supply line) during periods when water is not being always drawn.
- Preheating stages must not fall below 55 °C - except for 4 hours of charging time of hot water storage tanks.
- The distance from the node of the circulation line to the furthest consumer must not exceed 6m.
- Thermal disinfection of the entire hot water system with at least 70 °C must be possible.
- Temperature measuring nipples or taps for water sampling must be available at defined points.

Decentralised solutions and 2-pipe systems using an apartment station are not subject to the standard and can, therefore, also be operated at lower temperatures. In 2-pipe systems, the required temperature of the heating flow depends on the heating system and heat transfer as well as the required output of the home station.

Further standards which must be considered in the case of Domestic Hot Water (DHW) systems:

- DIN 1988-300: May 2012: Technical rules for drinking water installations - Part 300: Determination of pipe diameters; Technical rule of DVGW.
- DVGW Worksheet W 553 1998-12 Dimensioning of circulation systems in central drinking water heating systems.
- ONorm EN 806:
    - 1 Issue: 2001-03-01 Technical rules for drinking water installations Part 1: General.

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- 1/A1 Edition: 2002-03-01 Technical rules for drinking water installations Part 1: General (Amendment).
- 2 Issue: 2005-07-01 Technical rules for drinking water installations Part 2: Planning.
- 3 Issue: 2013-08-01 Technical rules for drinking water installations Part 3: Calculation of internal pipe diameters - Simplified method.
- 4 Issue: 2010-07-15 Technical rules for drinking water installations Part 4: Installation.
- 5 Issue: 2012-03-15 Technical rules for drinking water installations Part 5: Operation and maintenance.

- ONorm H 5142 Issue: 1990-08-01 Domestic installations; hydraulic circuits for heating systems.
- ONorm H 5151-1 Issue: 2010-12-15 Design of central hot water heating systems with or without domestic hot water production Part 1: Buildings with a specific transmission conductance > 0.5 W/(K - m2) and ONORM H 5155 Issue: 2013-09-01 Thermal insulation of piping and components of building services installations.

ONorm EN 378-1 to 4 describe and illustrate the safety requirements of refrigeration systems and heat pumps in more detail. In the first part of this ONORM, the basic requirements, classifications and selection criteria are described and defined, containing the:

- classification of refrigerants.
- classification of locations of refrigeration systems.
- classification of refrigeration systems (including description of different refrigeration systems).
- maximum permissible refrigerant charge.

The second part of this ONorm deals in more detail with the design, testing, marking and documentation of refrigeration systems and heat pumps, such as the:

- list of possible hazards (mechanical, electrical, thermal, due to materials and operating environment).
- safety requirements (general, for components and piping).
- requirements for the installed components.

The third part of this ONorm describes and defines the requirements for the installation site and the protection of persons when a refrigeration system or heat pump system is installed:

- requirement for the refrigeration components for installation outdoors/ in a machine room/ in a people accommodation area).
- requirement for the machine room (installation room of the heat pump) in terms of its access, ventilation, open flames, emergency lighting, doors, etc.
- the required airflow for mechanical emergency ventilation.

The fourth and last part of this ONorm describes and specifies the requirements to be met for operation, maintenance, repair and recovery.

- requirements for user's manual and documentation.
- requirements for maintenance and repair.
- requirements for recycling and disposal of the installed components.

The power supply for a heat pump must be electrically installed in such a way that it can be switched off independently of the power supply for other electrical equipment, in particular for lighting systems, ventilation systems, alarms and other safety equipment. The power connection of the refrigeration system shall comply with the requirements in EN 60204-1:2006, sections 4 and 5.

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2.2 Front Runner 2 – Croatian framework

2.2.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal equipment system design in Croatia are the following:

1. HRN (EN 12831, EN 16798-1, EN 15450, EN 378-1 to 4).
2. Regulation on Technical Standards for Ventilation and Air Conditioning Systems in Buildings (Official Gazette No. 53/91 and 69/97).
3. Ordinance on Energy Audits and Energy Certification of Buildings (Official Gazette No. 48/14, 150/14).
4. Type of Noise Source, Time, and Location of Occurrence (Official Gazette No. 143/2021).

The main norms that define the specifications for renewable energy sources and their integration into the energy market in Croatia are the following:

1. Law on Renewable Energy Sources and High-Efficiency Cogeneration (Official Gazette No. 138/2021, 83/2023): Focuses on expanding the use of RES like solar, geothermal, and biomass, and promotes high-efficiency cogeneration.
2. Law on the Electricity Market (Official Gazette No. 111/2021): Facilitates the integration of renewable energy technologies into the grid.
3. Decree on the Criteria for Conducting Public Tenders for Issuing Energy Permits (Official Gazette No. 70/2023): Sets conditions for energy permits for facilities producing renewable energy.

The main norms that regulate the district heating sector in Croatia are the following:

1. Energy Act (Official Gazette No. 120/2012, 14/2014, 102/2015, and 68/2018): This law provides a comprehensive legal framework for the energy sector in Croatia. It governs energy production, distribution, and the establishment of a reliable energy supply system.
2. Act on Regulation of Energy Activities (Official Gazette No. 120/2012 and 68/2018): This act regulates energy activities, setting the legal foundation for energy market operations and defining the responsibilities of regulatory bodies. It ensures transparency and competitiveness in energy markets.
3. Act on Heat Market (Official Gazette No. 80/2013, 14/2014, 102/2014, 95/2015, 76/2018, and 86/2019): This law establishes the framework for the heat energy market, focusing on the regulation of heating supply and distribution. It aims to ensure efficient, fair, and safe access to heating services.
4. Act on Renewable Sources of Energy and High-Efficiency Cogeneration (Official Gazette No. 100/2015 and 111/2018): This legislation promotes the use of renewable energy sources and high-efficiency cogeneration. It incentivises renewable projects and supports Croatia's environmental and sustainability goals.
5. Act on Energy Efficiency (Official Gazette No. 127/2014 and 116/2018): This act sets the national framework for promoting energy efficiency across sectors. It includes measures for energy savings and supports Croatia's commitment to reducing energy consumption.

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.2.2 Planning and Sizing Rules

2.2.2.1 Conditions

THERMAL COMFORT

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Indoor temperatures for different room types are regulated by the Ordinance on Energy Audits and Energy Certification of Buildings. The minimum required temperatures are as follows:

Table 2 Croatian Standard room temperatures

Room type	Standard indoor temperature in °C
Living rooms and bedrooms	≥ 20°C
Kitchen	≥ 20°C
Bathrooms	≥ 22°C
Toilets	≥ 15°C
Hallways, foyers	≥ 15°C
Staircases	≥ 15°C

It is common practice to maintain a comfortable temperature of 22°C in most living spaces. Humidity levels in indoor environments should be kept between 30% and 60%, as recommended by the Regulation on Technical Standards for Ventilation and Air Conditioning Systems in Buildings (Official Gazette No. 53/91 and 69/97).

ACOUSTIC COMFORT

For permanently installed heating and cooling systems, such as heat pumps, noise emissions must not exceed 40 dB(A) during nighttime hours (22:00 to 07:00) in residential areas, according to the Regulation on the Maximum Permissible Noise Levels with Regard to the Type of Noise Source, Time, and Location of Occurrence (Official Gazette No. 143/2021). Noise levels in spaces such as living rooms and bedrooms are more strictly regulated, typically limited to 30 dB(A). These requirements ensure minimal disruption to occupants.

For external systems, noise levels must not surpass local ambient noise levels during quiet periods, ensuring that the system does not exceed background noise levels in residential areas.

INDOOR AIR QUALIITY

Indoor air quality (IAQ) is crucial for occupants' health and comfort. In Croatia, the Ordinance on Energy Audits and Energy Certification of Buildings (Official Gazette No. 48/14, 150/14) requires sufficient ventilation to maintain high IAQ, typically achieved through mechanical or natural systems that control pollutants, moisture, and CO_2 levels.

The ventilation requirements are further detailed in HRN EN 16798-1, which outlines methods to ensure indoor air remains free of harmful pollutants and provides recommendations for fresh air flow rates depending on the building's use. According to these guidelines, indoor CO_2 concentrations should not exceed 1000 ppm, which is considered the limit for maintaining good air quality. For residential buildings, the minimum ventilation rate is 0.5 air changes per hour, ensuring consistent air exchange and the removal of indoor pollutants.

DHW GENERATION CONDITIONS

Croatian regulations related to the prevention of Legionella bacteria growth in central hot water systems are outlined in the Regulation on Water for Human Consumption (Pravilniku o vodi za ljudsku potrošnju). This regulation mandates that the temperature of hot water in centralised systems must be at least 60°C at the entry point to the distribution system. It also specifies that a minimum of 55°C must be maintained throughout

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the system during non-use periods, with thermal disinfection systems ensuring water temperatures reach at least 70°C when necessary.

These safety measures are critical for ensuring hygienic conditions in hot water systems, particularly in multi-residential buildings, hospitals, hotels, and other large facilities.

2.2.2.2 Energy Efficiency

Energy efficiency measures in Croatia are regulated by several legislative frameworks:

1. Law on Energy Efficiency (Official Gazette No. 127/2014, 116/2018, 25/2020, 32/2021, 41/2021): Promotes measures to improve energy efficiency, especially in buildings, including HVAC systems.
2. Regulation on the System for Monitoring, Measuring, and Verifying Energy Savings (Official Gazette No. 98/2021): Establishes a framework for monitoring energy savings.
3. Building Act (153/2013, 20/2017, 39/2019, 125/2019): Mandates the issuance of Energy Certificates for new or renovated buildings and those being sold or rented, which classify the building based on its energy consumption metrics for heating, cooling, and domestic hot water. Calculations follow standards like HRN EN 15603 and HRN EN 13790, considering Croatia's specific climate zones.
4. Ordinance on Energy Audits and Energy Certification of Buildings (Official Gazette No. 88/2017, 90/2020, 1/2021, 45/2021): Provides detailed guidelines for conducting energy audits and issuing energy certificates.

These frameworks focus on reducing energy consumption, increasing the efficiency of energy systems, and ensuring compliance with EU directives. For HVAC systems, correct sizing of components, such as heat pumps, is governed by HRN EN 15450, which includes guidelines on system performance optimisation.

2.2.2.3 Sizing of components and systems

The correct sizing of heat pump systems and associated components must comply with HRN EN 15450, which defines procedures based on the building's heating load and hot water requirements. These standards include reduction factors for system types and suggest the installation of buffer tanks with capacities between 10 and 30 litters per kW of heat pump output to improve system performance and minimise system cycling.

2.2.3 Safety Requirements

Safety requirements for HVAC and refrigeration systems are covered by the Safety requirements for HVAC and refrigeration systems are covered by the Regulation on Technical Requirements for Refrigeration and Air Conditioning Systems (Pravilnik o tehničkim zahtjevima za rashladne i klimatizacijske sustave), which implements European standards like HRN EN 378-1 to 4. These standards classify refrigerants, detail the installation requirements for refrigeration systems, and specify safety measures such as ventilation, fire protection, and emergency procedures.

These regulations also govern the installation of cooling systems, specifying site safety and equipment installation standards to protect users and maintenance personnel.

2.3 Front Runner 3 – French framework

2.3.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal equipment system design in France are the following:

1. Standard NF P52612/CN

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2. Technical Standard, NF DTU 65.16.
3. European standard (NF EN 15450, EN 378).
4. French decree (2020-912, decree of 30/12/2022).

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.3.2 Planning and Sizing Rules

2.3.2.1 Conditions

THERMAL COMFORT

In France, the calculation of the building's heating loads for the sizing of heating systems is based on the European standard EN12831 and its French annexe NF P52612/CN. Some simplified methods exist, in particular based on heat loss coefficients (G or Ubat), but they are dedicated to the most simple and straightforward cases.

In the French annexe NF P52612/CN, some specific parameters needed for the heat load calculation, are precise:

- **The outdoor sizing temperature depending on the location:** The outdoor sizing temperatures correspond to the minimum temperature based on 30-year weather data. On Figure 1 (source NF P52612/CN, https://formation.xpair.com), they are expressed according to the French departments. They are also adjusted according to the altitude.

Figure 1 French outdoor sizing temperatures

- **The indoor sizing temperature depending on the type of buildings:** In Table 3 (NF P52612/CN) indicates the indoor setpoint temperatures taken in account for the design heating load calculation, depending on the type of buildings.

Table 3 French Standard indoor temperatures

Type of building	Standard Indoor temperatures
Hospitals (in general and similar premises) **Dressing rooms** **Washrooms, shower rooms**	21°C
Standard residential premises, hotel rooms	19°C

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Offices **Classrooms, lecture halls and conference rooms** **Cafés, cafeterias, restaurants**	
Churches, services (outerwear kept) **Stores, museums** **Professional kitchens** **Gymnasiums** **Moderate physical activity workshops**	15°C
Intense physical activity workshops	12°C
Heavy handling premises	10°C
Heated garages (outerwear kept)	5°C

ACOUSTIC COMFORT

The last update of the French acoustic regulation for newly built residential buildings[1] occurred in 1999 ("Arrêté du 30 juin 1999"). This regulation set requirements for sound insulation between dwellings, impact noise, noise from building equipment (such as elevators, mechanical ventilation, etc.) and noise from individual equipment (heating and air conditioning).

In particular, for heating and air conditioning equipment, this regulation set a maximum sound pressure level of 35 dB(A) in the main rooms (living room, bedrooms) and 50 dB(A) in the kitchen. For American kitchen configurations (kitchen integrated in the living room), the maximum sound pressure level is 40 dB(A).

The French public health code contains regulatory settings related to the violation of the tranquillity of the neighbourhood by noise since 2006 (decree 2006-1099).

The global emergence of the noise characterises the disturbance to the tranquillity of the neighbourhood and sound pressure level is greater than 5 dB(A) in daytime (7:00 am to 10:00 pm) and 3 dB(A) during the night.

These maximum values are corrected (increased) depending on the duration of the noise: from 0 dB(A) for noise duration > 8h to +6 dB(A) for noise duration < 1 min.

These settings are applied only when the global ambient noise level is greater than:

- 25 dB(A) inside rooms housing (windows closed or opened).
- 30 dB(A) in other cases.

DHW GENERATION CONDITIONS

The calculation of the needs of domestic hot water comes from the European standard NF EN 15450, which indicates a specific rule of 25 litres of 60°C water per person and per day, corresponding to 1.45 kWh/day by considering the inlet cold water at a temperature of 10°C.

For a DHW production with storage, the French technical standard document NF DTU 65.16 proposes an adaptation of the production depending on the capacity charging strategy:

[1] For existing buildings, there's no requirements in terms of acoustic disturbances.

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- In the case of DHW production with storage capacity charging only during the night, the daily DHW consumption considered for sizing purposes is equal to twice the average daily DHW requirement per person, i.e. 50 litres per person per day at 60°C.
- In the case of a load that can be carried out at any time of day, the daily DHW consumption is equal to 1 time the average daily DHW requirement per person, i.e. 25 litres per person per day at 60°C (satisfying the morning or evening consumption peak).
- If two DHW reheating periods are planned (one at night, another in the afternoon or morning), the daily DHW consumption taken into account is equal to 1.5 times the average daily requirement per person, i.e. 37.5 litres per person per day at 60°C (satisfying peak morning and midday or midday and evening consumption peaks).

The French decree of 30/12/2022 is relative to legionella monitoring in collective installations for the production, storage and distribution of domestic hot water. It requires specific monitoring actions, details in Table 4.

Table 4 French Required monitoring actions for domestic hot water

Monitoring point	Mandatory measure (for each DHW network)
DHW production outlet (towards the distribution system)	Water temperature measurement (1 per month)
Hot water production and storage tank bottom, if applicable	Legionella analysis (1 per year) • In the last tank if the storage tanks are installed in series In one of the storage tanks if they are installed in parallels
the most representative point(s) of use at risk in the network or, the point(s) of use furthest away from the domestic hot water production system	Water temperature measurement (1 per month) Legionella analysis (1 per year)
Loop return (general return)	Water temperature measurement (1 per month) Legionella analysis (1 per year)

2.3.2.2 Energy Efficiency

The two French texts dealing with energy efficiency in buildings and presented below, are transposition texts of the European Directive “Energy Performance of Buildings”.

ENERGY PERFORMANCE DIAGNOSIS OF BUILDING (“DPE”)

The DPE has been created in 2006 and has been reinforced several times to become fully opposable in July 2021. For new buildings, and existing buildings (or dwellings) when sold or rented, the DPE describes :

- The building (surface area, orientation, walls, windows, materials, etc.)
- The heating, DHW, cooling and ventilation equipment.
- It calculates the performance in terms of primary energy consumption and GHG emissions (operating). The results are shown on a label (Figure 2). The resulting class of the dwelling is characterised by the worst class between both energy consumption and GHG emissions.

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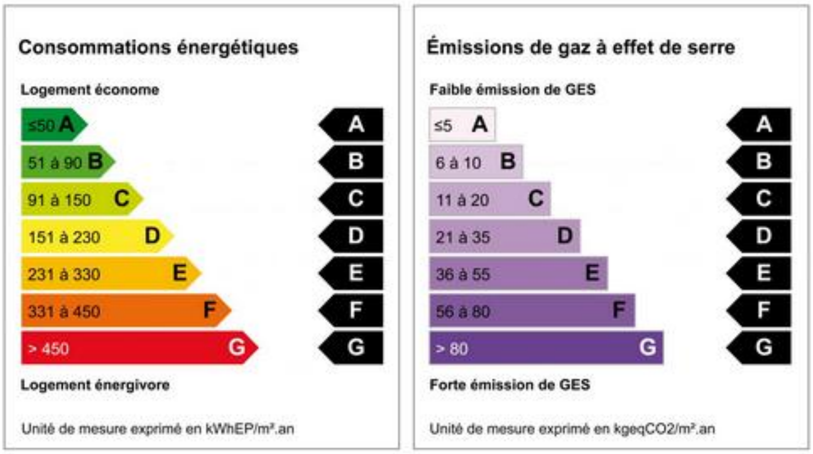

Figure 2 Label of French DPE

Depending on their class, dwellings can be declared not suitable for rent:

- G-rated dwellings from 2025.
- F-rated dwellings from 2028.
- E-rated dwellings from 2034.

REGULATION FOR NEW BUILDINGS (RE2020)

The RE2020, which entered into force in January 2022, sets requirements on energy and carbon performances for newly built buildings. These performances are calculated over a 50-year life of the future building, including construction and dismantling.

Several indicators are used for the characterisation of the building:

- Heating, cooling, lighting needs (B_{bio}),
- primary energy consumption, including or not renewable share (C_{ep}, $C_{ep,nr}$)
- carbon impact ($Ic_{energie}$ for operation, $Ic_{composants}$ for construction/dismantling and the total $Ic_{bâtiment}$).

The primary energy consumption and the carbon impact in operation are calculated taking into account ventilation, lighting, space and water heating, and space cooling.

Basic requirements for non-renewable energy consumption (C_{ep,nr_max}) and carbon impact during operation ($Ic_{energie}$) are set:

- 55 kWh(primary energy)/m^2.yr and 160 kgCO_2/m^2 for individual houses
- 70 kWh/m^2.yr and 560 kgCO2/m2 (260 kgCO_2/m^2 from 2025) for collective housing

This basic value is then corrected according to several parameters (size of the buildings, attic installation, opening of the windows), the main one being the location of the future building and the corresponding climate.

2.3.2.3 Sizing of components and systems

The sizing rules for heating systems in buildings are not strictly mandatory. However, they are included in a technical standard document, NF DTU 65.16, considered as a reference from a legal point of view. They are based on the calculation of the design heat load.

As a general rule, the heating system of a building has to be able to deliver 1.2 time the design heat load (D). This oversizing is a precaution in case of long intermittence.

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The sizing rules for heat pumps are shown in Table 5 French Sizing rules for heat pumps. It indicates only the heating capacity of the heat pump (P_{HP}) at design condition, the complement until 1.2 x D, being covered by a back-up heater.

Table 5 French Sizing rules for heat pumps

	Bivalent operation	Monovalent operation
Air-to-water HP (Fixed Speed)	70% x D < P_{HP} < 100% x D	
Air-to-water HP (Variable Speed)	Medium / High building inertia: 70% x D < P_{HP} < 100% x D Low building inertia: 80% x D < P_{HP} < 100% x D	
Air-to-Air HP	Medium / High building inertia: 70% x D < P_{HP} < 100% x D Low building inertia: 80% x D < P_{HP} < 100% x D	$P_{HP} \geq$ 120% x D
Ground-Source HP	Medium / High building inertia: 70% x D < P_{HP} < 100% x D Low building inertia: 80% x D < P_{HP} < 100% x D	$P_{HP} \geq$ 120% x D

2.3.3 Safety Requirements

HEAT PUMPS INSTALLATION

In France, the European Standard EN 378 is almost mandatory and has to be applied for the installation of heat pumps. Therefore, depending on the flammability and toxicity of the refrigerant contained in the heat pump, the size of the installing room, the ventilation, and the security sensors have to be adapted.

Moreover, some additional rules contained in the “CH35 article” of a French decree (“Arrêté du 10 mai 2019”) are dedicated to the management of flammable refrigerants in public-access buildings.

MAINTENANCE

The French decree 2020-912 requires a maintenance visit every 2 years for thermodynamical systems from 4 to 70 kW capacity. This maintenance includes:

- System verification.
- System cleaning.
- Leakage detection for systems that are not concerned by the F-gas regulation.
- System setting.
- Advice for the correct use.

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2.4 Front Runner 4 – Greek framework

2.4.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal and cooling equipment system design in Greece are the following:

1. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 20701-1/2017): Analytical national specifications of parameters for the calculation of the energy efficiency of buildings and the issuance of the energy performance certificate.
2. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 20701-4/2017): Instructions and forms of energy reports inspections of buildings, heating systems and air conditioning systems.
3. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2411/86): Facilities in buildings and land plots. distribution of cold-hot water.
4. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2423/86): Facilities in buildings. Air conditioning of building spaces.
5. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2425/86): Facilities in buildings. Air conditioning load calculation for building spaces.
6. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 20701-3/2017): Climate data of Greek regions.
7. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2421/86): Hot water distribution networks for heating building spaces.
8. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2423/): Building installations: Air conditioning of building spaces.
9. Technical Directive from Technical Champer of Greece (T.O.T.E.E. 2451/86): Building installations: Permanent water-based firefighting systems.

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.4.2 Planning and Sizing Rules

2.4.2.1 Conditions

THERMAL COMFORT

Based on the standards of **EN 15251:2007,** the temperature values for indoor spaces that should be followed are between 20 and 26°C. Ancillary spaces (e.g. stairwells, corridors, bathrooms, storerooms, etc.) temperature values that should be followed are between 18 and 26°C

In all new or radically renovated buildings, according to **Article 8 of the Regulation on Energy Efficiency of Buildings,** it is mandatory to cover a significant part of the hot water needs from solar thermal systems. The minimum percentage of the solar share on an annual basis is set at 60% of total DHW consumption. This obligation does not apply when DHW needs are covered by other energy supply systems based on RES, CHP, district heating systems on a district scale or building block, as well as from heat pumps that offer significantly more percentage of thermal energy from what they consume for their operation.

For single-family and multi-family houses, the average consumption of DHW is calculated at 50 l/person/day, and its temperature is regulated to 45°C.

ACOUSTIC COMFORT

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After the institution of the **Greek Law 66006/2360 (**of 2023**), article 22 – Soundproofing – Sound pollution** divides all new buildings into the three following categories regarding the auditory comfort they offer:

A. “High auditory comfort”
B. “Medium auditory comfort”
C. “Low auditory comfort”

According to sections 4,5 and tables 1-3 of the same article it is derived that in dwellings the maximum value of noise that can be derived from common-used or individually used facilities is set at 25dB(A) for category A and at 30dB(A) for category B. Section 5 enforces all new buildings to cover at least the requirements of the medium auditory comfort, category B. For older dwellings, the recommended maximum noise level is set to 25dB.

Finally, as mentioned above, EN 15521-2006 also covers permitted noise levels (among other parameters), within the scope of its outlined limitations.

INDOOR AIR QUALIITY

In a general direction, the **fresh air requirements** are determined so as to cover the **minimum ventilation required** (m^3/h/person), depending on the population density (people/m^2). For a single-family and multi-family house with a default population density of 5 people/m^2, the fresh air required is set to 15 m^3/h/person or 0,75 m^3/h/ m^2.

In this section, we include a general reference to TOTEE 20701-1/2017, which describes the required fresh air flow for each type of building use—though the ventilation rates therein are primarily intended for calculating the energy performance of a reference building. For specific design studies, it is common to consider the ventilation rates proposed in ASHRAE 62.1-2019 (Ventilation for Acceptable Indoor Air Quality), or, in the case of healthcare facilities, ASHRAE 170-2017 (Ventilation of Health Care Facilities). Additionally, EN 15521-2006 (Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics) should be consulted, as it addresses not only acceptable ventilation levels but also acceptable temperature ranges, noise limits, and other related parameters.

2.4.2.2 Energy Efficiency

HEAT PUMPS COEFFICIENT OF PERFORMANCE (HEATING)

For heat pumps used for indoor space heating, efficiency is determined either by the seasonal coefficient of performance (SCOP) or by the coefficient of performance (COP) at specific operating conditions or otherwise the coefficient of performance of the heat pumps at nominal operating conditions (for heating), as given in the manufacturer's technical specifications. It is clarified that the term SCOP corresponds to the seasonal efficiency of heat pumps (H/C) in heating mode only.

Table 6 Greek Average overall seasonal coefficient of performance (SCOP) for heat pump units for various heat medium temperatures

Source of heating	Tertiary sector buildings			Dwellings	
	T <35°C	35°C ≤ T <45°C	45°C ≤ T <55°C	T <35°C	35°C ≤ T <45°C
Fresh air	3,4	3,1	2,8	3,7	3,3
Ground	5,5	5,1	4,7	3,8	3,4

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Thermal energy from steam (e.g. CHP)	6,1	5,1	4,4	-	-
Underground water/seawater	4,7	4,2	3,6	4,5	4,1
Surface water	4,1	3,7	3,3	-	-

HEAT PUMPS ENERGY EFFICIENCY RATIO (COOLING)

Each cooling production unit has a nominal cooling efficiency Energy Efficiency Ratio (EER) according to the technical characteristics given by the manufacturer from the unit's certification. However, the actual operating efficiency of a cooling unit varies and depends on the duration of the cooling period, the operating time of the building and, by extension, the cooling system, the internal summer operating conditions of the spaces, the automation devices (compensation thermostats), the correct sizing of the unit, etc. For the calculations of the building's energy efficiency, it is required to determine the average seasonal energy efficiency ratio (SEER) of the cooling unit.

For air-cooled heat pumps that comply with the Ecodesign Regulation and are accompanied by an Energy Label, in accordance with the EU Energy Labelling Regulation 626/2011, the Seasonal Energy Efficiency Ratio of the unit $SEER_{ac}$ in the average climate is taken into account. The Average Seasonal Energy Efficiency Ratio SEER of the heat pump with an Energy Label is equal to:

$$SEER = 0.60 \cdot SEER_{ac}$$

For air-cooled heat pumps - chillers that are not accompanied by an Energy Label, the Energy Efficiency Ratio of the unit EER for an outdoor temperature of 35°C and an indoor temperature of 26°C is taken into account.

For heat pumps and/or chillers with a total cooling capacity below 100 kW, because the estimation of the average seasonal efficiency index SEER is not easy, for the calculations of the energy efficiency of the building of central air-conditioning installations, the nominal efficiency index EER for nominal operating conditions of outdoor air temperature 35°C and incoming refrigerant temperature 7°C in accordance with the European standard EN 14511:2007 is taken as the final cooling efficiency during the study or inspection, as given by the manufacturer and indicated in the technical specifications and/or in the context of the cooling unit. Correspondingly, in the case of geothermal heat pumps, the value referred to in operating conditions for geo-exchanger temperature 15°C and medium temperature 7°C is taken as the EER efficiency index during the calculations.

2.4.2.3 Sizing of components and systems

Heating installations sizing in Greece must align with the Technical Chamber of Greece Guidelines for the **Inspection of Boilers & Heating installations** under **theme section 2: Design of central heating installation of buildings.**

Air conditioning installation sizing in Greece must align with the Technical Chamber of Greece Guidelines for the **Inspection of Air conditioning installations** under **theme section 2: Design of air conditioning installation of buildings.**

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2.4.3 Safety Requirements

Rulings for DHW facilities, as well as protection of water inside the pipes of the facility, can be found on pages 75-91 of **T.O.T.E.E. 2411/86.**

These rulings include specifications for:

- Hot water production facilities.
- System cleaning.
- Piping.
- Connection with cold water.
- Perforation.
- Insulation.

2.5 Front Runner 5 – Italian framework

2.5.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal equipment system design in Italy are the following:

1. Ministerial Decree on Health of 5 July 1975 (Decreto ministeriale Sanità 5 luglio 1975 e s.m.i.).
2. Law no. 10 of 9 January 1991 (Legge 9 gennaio 1991, n. 10 e s.m.i.).
3. Decree of the President of the Republic no. 412 of 26 August 1993 (Decreto del Presidente della Repubblica 26 agosto 1993, n. 412 e s.m.i.).
4. Decree Of The President Of The Council Of Ministers (14 November 1997, 5 December 1997).
5. Legislative Decree no. 192 of 19 August 2005, Implementation of Directive (EU) 2018/844 (Decreto Legislativo 19 agosto 2005, n. 192 e s.m.i.).
6. Decree of the President of the Republic no. 59 of 2 April 2009 (Decreto del Presidente della Repubblica 2 aprile 2009, n. 59 e s.m.i.)

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.5.2 Planning and Sizing Rules

2.5.2.1 Conditions

THERMAL COMFORT

Temperature: the design temperature has to be between 18°C and 20°C for the heating systems.

ACOUSTIC COMFORT

- For external sources, noise emissions shall be limited to values indicated in the annex of (4) depending on the urban classification of the location.
- For Internal sources, noise emissions shall be limited to values indicated in the annex of (5) and for residential buildings is 35 dB (A) for non-continuous noise sources and 25 dB(A) for continuous noise sources.

INDOOR AIR QUALIITY

- For the calculation of the energy requirements of the building, it is mandatory to use the UNI TS 11300, which imposes specific air change rates depending on the designated use of the rooms.

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- In order to guarantee a minimum air quality in residential dwellings the openable windows surface shall not be less than 1/8 of the floor surface.

DHW GENERATION CONDITIONS

Anti-legionellosis measures: The “Guidelines for the Prevention and Control of Legionellosis” published on the 13th of May 2015 by the Italian Ministry of Health aims to merge, update and integrate all the specifications above national guidelines and regulations regarding the Legionella disease (Italian Ministry of Health, 2015). With respect to centralised DHW distribution systems, it states that the temperature of water in the accumulation tanks must be maintained at 60º degrees at least, while the distribution water temperature must be at 50º degrees at least. No prescriptions are given for single-apartment systems.

In general, the guideline suggests that low-temperature water (between 20°C and 50°C) should never stagnate in dead- or poorly used branches of the DHW distribution system.

2.5.2.2 Energy Efficiency

- Efficiency in the heating/cooling equipment as well as fluid transport equipment: the energy performance limits are exposed in section 3.
- Minimum insulation in distribution piping: the minimum insulation is presented in the annex of (2), it requires different thickness depending on the pipe size, the conductivity of the insulation and the place where the pipe is placed. In general, for pipes installed inside the thermal envelope, the insulation must equal the pipe dimeter at least. For outdoor installations, the insulation must equal at least twice the pipe diameter.
- Installation of metering, regulation and distribution systems: according to (3), the heating systems dedicated to multiple users shall have a temperature control unit and a metering system in every housing unit.
- Installation of renewable energies: there is a minimum share of renewable energies, section 3

In Italy, the energy performance certificate is compulsory for the following buildings:

- New buildings.
- Existing buildings or parts of buildings which are sold or rented
- For the retrofit to be eligible for the Superbonus (see section 3), the performance certificate must prove the improvement of the energy performance of the building by at least two classes or the achievement of the best class.

The certification and labelling procedure are regulated by **Decreto Legislativo** 63 del giugno 2013.

2.5.2.3 Sizing of components and systems

- Heating systems, newly installed or subject to refurbishment, shall be sized according to the **UNI-TS 11300** and the **UNI EN 12831** that define the calculation of the energy requirements of the buildings and the calculations of heat pump performances.
- DHW systems, including the storage, newly installed or subject to a refurbishment that is intended to serve a communal system, shall be sized according to the **UNI 9182**.

2.5.3 Safety Requirements

Heating systems are subject to the **Decreto Ministeriale** 1 dicembre 1975 which states the need for a correctly deigned expansion vessel, a supply of the heat transfer fluid, a safety thermometer and a pressure gauge.

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Heating systems and DHW systems are subject to the **Decreto legislativo** 15 febbraio 2016, n. 26 which is the transposition of the **directive 2014/68/UE** that shall apply to the design, manufacture and conformity assessment of pressure equipment and assemblies.

Heat pumps are subject to the **UNI EN 378** covering safety and environmental requirements. This standard specifies the requirements for the safety of people and property, provides guidance for environmental protection and establishes procedures for the operation, maintenance and repair of refrigeration systems and the recovery of refrigerants. In particular, the first part describes the criteria for the classification and selection of these systems. The second part considers the design, construction and installation of the systems, the third part describes the requirements of the installation site from a safety point of view, and the fourth part is about the safety of people and goods. The standard also gives attention to environmental issues.

The refrigerants that are used in the heat pumps are subject to the **Decreto del Presidente della Repubblica** 16 novembre 2018, n. 146 about F-gas with global warming effects.

2.6 Front Runner 6 – Spanish framework

2.6.1 Relevant Laws, Legislations, and Directives

The main norms that define the specifications for the thermal equipment system design in Spain are the following:

5. CTE-DB HE2 – Conditions of thermal installations (Spanish Government, 2019).
6. RITE - Regulation of Thermal Installations in Buildings (Spanish Government, 2007).

The main requirements defined by those norms are related to the following aspects in the subsequent sections.

2.6.2 Planning and Sizing Rules

2.6.2.1 Conditions

THERMAL COMFORT

For the case of dwellings, the suggested values for thermal comfort are the following:

- Temperature: 21-25 ºC
- Humidity: 40-60%

ACOUSTIC COMFORT

Acoustic ambient requirements, which must also be met by thermal installations, defined by **DB-HR**:

- The power of equipment generating *stationary noise* (as the one produced by pumps, compressors and other equipment as such), as well as ventilation grills and HVAC terminal units, will comply with the limits established by **Law 37/2003**:
- Ldn (day-night average sound level) = 45 dBA for regular rooms / 40 dBA for bedrooms.
- Further mounting instructions for such equipment:
- The contact points between machinery and the building will be designed in a way that noise and vibration levels are limited and will not increase noticeably when compared to the rest of the noise sources of the building. This can be done, e.g., by including anti-vibration supports or by inertial mounting.
- In the case of equipment installed on top of inertial mounting (such as pumps), the mounting will be made of concrete or steel in order to have enough inertial mass and avoid vibration transmission. Anti-vibrating elements must be placed between the mounting and the building structure.

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- Anti-vibrating supports and flexible connectors complying with **UNE100153IN** are considered valid.
- Flexible connectors will be installed between equipment inlet and outlets.

INDOOR AIR QUALIITY

For the case of dwellings, this is defined by the HS3 document of the **CTE**, which specifies:

- Enough outdoor air flow must be provided in order to keep a yearly average CO_2 concentration below 900 ppm, and the yearly CO2 aggregate exceeding 1600 ppm must be below 500,000 ppm*h.
- That outdoor air flow must be sufficient to eliminate pollutants which are not directly related to human presence. To do so, a minimum flow of 1,5 l/s per habitable space is defined for the non-occupancy periods.

DHW GENERATION CONDITIONS

As anti-legionellosis measures: according to the **Royal Decree 865/2003**, central DHW installations must have a design storage temperature of 60ºC and reach periodically 70ºC. However, this requirement does not apply to residential buildings. Article 2 states: “Installations located in buildings dedicated to housing exclusively are excluded from the scope of this regulation, except those affecting directly the external environment of the buildings”.

2.6.2.2 Energy Efficiency

See the previous section:

- Efficiency in the heating/cooling equipment as well as fluid transport equipment.
- Minimum insulation in distribution piping.
- Installation of metering, regulation and distribution systems.
- Installation of systems enabling energy recovery.
- Installation of renewable energies.

In Spain, the energy performance certificate is compulsory for the following buildings:

- New buildings.
- Existing buildings or parts of buildings which are sold or rented.
- Buildings or part of buildings in which more than 250m^2 useful floor area are occupied by a public authority and are habitually frequented by public.

The certification and labelling procedure are regulated by **Royal Decree 235/2013**.

2.6.2.3 Sizing of components and systems

In Spain there are not norms to size the thermal systems in general, but the **RITE** has recognised documents that can be taken as guidelines to do that. Those documents are guides (no norms) to support on the sizing of thermal systems and the most significant are listed below:

- Practical guide on centralised and DHW installations in residential buildings (Guía práctica sobre instalaciones centralizadas de calefacción y agua caliente sanitaria (ACS) en edificios de viviendas).
- Technical guide for the design of efficient heat plants (Guía técnica de diseño de centrales de calor eficientes).
- Technical guide for air conditioning installations with water (Guía técnica de Instalaciones de climatización por agua).
- Technical guide for energy saving and recovering in air conditioning installations (Guía técnica de Ahorro y recuperación de energía en instalaciones de climatización).

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- Technical guide on Project outdoor climatic conditions (Guía técnica de Condiciones climáticas exteriores de proyecto).

All of these guides are published by **IDAE** (*Instituto para la Diversificación y Ahorro de la Energía*). This institute belongs to the **Ministry of Industry, Tourism and Commerce**.

2.6.3 Safety Requirements

Heat pumps (and refrigeration equipment, in general) are currently undergoing important changes. All the regulation and trends toward sustainability are pushing towards phasing out high GWP refrigerants, fostering the use of natural refrigerants with very low GWP. International safety standards (e.g. IEC EN 60335-2-40) often pose the main barrier to the deployment of natural refrigerants (such as hydrocarbons). This has to be considered for the use of R290 as refrigerant in domestic environments, due to flammability issues. At the time of writing, R290, classified as A3 (flammable), is limited to a charge of 150g for devices at dwelling level.

In Spain, heat pumps must comply with European safety regulations (EN378). Some national regulations that apply to heat pumps are the following:

- **Royal decree 552/2019:** defines the safety regulation for refrigeration installations. The main innovation is that the A2L category is created, in which slightly flammable refrigerants are included, such as R32 and HFOs.
- **Royal decree 20/2018:** previously introduced modifications for A2L refrigerants for domestic heat pumps and HVAC units.
- **Royal decree 115/2017:** establishes that professionals currently qualified with a refrigerant manipulation certificate must take the complementary formation about alternative technologies to replace HFCs.

In addition to fire safety, other requirements apply to:

- Minimum conditions for avoiding/reducing the risk of accidents.
- Appropriate maintenance ensuring the continuity of the equipment characteristics and proper functioning.

The **maintenance** of thermal equipment, it is regulated by **RITE** (Regulation of Thermal Installations in Buildings) in its section "**IT3**":

The specifications defined in the "user and maintenance manuals" are always prioritised, meaning that the actions there defined prevail over the "generic" requirements established by the norm. In the event of the absence of such a manual, minimum periodicities are established by the norm.

- HP for DHW with nominal capacity ≤ 12 kW: every 4 years.
- HP for DHW with nominal capacity between 12k W-70 kW: every 2 years.
- A/C units with nominal capacity ≤ 12 kW: every 4 years.

In all cases, maintenance operations will be carried out considering the specifications from the manufacturers for all equipment. For installations with nominal capacity below 70 kW and no "user and maintenance value", maintenance operations will take place according to the professional judgment of the maintenance company.

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3 Technologies for electrifying building thermal energy demand

The purpose of this section is to present the technologies allowing the electrification of the building's thermal demand. These technologies include five heat pumps with different innovative dimensions to each of them. The size of the technologies ranges from kW, addressing the thermal demand of single/multi-family buildings, to MW, supporting the district heating operation. The section provides insight into each technology, including its starting status, core innovation, current status, and short-term and long-term future plans.

3.1 R290 brine-to-water HP

3.1.1 Overview

This section details the development of a 35 kW Brine-Water (BW) heat pump utilising natural refrigerant R290, designed to address a significant market need for efficient, eco-friendly heating and cooling in residential and multi-family housing. The project builds on iDM's existing expertise in Air-Water and BW heat pumps, where R290 is already used for Air-Water units, though a 35 kW BW heat pump featuring natural refrigerants is not yet part of their catalogue.

The innovation centres on an inverter-driven, modulating system that supports multiple heat sources, including groundwater wells and ground collectors, enhancing operational flexibility. Its low-noise design, achieved through advanced damper technology, makes it ideal for residential environments. Initial design work has included component selection, performance calculations, and schematics for the refrigerant cycle and different operation modes. The prototype has been assembled, with a promising compressor integrated and first-stage testing showing alignment with design expectations.

Future steps focus on testing further component combinations, refining the design of the housing, and conducting extensive testing under various conditions. The long-term plan involves scaling production, field trials, and incorporating user feedback for continuous improvement, positioning this heat pump as a leading solution in sustainable, energy-efficient systems.

3.1.2 Starting status, description and constraints

iDM currently maintains an extensive product catalogue featuring both Air-Water and BW heat pumps with thermal output powers ranging from 2 kW to 1 MW. A significant portion of iDM’s Air-Water heat pumps already employ the natural refrigerant R290 (propane), aligning with contemporary environmental standards and sustainability goals. In terms of development for BW heat pumps, iDM is actively working on the creation of two small-scale units with less than 150 g of refrigerant. These units are part of an ongoing research project focused on safety concepts for systems that aim to replace decentral gas heating. Despite this progress, iDM's product catalogue does not currently feature a BW heat pump in the 35 kW thermal power range that utilises a natural refrigerant. Market analysis has shown a strong demand for BW heat pumps in the 35 kW range, particularly for use in heating and cooling multi-family houses. This demand underlines the need for innovation in this area to fill a crucial market gap. To address this need, the META BUILD project’s first technical exercise (TE1) includes the development of a 35 kW BW heat pump utilising the natural refrigerant R290. This initiative not only responds to market requirements but also advances the development of sustainable and safe heating and cooling solutions.

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3.1.3 Core innovation technology

This section outlines a detailed overview of the innovations and technological advancements that will be introduced through this technology as part of the META BUILD project. The main goal of this subtask is to develop an advanced BW heat pump that utilises a natural refrigerant, with a thermal output power of 35 kW. This innovation is designed to address an existing market need and set new standards for sustainable heating and cooling systems.

The innovative aspect of this technology lies in the combination of an eco-friendly refrigerant, high efficiency, and versatile application. The heat pump will be driven by an inverter, allowing for modulation that adapts the system's output to meet varying demands efficiently. This will enhance the system's overall energy performance and operational flexibility, ensuring optimal energy consumption even at partial load conditions.

The technology will support multiple heat sources, including groundwater wells and ground collectors. This adaptability provides greater design flexibility, making it easier to integrate the system into a variety of installation scenarios, whether for new builds or retrofitting existing structures. The utilisation of natural refrigerants, such as R290, not only aligns with environmental regulations but also significantly reduces the carbon footprint compared to synthetic refrigerants. However, R290 as a flammable refrigerant makes an extensive safety discussion necessary.

One of the key aspects of this heat pump's design is its low noise operation. This is achieved through an efficient damper design that minimises acoustic emissions while maintaining high performance. This feature is particularly advantageous in residential and multi-family housing applications where noise reduction is an essential consideration.

The expected outcome of this project is a state-of-the-art 35 kW BW heat pump that leads the way in energy efficiency, sustainability, and user comfort. META BUILD will contribute to meeting key performance indicators (KPIs) related to reducing greenhouse gas emissions, energy consumption, and overall system noise. By offering a robust, versatile, and eco-friendly solution, this development will make a significant difference in the heating and cooling sector, supporting a shift towards greener and more efficient energy solutions.

3.1.4 Technology progress and status

This section provides an in-depth review of the current status, and the progress made in the development of the 35 kW BW heat pump. The following subsections detail the stages of development over the last 12 months, including design, prototype development, and testing. This structured approach highlights key achievements and milestones reached in each stage.

Design

The design phase has laid the foundational work necessary for the development of the heat pump. A comprehensive selection process for the major components was undertaken, leading to the identification of eleven different compressor types from various manufacturers that were deemed suitable for the intended application. This selection process ensures flexibility and enables the evaluation of optimal performance under different operating conditions.

A thorough examination was conducted to identify various suitable evaporators and condensers. This effort facilitated the creation of a detailed table that maps potential component combinations, ensuring that the most efficient and effective configurations can be chosen during subsequent stages.

Steady-state performance calculations were established for each compressor type to understand their behaviour under different conditions. This data is critical for assessing the feasibility and efficiency of the system. For promising component combinations, a stationary simulation was performed using IMST Art, a software developed by Universidad Politècnica de Valencia. The stationary simulation showed promising results for the chosen set of components regarding COP and thermal power. shows the resulting data for one selected component combination. Additionally, schematical drawings for the refrigerant cycle were developed to visually represent the flow and interaction of the system's key components. This was supplemented by detailed schematics for various operating modes - heating, cooling, heating + cooling, and passive cooling - as well as for different heat source scenarios, including groundwater wells and ground collectors.

A key preliminary estimate for the refrigerant charge was calculated, indicating that approximately 2.5 kg of propane (R290) is required. It is important to note that this value is an initial estimate and will vary depending on the selected components as the project progresses and the product specifications become more refined.

Compressor Speed (*)	Source T	Supply T	COP(HPA)	Heating Capacity
rpm	°C	°C		kW
2400	2	45	3.7412	10.893
2400	2	55	2.9745	10.275
2400	5	45	4.0572	11.854
2400	5	55	3.2011	11.147
3600	2	45	3.6791	16.543
3600	2	55	2.9817	15.616
3600	5	45	3.9661	17.969
3600	5	55	3.1955	16.926
4800	2	45	3.4871	21.862
4800	2	55	2.8655	20.688
4800	5	45	3.7402	23.746
4800	5	55	3.0596	22.433
6000	2	45	3.2821	27.081
6000	2	55	2.7342	25.697
6000	5	45	3.5006	29.389
6000	5	55	2.9062	27.847
7200	2	45	3.0616	32.2
7200	2	55	2.5867	30.651
7200	5	45	3.2485	34.915
7200	5	55	2.7364	33.187

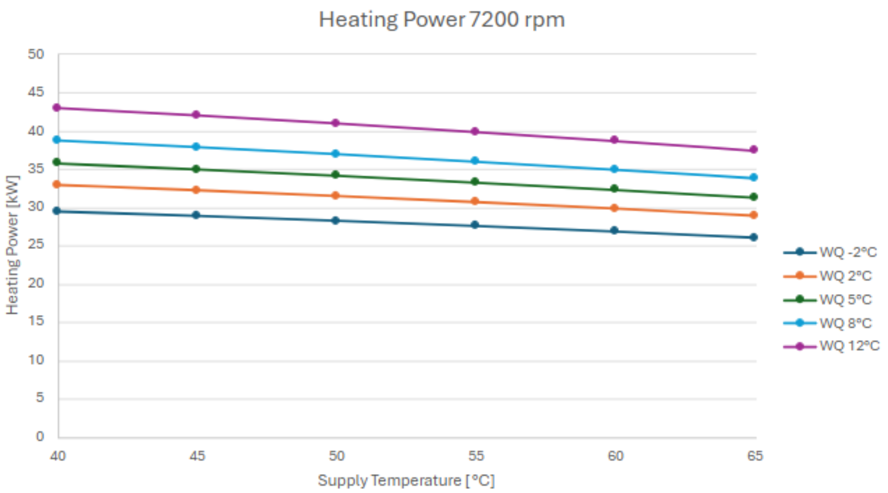

Figure 3 Results of Steady-State Performance Calculation for several operating points and compressor speeds (left), Heating Power vs. Supply Temperature at different Source Temperatures (right).

Prototype Development

The prototype development stage has seen significant progress, culminating in the creation of a comprehensive CAD drawing that includes the complete refrigerant cycle and all associated components (see Figure 4 and Figure 5). These drawings serve as the blueprint for the manufacturing, assembly and further refinement of the prototype.

A robust frame was designed, manufactured, and assembled to house the components securely. This frame acts as the structural backbone of the prototype, ensuring stability and ease of integration for testing and future modifications.

Manufacturing and installation of the piping for the refrigerant cycle were completed to facilitate the transfer and management of the refrigerant throughout the system. The assembly phase included the integration of the various components, with a promising compressor selected and incorporated for the first round of testing. This marked a significant milestone, as it laid the groundwork for the operational testing of the prototype.

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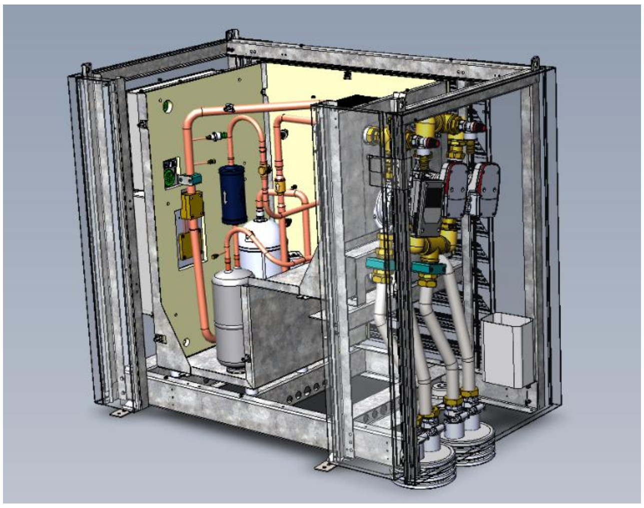

Figure 4 CAD-Drawing, rear-side - main assembly of R290 35kW BW-HP showing hydraulic interfaces and refrigerant cycle.

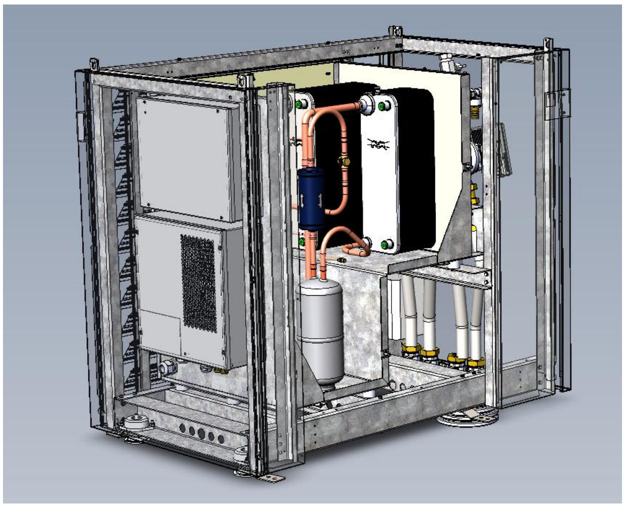

Figure 5 CAD-Drawing, front-side - main assembly of R290 35kW BW-HP showing control cabinet and heat exchangers.

Testing

The testing phase was initiated with the establishment of a comprehensive test procedure, which outlines the methodology for assessing the first combination of components. This procedure ensures that each test is conducted under controlled and consistent conditions, providing reliable and comparable results.

The tests for the first component combination were completed at the end of week 48, and the outcomes aligned well with the design calculations. These positive results confirm that the initial design assumptions were sound and demonstrate the feasibility of the chosen configuration. The success of this phase serves as a benchmark, providing a base case for further tests involving different component combinations.

The data and insights obtained from these preliminary tests will be used to fine-tune the system and guide the selection of components in future iterations. Figure 6 and Figure 7show the prototype at the test bench, Figure 8 and Figure 9 show the results for the first round of performance tests. The continued testing will focus on optimising performance, verifying energy efficiency, and ensuring that the system meets the defined KPIs for sustainability, noise reduction, and overall performance.

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Figure 6 Hydraulic connection of R290 35kW BW-HP on test bench

Figure 7 Control Cabinet and refrigeration cycle of R290 35kW BW-HP on test bench

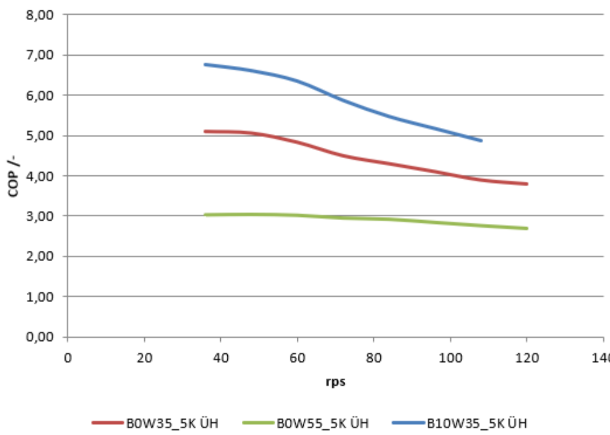

Figure 8 Test Results: Coefficients of Performance for three operating points vs. compressor speed

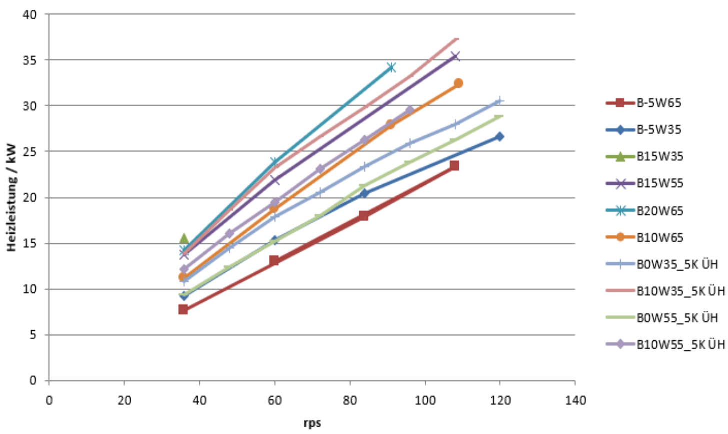

Figure 9 Test Results: Heating Power for different operating points vs. compressor speed

3.1.5 Future steps

This section outlines the planned next steps for the technology development, focusing on both short-term and long-term goals to advance the project further. The steps outlined below detail the actions needed to refine the technology, optimise performance, and prepare for broader deployment.

Short-Term Steps

In the immediate future, the next stage of development will involve comprehensive testing of additional component combinations. This will help to determine the best-performing configurations and provide valuable insights for optimising the system's efficiency, functionality, and reliability.

The design phase will also progress to include the creation of housing for the units. This will ensure that the prototype is protected and operational under various conditions while maintaining structural integrity and ease of installation.

Further in-depth testing will be conducted to evaluate the system's performance under both nominal and extreme conditions. This includes simulating different operational scenarios to confirm that the system can perform effectively across a range of expected conditions, ensuring both reliability and durability.

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Performance and noise tests will be prioritised to ensure that the system meets the necessary performance metrics and operates within acceptable noise levels. These tests will provide critical data for refining the design and ensuring compliance with industry standards for residential and multi-family housing applications.

Finally, the manufacturing phase will expand to include the assembly of six units, encompassing the complete refrigerant cycle, frame, and housing. This batch will be used for further testing and for field deployment as part of the Vienna Front Runner.

Long-Term Goals

While the immediate steps focus on refining the prototype and confirming its performance under various conditions, the long-term strategy will centre around scaling the production and market introduction of the final product. The development process will include the evaluation of the technology’s feasibility for larger-scale production and the potential for broader market integration.

Efforts will also be directed towards the integration of the 35 kW BW heat pump into existing infrastructure and potential collaboration with industry partners for further pilots e.g. in some of the replicators of the META BUILD project. This will allow for real-world data collection and further validation of the system’s performance, efficiency, and user acceptance.

Additionally, the long-term roadmap will incorporate feedback from initial deployments to make design adjustments, improve component durability, and fine-tune the technology for even greater energy efficiency. Continuous R&D efforts will be essential to keep the product competitive and aligned with future energy efficiency standards and environmental goals.

Through these strategic steps, the project aims to deliver an advanced, market-ready 35 kW BW heat pump that meets sustainability and performance targets, positioning it as a leading solution in the heating and cooling sector.

Activities related to the Croatian pilot project include the renovation of 6 residential buildings in Velika Gorica and the integration of a heat pump into the existing district heating system at the Cibljanica boiler room location.

3.2 District heating connected HPs

3.2.1 Overview

CER is developing innovative high-capacity district-heating-connected HPs that will be performed at the location of the existing oil-fired boiler room.

In META BUILD, CER is leading the development of an innovative solution that will be able to operate in the existing temperature regime (high temperature regime 90°C/60°C) and be able to adapt to the future lower operating temperature regime.

Future steps focus on final decision of the HP’s technology and capacity, and final design.

3.2.2 Starting status, description and constraints

Prior to META BUILD, at the location of future heat pump, HEPT (HEP Toplinarstvo) which is the largest entity in the Croatian thermal energy market, owns and operate with district heating boiler room called Cibljanica, which is outdated and not frequently used.

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CER will, in cooperation with HEPT, support their strategic objectives to maintain its leadership position as an environmentally conscious and socially responsible company, develop an innovative solution of HPs tailored for district heating that runs at high temperature regime 90°C/60°C and with results of this project enhance their performance and create new opportunities in the market.

A comprehensive renovation of the boiler room is planned, where existing boilers will be replaced with new low-temperature boiler, together with heat pump that will allow usage of renewable energy sources for heating and preparation of warm water.

3.2.3 Core innovation technology

Since in Republic of Croatia, there is no project like this before, our innovation is based on the implementation of the heat pump into existing district heating system. Considering really high temperature regime for district heating in Croatia, compared to other district heating systems in Europe, it is really challenging to design HP that will be able to operate efficiently in this system.

Innovative part by itself is not only HP, but implementation to the existing district heating system and securing heat production in peak heat demand, co-existing with low-temperature boiler. It is planned that HP will be working in the summertime, covering whole demand for hot water in households.

3.2.4 Technology progress and status

CER is working on design and potential solutions of HP that will be implemented in existing district heating system, and has already proposed few solutions and variations to the infrastructure owner.

While considering that there will be option to decrease temperature regime in DHS, and limited by the budget, different type of technologies were considered, and few options are shown in Table 7.

Table 7 CER HP technologies specifications

Operating conditions				
Evaporator				
Type of fluid	Water			
Outlet temperature (°C)	5,00			
Inlet temperature (°C)	10,00			
Fluid flow (l/s)	24,80	22,50	19,40	17,60
Total pressure drop (kPa)	18,40	15,60	15,00	15,00
Condenser				
Type of fluid	Water			
Outlet temperature (°C)	50,00	60,00	70,00	75,00
Inlet temperature (°C)	30,10	40,60	51,30	56,80
Fluid flow (l/s)	8,00	8,00	8,00	8,00
Total pressure drop (kPa)	15,00	15,00	15,00	15,00
Performance information				
Operating mode	Heating			
Heating capacity (kW)	657,00	639,00	613,00	596,00
Heating efficiency (COP)	4,34	3,53	2,81	2,50

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Input power (kW)	151,00	181,00	218,00	239,00
Minimum capacity (kW)	322,00	313,00	300,00	294,00
Maximum capacity (kW)	657,00	639,00	613,00	596,00
Working substance	R-1234ze(E)			

This system is water-water HP designed for efficient heating, that has COP 2,5 at highest temperature regime 75°C/56°C, and has heating capacity of 596 kW, using R-1234ze(E) as the working fluid, known for its low environmental impact. This option requires drilling of the wells for water exploitation.

Second option was combination of water-water HP and an air-water HP, with thermal storage thank that didn't require drilling of the wells, which could provide heating capacity of 500kW and could operate at higher temperature regime of 85°C for the supply and 65°C for the return. It is designed to function efficiently in a wide range of outdoor temperatures, from -20°C to +40°C.The heating mode of this combined system has a COP of 1.62, which indicates good efficiency. Like the first option, it uses R-1234ze(E) as the working fluid.

Most suitable technology is water-water HP with exploitation wells because of their better COP compared to other solutions.

Recently, HEPT organised drilling of exploration well to confirm that there is reservoir of underground water beneath their boiler room. We are still waiting final report of the contracted company, that will help with taking the final decision of the design of the HP and its technology. CER and HEPT agreed that minimum requirement for the HPs outlet temperature should be 80°C, and with heating capacity of at least 1 MW.

Figure 10 Drilling exploration in Croatia

3.2.5 Future steps

After receiving final results of the test well and its evaluation, CER will bring final design of the HP. According to plan, CER will provide final decision of the technology (capacity, technology, temperature regime) and

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project design in the beginning of 2025, while procurement of the equipment is planned to start from April 2025, and installation on the field in October 2025. Test run of the installed system is planned for 2026.

3.3 Large-size reversible HP system for building heating and cooling

3.3.1 Overview

The technology relies on a heat pump-based thermal energy system to provide heating and cooling for the KM0 pilot building, a mix-used building (Figure 11). The pilot building currently relies on gas boilers for heating and an ageing refrigeration unit for cooling. The technology would help covering the largest part of the heating energy needs along with the full cooling energy needs. It would be constituted of a heat pump or a reversible refrigeration unit, seconded by the existing gas boilers for specific extreme needs that the thermodynamic system could not cover. Innovation resides in assembling and operating a high-capacity heat pump system hybridised with existing gas boilers, flexible enough to sustain the integration of other technologies – such as a future heating network and PVT systems – and possible retrofit actions and building extensions in the near future. Currently, the technology is being sourced among manufacturers to select the appropriate systems, considering the thorough data analysis that has been led based on data from the BEMS. Next steps include selecting the adapted technology and modeling the thermal energy system to assess the investment and maintenance costs to be expected, the energy consumption and CO_2 emissions savings, as well as the performances of the technology.

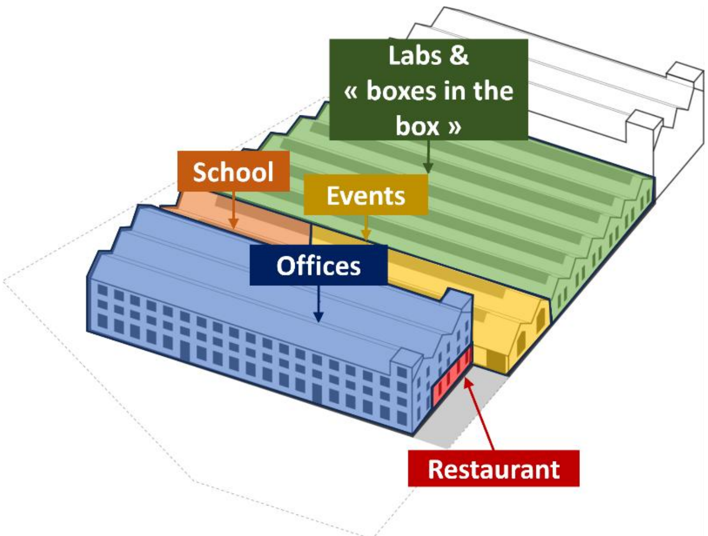

Figure 11 Schematic of the different tertiary spaces of the KM0 pilot building

3.3.2 Starting status, description and constraints

Prior to the start of the META BUILD project, the KM0 pilot building – a 11,000 m² mixed-used building including office spaces, labs, computer science schools and event hosting – did (and still does) rely on a 2MW-gas boiler group (one boiler of 250 kW and two boilers of 850 kW) for heating. Domestic hot water is produced with electric water tanks. Cooling is provided by a refrigeration unit of unknown nominal power.

For heating there are two types of emitters, including water-to-air heaters and fan coils. The later are reversible units, used for cooling as well. This means only part of the building is using the cooling system over the summer, as highlighted in the below figure.

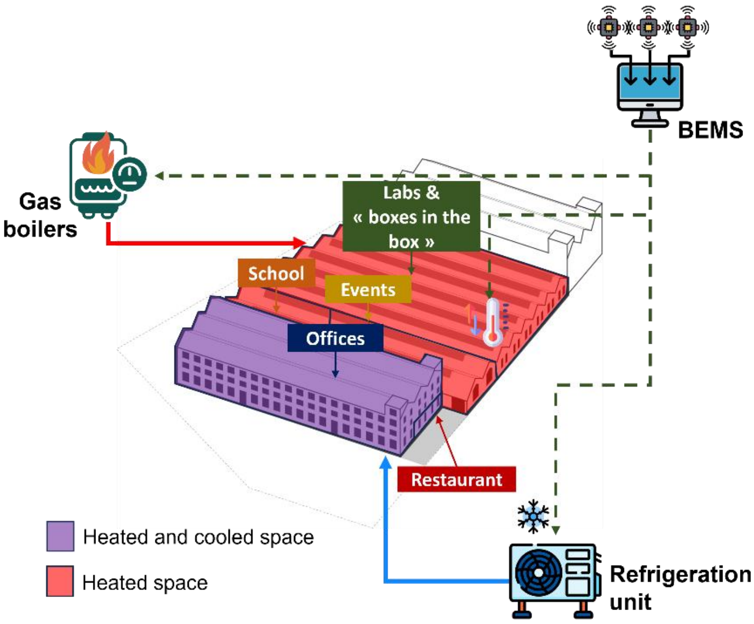

Figure 12 Heated and cooled spaces with the initial thermal energy systems

The whole building is supervised with a building energy management system (BEMS) collecting various data related to thermal energy consumption, indoor space conditions and the operation of energy systems.

Electrifying building thermal energy demand faces several constraints:

- Matching the largest part of the thermal (heating and cooling) energy needs with a decarbonised solution, while preserving occupants' comfort.
- Being conservative regarding the overall investment cost for the energy systems, installation, operation and maintenance, considering that the boilers have been installed in 2018-2019.
- Being installed while the building is occupied.
- Being flexible enough to account for changes in heating and cooling habits, as well as potential further building retrofit actions, building extensions and mandatory uses of other decarbonised energy sources in the near future such as heating networks.

As most of the energy consumption, for heating, is gas-based, the main goal is to work on a solution to electrify thermal energy demand. Also, the current refrigeration unit being ageing, the technical pre-analysis led to the choice of a heat pump system or reversible refrigeration unit, to be hybridised with the current gas boilers. Indeed, the current available heating power suggested that the KM0 building requires significant thermal energy demand and a thermodynamic energy system might not be able to cover the whole energy needs at a reasonable cost. Also, the gas boilers could be used as secondary systems for extreme-cold temperatures, specific events and potential building extensions in the upcoming years that cannot be properly qualified for energy system sizing for now.

Finally, it should be noted that two heating technologies might be included later on, including:

- A heating network planned in the neighbourhood near the pilot building in the upcoming years, but with no specific development plan or information available at this time.
- A PVT (photovoltaic thermal) energy system that could be used to pre-heat inlet water or air for the heat pump system.

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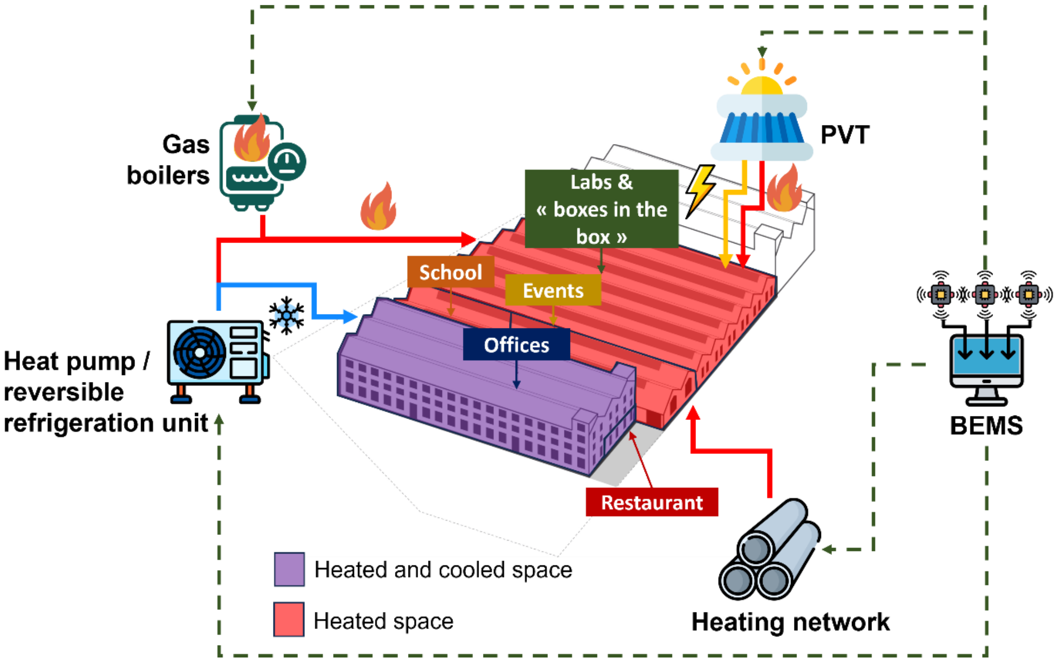

Figure 13 Thermal energy systems for the hybrid technology along with future potential developments including PVT and heating network

Hence, the key innovations reside in:

- Providing a high-capacity reversible system with a HP or a reversible refrigeration unit for the largest part of the cooling and heating energy demand, and gas boilers for specific uses.
- Ensuring the proper operation of the hybrid system, taking into account the integration of the future heating network and the PVT system.

The design of the system heavily relies on the availability and reliability of data from the BEMS to characterise the detailed energy consumption. Preferably, these data would be available at hourly time-step and both at building-scale and building zone-scale.

3.3.3 Core innovation technology

The end goal of the technology is to cover the largest part of the building pilot energy needs, preferably both for heating and cooling, using electricity as an energy source.

The approach to choose the adapted technology can be divided into 3 steps:

- **Thorough data review and analysis**: A thorough data review should be conducted to assess the availability and reliability of the BEMS data for the energy system operation and energy consumption at building-scale and at a lower-scale level. Ideally, data would include thermal energy consumption, inlet and outlet temperatures from the current energy systems and water flows, along with the local outdoor air temperature. Out of this analysis, we would expect to characterise the daily, weekly, monthly and annual thermal energy signature of the building and its zones, as well as the operation of the thermal energy systems. The former is necessary to assess which part(s) of the thermal energy demand and how the {heat pump + boilers} system could match the energy needs. The latter should inform on the feasibility of the hybridisation and potential modification to the hydraulic circuit required.
- **Hybridisation modeling**: It relies on a tool which can assess the power sizing, heating and cooling needs coverage, energy consumption and CO_2 savings, COP of the system and provide a cost analysis of a hybrid system, based on the analysis of heating and cooling needs and the outdoor air temperature.

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- **Technology selection**: In parallel to the hybridisation modeling, the heat pump/reversible refrigeration unit can be selected along with technology providers to match the highlights of the data analysis, results of the modeling and to provide the expected thermal needs for the pilot building along with the characteristics of existing thermodynamic technologies.

3.3.4 Technology progress and status

As EDF does not provide nor develops a specific technology, we should source the existing technologies that can match the thermal energy needs of the KM0 pilot building, but also the technical requirements of the hybridisation project. Providing advice on assembling and integration of these technologies in the building energy system is also a key contribution.

So far, data analyses have highlighted that the heat pump or reversible refrigeration unit should be able to cover at least 80% of heating needs of the building in its current operation state, considering a 200-250 kW power for a -5°C temperature. Optimising the operation of heating systems to fit with the integration of a thermodynamic system could even allow a better coverage of heating energy needs. Further information on the thermal energy systems would be available along with the sourcing of adapted technologies that is currently ongoing with manufacturers.

The data analysis on cooling energy needs is currently ongoing as well and should provide further information on the requirements for the energy systems if a reversible heating/cooling solution is selected.

3.3.5 Future steps

Future steps include:

- Finishing data analysis for cooling energy needs.
- Continuing the sourcing of technologies in line with the results of data analyses for heating and cooling energy demand.
- Conducting the hybridisation modeling study to assess the key information regarding investment cost, energy consumption and CO_2 savings and thermal energy system performances.
- Move forward on heat pump integration (heating circuit, electricity grid, outdoor unit location).

3.4 R290 Heat pump and PCM storage

3.4.1 Overview

As a technology provider Innova is developing a R290 heat pump and PCM storage to be installed in the pilot site. Those technologies will be developed with commercialisation into account and be competitive on the market while providing cutting edge performances.

R290 propane heat pumps offer an efficient and environmentally friendly solution for heating and cooling. Using propane as a low-GWP refrigerant, these systems provide high performance while minimising environmental impact. Designed with advanced safety measures, R290 heat pumps are a reliable and sustainable choice for modern HVAC applications.

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Figure 14 Innova Stone HP

PCM (Phase Change Material) storages provide efficient thermal energy storage by leveraging materials that absorb and release heat during phase transitions, such as melting and solidifying. These systems offer high energy density, enable temperature control, and improve energy efficiency in heating and cooling applications. PCM storages are a versatile and sustainable solution for optimising energy use in residential, commercial, and industrial settings.

3.4.2 Starting status, description and constraints

R290 technology has been studied and developed in the past years by Innova. We have already overcome many of the difficulties and challenges that are connected to the use of such refrigerant. What is left for this project is to port those innovations to a proprietary custom design that allows such heat pumps to be installed in more convenient and space saving configuration (see picture for reference). On the other hand, PCM technology is quite new for us and will need more effort to be mastered and made cheap, efficient and easy to use. We are already in contact with many companies that provide either PCMs or similar solutions and have already tested many variables in our laboratory to assert the feasibly of this project.

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Figure 15 R290 HPs in laboratory and field test

		PDC5				PDC7				PDC9				PDC12				PDC15			
	ACTIVITY	Capacity [W]	COP/EER	Date	Note	Capacity [W]	COP/EER	Date	Note	Capacity [W]	COP/EER	Date	Note	Capacity [W]	COP/EER	Date	Note	Capacity [W]	COP/EER	Date	Note
EN 14511	TEST RATING heating A7, W30-35	5,11	5,23	28/8/2024		6,68	4,55	13/8/2024		8,71	5,09	24/9/2024		11,83	5,03	3/10/2024		14,45	4,72	1/10/2024	
	TEST RATING heating A7, W47-55	4,79	3,2	22/8/2024		6,74	3,03	14/8/2024		9,05	3,06	8/8/2024		11,94	3,19	2/10/2024		14,57	3,05	2/10/2024	
	TEST ERP heating A7, W30-35	3,06	5,5	22/8/2024		4,19	5,12	13/8/2024		5,45	5,39	8/8/2024		7,3	5,50	3/10/2024		8,83	5,37	1/10/2024	
	TEST ERP heating A7, W47-55	3,06	3,26	18/8/2024		4,23	3,19	14/8/2024		5,33	3,23	8/8/2024		7,22	3,36	2/10/2024		8,64	3,31	2/10/2024	
	TEST RATING cooling W23-18	3,83	5,92	3/9/2024		5,27	5,09	28/8/2024		7,09	5,50	13/8/2024		8,99	5,31	24/10/2024		10,56	4,93	12/11/2024	
	TEST RATING cooling W12-7	3,74	3,66	3/9/2024		5,35	3,09	28/8/2024		6,77	3,52	13/8/2024		8,91	3,20	24/10/2024		10,87	3,04	25/10/2024	
	TEST RATING heating A-7W35	4,75	2,81	18/12/2024		4,94	2,73	20/12/2024		7,46	2,75	18/12/2024		9,23	2,97	19/12/2024		10,33	2,83	19/12/2024	
	Max Power heating A-7W35	4,94	-	18/12/2024		5,75	-	20/12/2024		8,23	-	18/12/2024		11,09	-	19/12/2024		11,71	-	19/12/2024	
EN 14825 H L A	A-10W35	4,19	2,44	29/8/2024		4,59	2,07	27/8/2024		6,76	2,34	21/10/2024		10,04	2,27	16/11/2024		10,87	2,26	17/11/2024	
	A-7W34	4,53	2,7	28/8/2024		5,42	2,84	26/8/2024		6,87	2,59	20/10/2024		10,04	2,82	4/11/2024		10,52	2,74	16/11/2024	
	A2W30	2,65	4,92	28/8/2024		3,17	4,50	22/8/2024		4,19	5,14	9/8/2024		5,27	5,00	29/10/2024		6,36	4,91	23/10/2024	
	A7W27	1,65	6,95	30/8/2024		2,21	7,03	27/8/2024		3,19	7,76	22/10/2024		4,17	7,38	27/10/2024		4,19	7,52	27/10/2024	
	A12W24	1,31	10,15	30/8/2024		1,12	8.70	28/8/2024		2,70	11,53	22/10/2024		3,91	9,87	28/10/2024		3,89	9,65	28/10/2024	
	SCOP L	Pdes = 4.85	4,97			Pdes = 6,00	4.70			Pdes = 7,50	5,20			Pdes = 10,00	5,06			Pdes = 11,20	5,08		
EN 14825 H M A	A-10W55	4,02	1,87	29/8/2024		4,11	1,52	27/8/2024		6,2	1,73	21/10/2024		8,3	1,97	22/11/2024		8,45	1,94	22/11/2024	
	A-7W52	4,22	2,08	29/8/2024		5,07	1,89	26/8/2024		6,5	1,89	24/9/2024		10,39	2,17	16/11/2024		10,32	2,08	6/11/2024	
	A2W42	2,59	3,71	2/9/2024		3,22	3,42	22/8/2024		3,82	3,78	9/8/2024		6,53	3,70	29/10/2024		6,48	3,68	23/10/2024	
	A7W36	1,68	5,21	31/8/2024		2,21	5,21	27/8/2024		2,99	5,50	21/10/2024		3,64	5,27	16/11/2024		3,70	5,39	21/11/2024	
	A12W30	0,63	3,4	2/9/2024		1,15	4,30	28/8/2024		2,62	8,64	21/10/2024		4,03	8,24	21/11/2024		3,99	8,11	21/11/2024	
	SCOP M	Pdes = 4.85	3.41			Pdes = 6,00	3,36			Pdes = 7,5	3,60			Pdes = 10,00	3,77			Pdes =11,20	3,76		
EN 14825 C	A35W23/18	3,83	5,92	3/9/2024		5,27	5,09	28/8/2024		7,09	5,50	13/8/2024		8,99	5,31	24/10/2024		10,56	4,93	12/11/2024	
	A30W18	2,81	7,29	3/9/2024		3,90	6,08	30/8/2024		5,31	7,38	19/10/2024		7,43	7,21	25/10/2024		8.28	5,89	25/10/2024	
	A25W18	1,83	11,77	3/9/2024		2,56	9,62	29/8/2024		3,49	10,18	19/10/2024		4,42	9,33	25/10/2024		5,09	9,00	25/10/2024	
	A20W18	1,64	18,16	1/9/2024		2,29	13,22	30/8/2024		2,93	14,64	19/10/2024		4,64	12,24	25/10/2024		4,64	12,24	25/10/2024	
	SEER	Pdes = 3.83	7,57			Pdes = 5,27	7,69			Pdes = 7	8,66			Pdes = 9,50	8,11			Pdes = 11,00	7,59		

		PDC5	PDC7	PDC9	PDC12	PDC15
ACUSTICA	A7, W30-35	55	57	57	60	62
	ERP	51	52	52	53	55

Figure 16 HP test results

3.4.3 Core innovation technology

The goal is to develop a system where heat pumps and storages collaborate to reduce the energy consumption of residential buildings by using the available energy in the most efficient way whenever possible and storing the product of such process to satisfy future demands. This means that the two technologies will be developed with care to ensure collaboration with each other and also with not proprietary systems.

3.4.4 Technology progress and status

Currently we are in the first phase of testing the R290 technology on the custom design, meaning we have already ported the solution and are working on fine tuning it to the new design. Regarding the PCM storages we have already worked out an initial mechanical design for the storages and we are working to get it testes as soon as possible to validate and refine our initial design.

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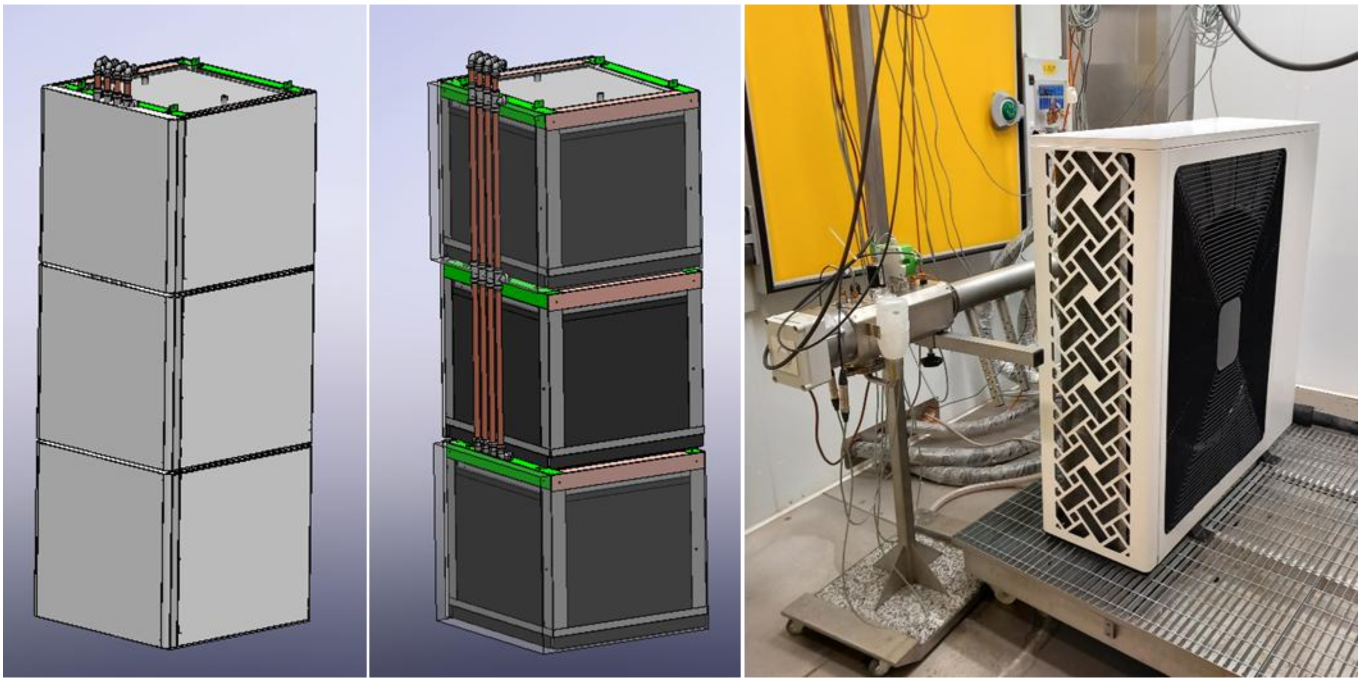

Figure 17 PCM prototype and R290 HP

3.4.5 Future steps

For R290, we will proceed to a more advanced testing phase soon to validate performances. Meanwhile, final refinements and negotiation with suppliers will make the product a great competitor on the market, allowing for a practical endpoint for this part of the project. Once the current test phase on PCM is ended, we will finalise the mechanical design phase and move on to develop a controller for such storage that can communicate with external controllers and operate the hydronic components of the system.

Figure 18 PCM first prototypes

3.5 Dual source Heat pump

3.5.1 Overview

The Dual Source heat pump (DSHP) based on a natural refrigerant, propane (R290), is an excellent solution for combinations of different sources such as geothermal, aerothermal, or solar through PVT (solar

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photovoltaics and thermal) panels. The DSHP has the possibility of combining with cooling-heating networks, when integrated as both source or sink, compensating unexpected demands. DSHPs offer an alternative to conventional water-to-water and air-to-water HPs, leveraging the strengths of both technologies in an efficient manner.

The innovative approach proposed in this study eliminates the need to divide the refrigerant flow rate between two external heat exchangers (HX). The novelty of the DSHP lies in the direct heat exchange in between refrigerant and air and/or brine in the same component, the dual-source heat exchanger (DSHX), avoiding:

- The addition of an extra heat exchanger and valves to switch from one source/sink to another.
- Refrigerant misdistribution.
- Refrigerant charge increase.
- Refrigerant bypass possibility.

In addition, the innovative DSHX eliminates the need for drainage circuits to recover refrigerant from the unused external unit. y, by optimising system operation, flexibility in choosing the most appropriate heat source is increased, resulting in significantly improved seasonal performance, avoiding energy losses associated with defrost cycles typically required in air source heat pumps.

In summary, in the following subsections, the key aspects of the DSHP technology in the frame of META BUILD are presented, showing the starting point in the project, the innovation related to DSHP technology and its adaption for the real demo site, the development progress, and the future steps.

3.5.2 Starting status, description and constraints

The initial status of the Dual-source heat pump is a prototype validated on a laboratory scale. The design manufacturing and lab scale characterisation of the mentioned prototype was developed in the frame of the TRI-HP project funded by the European Union’s Horizon 2020 research and innovation programme, Project No. 814888. The modelling and experimental validation of the design of the dual source HX and dual source HP are described in Peña-Anton et al. (1).

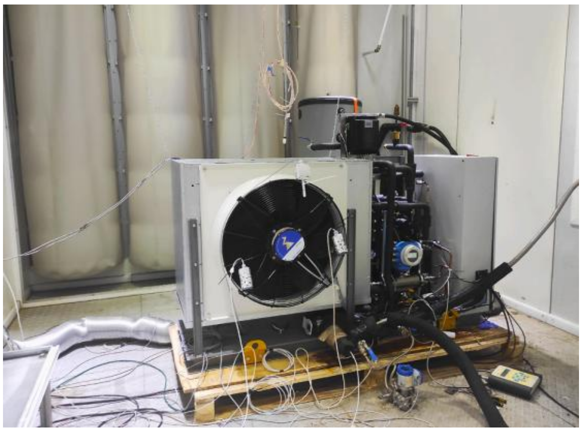

Figure 19 DSHP prototype installed in the lab’s climatic chamber

The DSHP was tested in several working conditions, as could be seen in the paper referenced; anyway, the control to select the most appropriate source was not defined, nor were the thresholds to change from one source to another optimised. In addition, the initial status of the control system doesn’t include a capacity control; previously, the compressor speed was introduced manually.

Regarding protection aspects, the adaption of the DSHP prototype for the IP55 protection level should be carried out. Being placed outside, the inverter requires to be specially protected creating a specific cabinet.

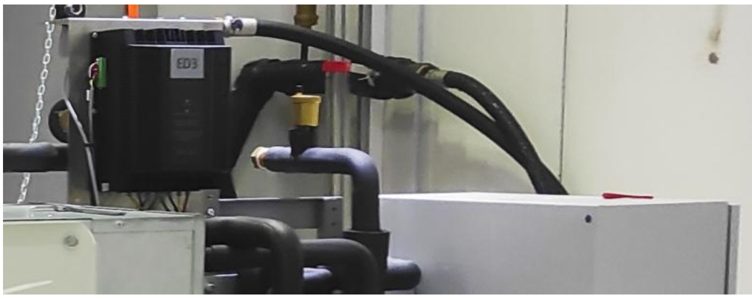

Figure 20 Detail of the initial position of the inverter

In addition, an enclosure needs to be created for the central part of the DSHP in which the refrigerant circuit main components are placed, including the compressor and the desuperheater, 4-way valve, expansion valve, space conditioning HX (SCHX), etc.

Figure 21 : Refrigerant circuit main components without enclosure

Furthermore, being a prototype tested in a climatic chamber which has its own leak detection sensors, the DSHP does not include a leak detection and extraction system. Therefore, in order to have a safe and autonomous prototype installed in the real demo site building, a leak detection system needs to be implemented and an ATEX fan fixed to the enclosure to extract the possible leak, avoiding the lower flammability limit (LFL) being achieved.

3.5.3 Core innovation technology

In order to achieve the goal of having a dual source heat pump installed and monitored in a real demo building fulfilling the heating demands requested, the prototype must advance technologically to become totally autonomous, fulfilling all the safety standards.

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On one hand, capacity control is implemented to regulate the compressor speed depending on the demand. A PI control is defined in order to regulate the compressor charge and discharge processes, fixing and adjusting the proportional and the Integer for an optimal operation.

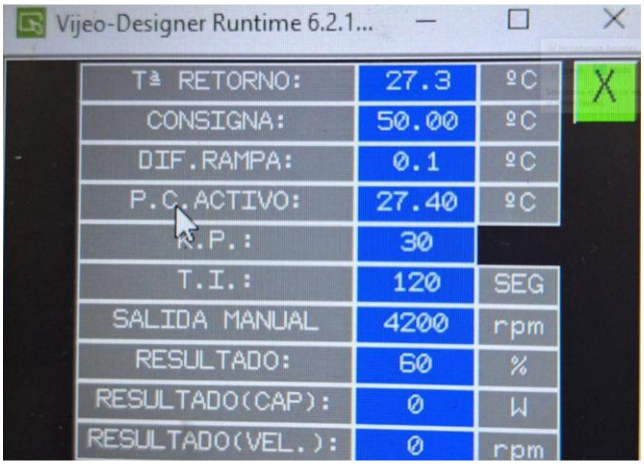

Figure 22 PI control definition panel's screenshot

The differential of the slope to achieve the set point is defined. Furthermore, some limits are adjusted to block the charge and discharge processes depending on the pressure limits on the DSHP, avoiding achieving the limit values of the high- and low-pressure switches that could stop the machine.

Figure 23 Maximum and minimum compressor charge and discharge limits

On the other hand, the control to select the most appropriate source is defined, and the thresholds to change from one source to another are optimised.

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Figure 24 Threshold and its hysteresis definition panel

In order to adjust the threshold for changing from a geothermal or solar source to an aerothermal source, an analysis of the results of all the experimental data is performed. After analysing the behaviour at different compressor speeds, an initial value of 4 ºC for mentioned threshold with a hysteresis of 1 ºC is determined. This parameter could be fine-tuned in the real demo site once the commissioning of the DSHP is performed.

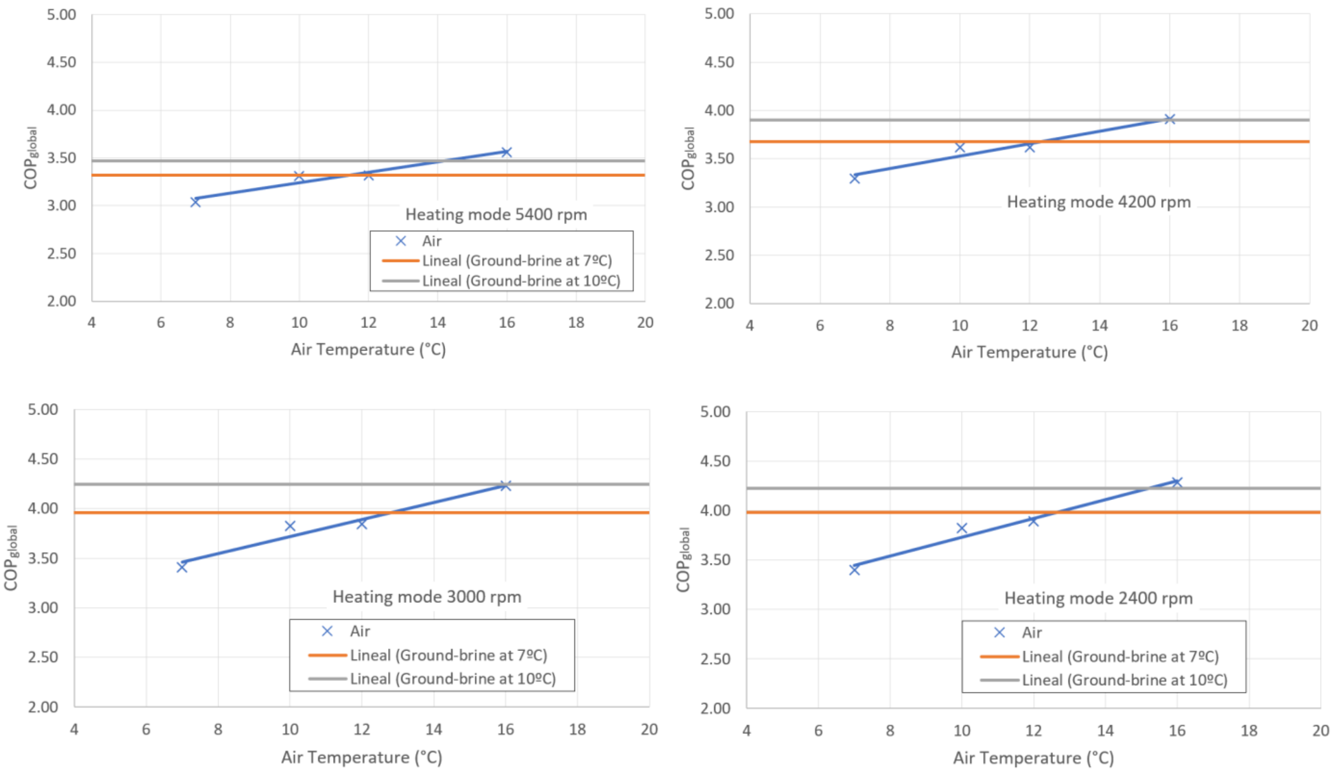

Figure 25 Threshold analysis for different operation conditions and compressor speed

The comparison between both sources has to be performed when the geothermal or solar thermal source circulation pump is activated. Therefore, after some tests carried out, it is determined that each hour, the circulating pumps must be switched on to compare both sources, the air or the glycol coming from boreholes or PVT panels and select the one that maximises the global Coefficient Of Performance or COP, taking into account the previously defined threshold.

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Figure 26 Pump and fans percentage set points definition of the period between source T comparison

Those new capabilities are implemented in the Schneider PLC, creating new adjustable parameters defined in different screens to properly adjust DSHP's capacity and select the most favourable heat source. Thereby, the DSHP initially in TRL 6 is tested in the lab to validate required adaptions and control system improvements for it to work in a real demo case using 3 different sources: solar (PVT), geothermal (thermally activated foundation), and aerothermal.

Regarding protection aspects, the adaption of the DSHP prototype for the IP55 protection level has been carried out. Being placed outside the inverter should be specially protected. In order to do that, a specific cabinet is developed with specific ATEX fans in order to maintain the temperature of the inverter always below the maximum limit suggested by the manufacturer.

Figure 27 Inverter's cabinet with the temperature control fans

In addition, an enclosure is designed and will be ready for the end of January 2025 to protect the central part of the DSHP, in which the refrigerant circuit main components are placed, from the exposure to the outdoor ambient. In the following pictures, the 3D of the manufactured enclosure and the final aspect of the DSHP totally prepared for outdoor operation could be seen.

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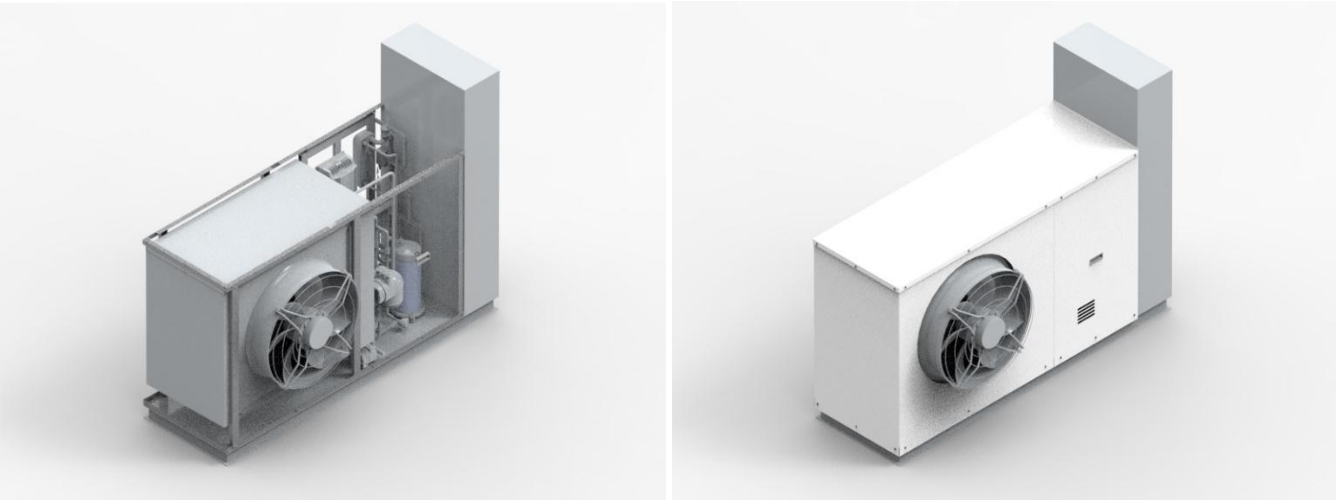

Figure 28 Designed new enclosure for the DSHP

Finally, a leak detection system is implemented, and an ATEX fan is fixed to the enclosure to extract all the internal air in case of a leak, avoiding the lower flammability limit (LFL) being achieved inside. The leak detector is a Danfoss gas sensor. Type DGS is specially prepared for propane. The mentioned sensor signal is in charge of cutting the electrical supply to the DSHP in case of a leak, maintaining only the extraction ATEX EC axial fan in order to evacuate the air-diluted propane from the enclosure, never achieving the LFL.

Figure 29 Leak detection sensor and extraction fan

In order to validate all the modifications and safety protocols, the DSHP is introduced and tested in the TECNALIA's lab climatic chamber, developing an experimental campaign in order to tune the different parameters previously described. Dynamic tests are performed to validate the strategies for capacity control and for source selection.

Figure 30 DSHP installed in the climatic chamber to verify the carried-out adaptions

Afterwards, some stationary tests are performed to doublecheck that the changes introduced in the PLC are not affecting the behaviour of the DSHP and that the capacity and COP values are in agreement with the previously achieved ones. The methodology followed in the stationary tests is based on the recommendations of the UNE-EN 14511:2014 standard. The duration of the steady-state period of the tests is determined to be 30 minutes.

Regarding data acquisition, the data is continuously recorded every second. In the following figure, the evolution of the heating capacity, COP expansion valve opening, and high- and low- pressure values could be seen in a steady-state tests, having ambient temperature at 7 ºC, compressor speed at 5400 rpm and hot side temperature setpoint at 55 ºC.

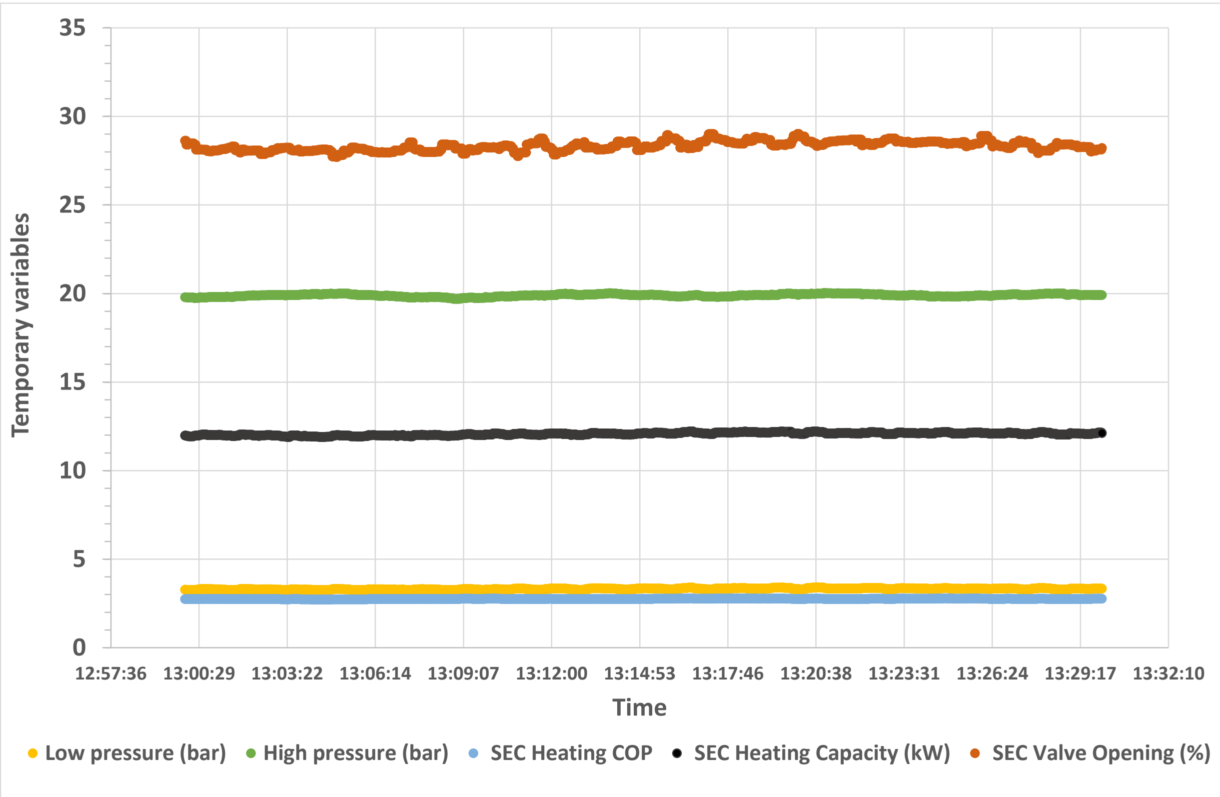

Figure 31 : Evolution of different variables in a steady-state test at 7ºC T_{amb}, 55 ºC set point and compressor at 5400 rpm

The configuration of the whole installation is presented in Figure 32, in which some flow switch sensors are introduced to stop the DSHP in case it does not achieve the required flow rate in the source or sink circuits.

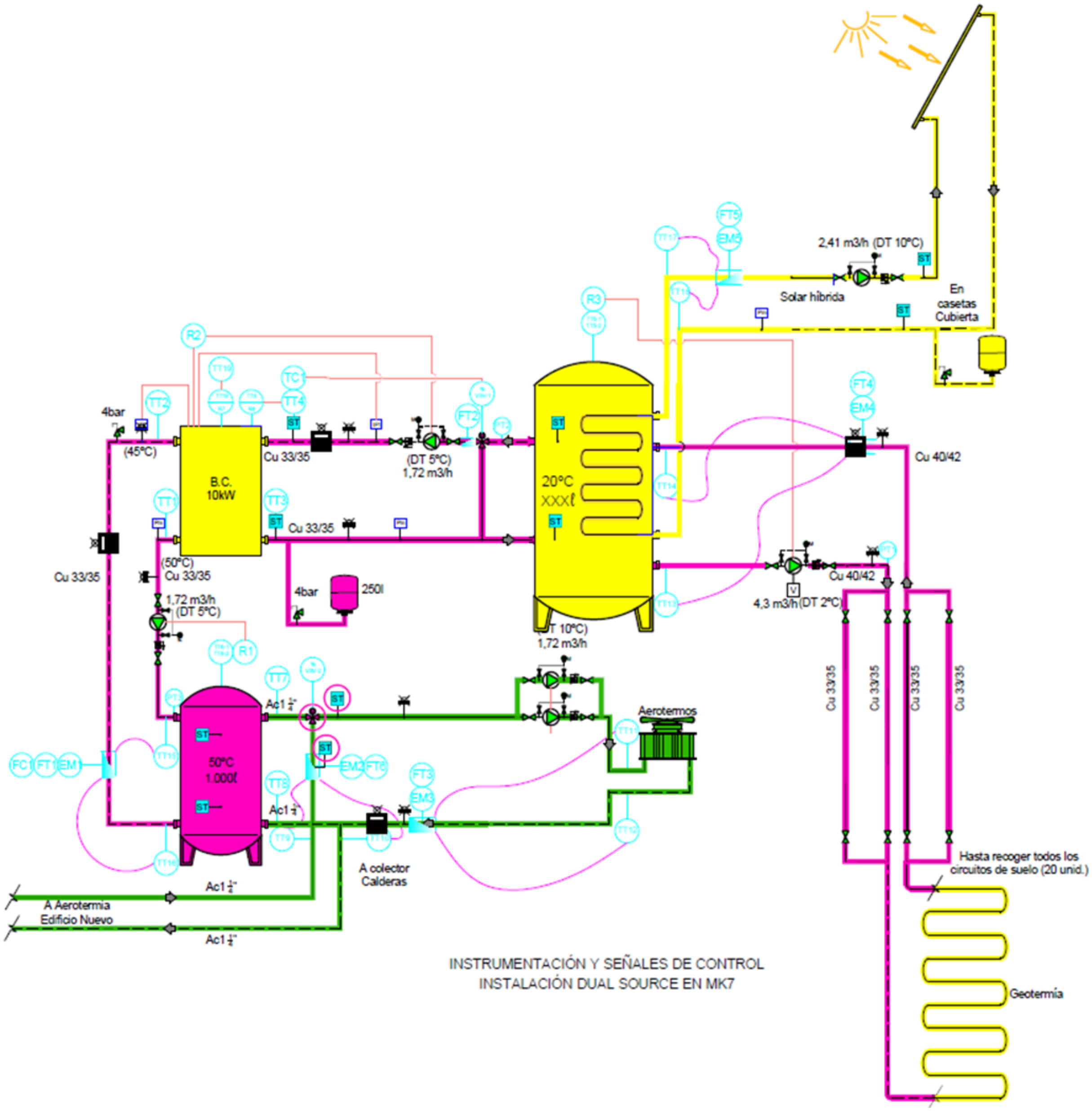

Figure 32 Piping and instrumentation diagram (P&ID)

3.5.4 Technology progress and status

The current status of the technology is that the DSHP is designed, manufactured, and experimentally validated, and the control strategies are implemented and improved in order to be installed in a real demo site. The MK7 building in Donostia - San Sebastián is going to be the building in which the prototype will be installed. The prototype is adapted to be placed outside. Adaption of the DSHP for IP55 protection is performed.

The validation in the laboratory of the different adaptions is performed. The final enclosure is designed, and currently, the manufacturing process of the mentioned enclosure is ongoing and is expected to be finalised by the end of January 2025. According to the planning, the commissioning of DSHP in the demo site is planned to be carried out before the end of March.

3.5.5 Future steps

The first step comprises the commissioning of DSHP in the demo site in March 2025. Once the commissioning is properly accomplished, the monitoring of the DSHP during winter periods will be carried out. The results of the monitoring analysis are going to be crucial to obtain SCOP value. Based on the conclusions obtained from the monitoring period, an improved DSHP 2nd prototype will be developed, with a focus on compactness and an advanced optimised control system.

The DSHP in the demo site installation will be placed on the roof of the building, close to the accumulation tank and the PVT panels.

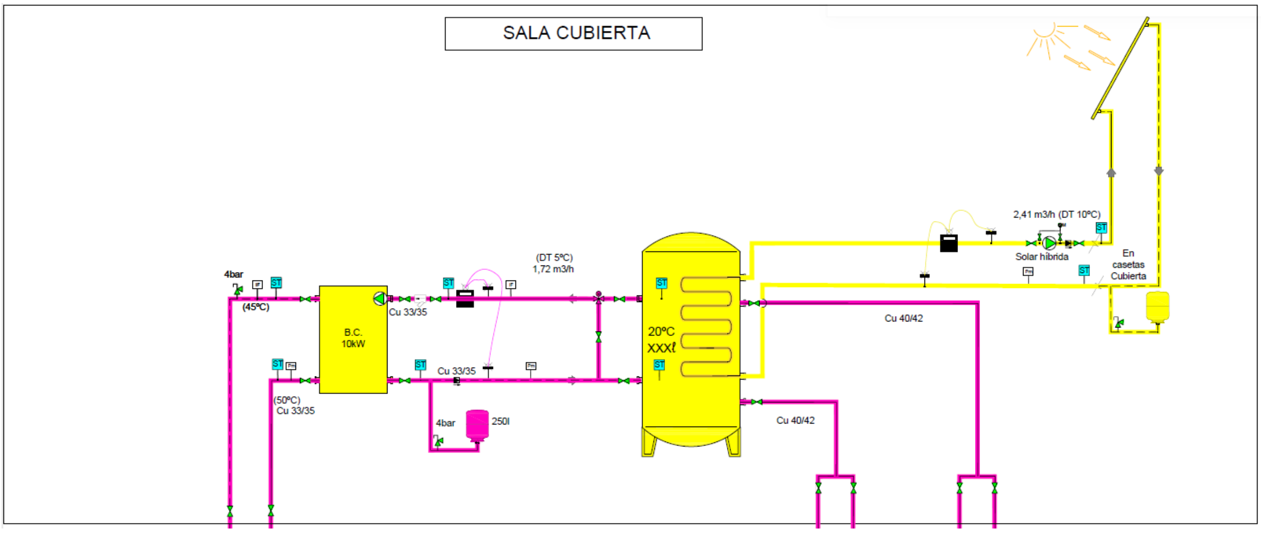

Figure 33 Piping and instrumentation diagram rooftop installation

The rest of the installation and the overall control and data acquisition system will be placed in a technical room.

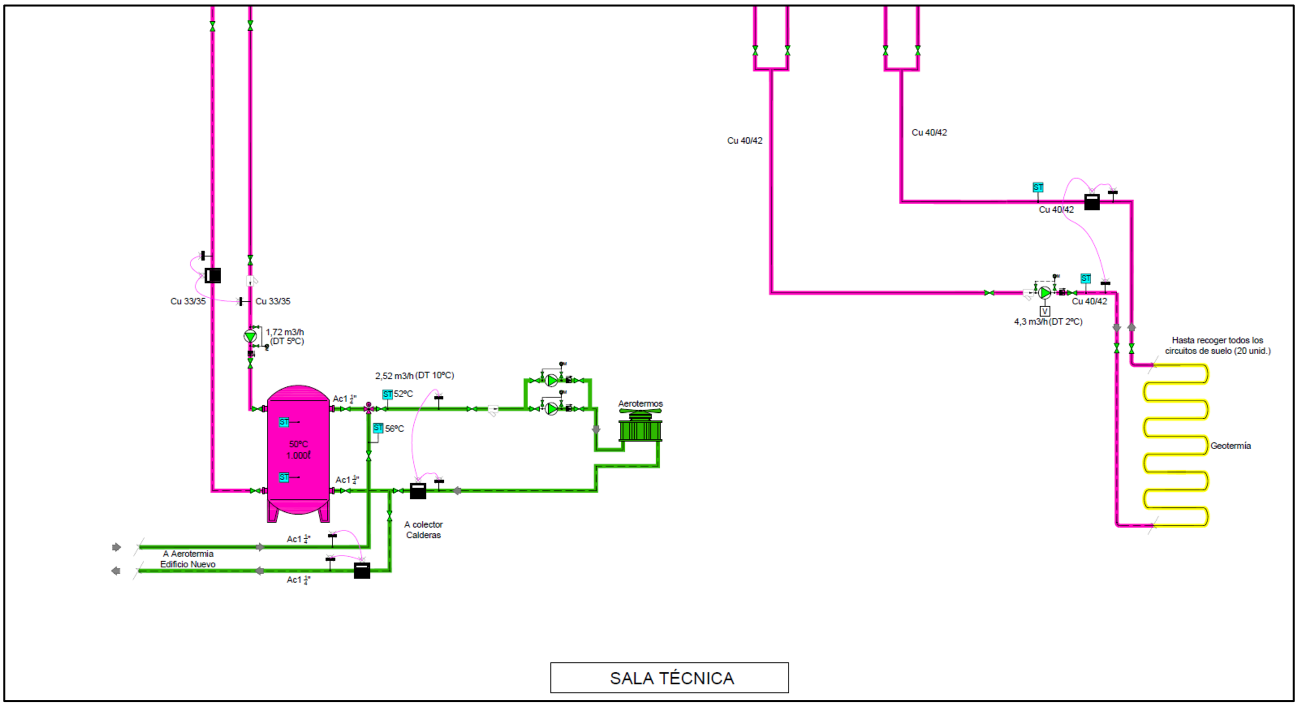

Figure 34 Piping and instrumentation diagram and thermally activated foundation, technical room

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4 Technologies integrating RES & Storage

The section presents the technologies that are developed within META BUILD that support the integration of renewable energy in the building and allow it to support grid operation. These technologies include photovoltaic-thermal (PVT) systems and second-life batteries. Similar to the previous section, the following section provides an overview of the technology, a description of its starting status, and core innovations, followed by its current progress and future steps.

4.1 PVTs with direct lamination aluminium absorber crystalline silicon unglazed collector

4.1.1 Overview

The initial status of the PVT collector development is the result of the ENSNARE project, where a direct lamination of a PV module on top of a thermal absorber was carried out. The complexity of the absorber's geometry and the curving of the final collector require a different approach for the current big size market trend.

The key innovation within META BUILD is to enable a feasible, industry scalable, economic, flexible and efficient PVT collector solution. The approach to achieve the goal is double, by means of conventional PV modules or fiber reinforced polymers to encapsulate or glue the components (PV laminate and ST absorber) of the PVT collector. The core innovations included in the collector design and manufacturing process should allow the achievement of the following specific objectives: industry scalable (prepared for the current industrial manufacturing lines), big format collectors (starting from 2.2m2 till 2.8m2), economic (the extra cost versus the PV reference by a factor of x2), flexible (easy to be adapted to other PV technologies) and efficient (>70% overall efficiency).

The activities carried out till now include PVT collector design (concluded), agreement with industrial partners (for manufacturing demonstrator units), manufacturing of IEC samples, start of the testing sequence and determination of demonstrator needs. The future steps are to conclude and pass the IEC 61215 standard (2) tests, to upscale the solution for a 2.2m2 device and to manufacture prototypes for the demonstrator.

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4.1.2 Starting status, description and constraints

The initial status of the PVT collector development is the result of the ENSNARE project, where a direct lamination of a PV module on top of a ST absorber was carried out.

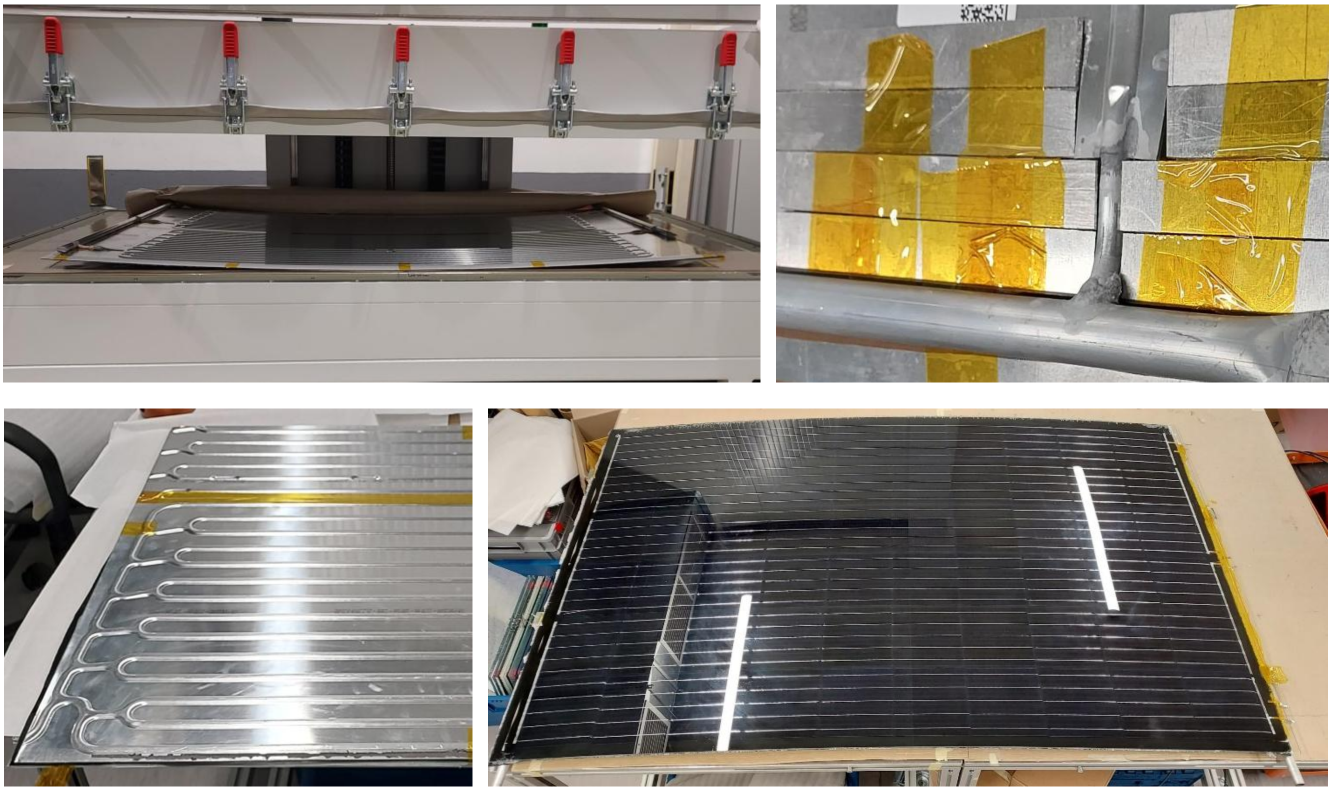

Figure 35 Curved PVT collector after lamination (top left), sample preparation before lamination (top right), samples for IEC test (bottom left) and finish 1.6 m2 PVT collector with direct lamination (bottom right)

Regarding the PVT collector manufacturing, TECNALIA developed the process to laminate the collectors based on the standard PV manufacturing process. After a preliminary phase where the substrate was characterised by adhesion tests to EVA and accelerated ageing tests on small scale (6 solar cells modules), according to the IEC 61215 standard, a suitable configuration for the PVT module was chosen and subsequently upscaled. In the upscaling phase, different issues were observed, leading to the conclusion that the current design of the rollbond absorber was not suitable for the industrial scale PV manufacturing process. The complexity of the geometry of the absorbers, especially the presence of inlet/outlet points and the tube, and the curving of the final 1:1 scale 1.6 m^2 PVT collector (PV module + thermal absorber), made obtaining a viable process difficult. The process resulted very manual and customised. The results improved after the upgrade of the laminator frame (enabling a better transfer of the pressure from the laminator membrane to the assembly) and the cooling process after lamination (to correct the extreme curvature), improving the overall result. All in all, given that the laboratory process developed by TECNALIA was not directly applicable industry, the activity concluded to a two-step manufacturing process, featuring a PV module lamination followed by the adhesion of the absorbers to the backsheet of the module to assembly the PVT collector. This strategy seems to be valid to follow PV module size increase till the current 2.2m2. This approach gives also more flexibility to the solution, in order to couple different kind of ST absorbers and PV layers. Thus, this is the one selected to be worked out in META BUILD.

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The key innovation within META BUILD is to enable an industry scalable feasible, economic, flexible and efficient solution of a big format (>2.2m2) PVT collector. The approach to achieve the goal is double. On the one hand, to use conventional PV modules ready in the market and process them to integrate non-critical thermal absorber by means of a high conductive adhesion process. On the other, to use a fiber reinforced polymer to encapsulate the PV layer and integrate it (by lamination or adhesion) with the thermal absorber.

4.1.3 Core innovation technology

As stated, the end goal of the project is to obtain a valid PVT collector. More in detail the following specific objectives are pretended.

- Industry scalable: in order to achieve this goal, TECNALIA is closely working with a current PVT collector manufacturer to include their restriction from the initial design phase.
- Big format: within the project, TECNALIA will work with a 2.2m2 (2m length and 1.1m wide) collector goal, but the solution should be valid for even higher upcoming standards 2.8m2 (2.4m length and 1.2m wide).
- Economic: the extra cost for the hybridisation of the PV module to obtaining a PVT collector should be close to the PV module cost. The current cost reference for PV module is around 16c€/Wp for non-EU manufacturing devices, 31.8€/m2. Thus, the total cost of the PVT collector should be around 65€/m2.
- Flexible: the manufacturing process should be easy adaptable, so it maintains valid for different PV modules or ST absorbers. At least two different approaches will be worked out (conventional PV module and fiber reinforced polymer).
- Efficient: the optical efficiency for the collector should be above 70% (>21% for electricity conversion and >49% for thermal outcome).

4.1.4 Technology progress and status

The activities carried out in the first 12 months of the project are the following:

PVT collector design

The design has mainly addressed three main items: PV laminate, ST absorber and interface between electric and thermal layers.

- The PV module selected is the following one, Longi's LR5-66HTH in its 535Wp version (Figure 36). This half-cell crystalline silicon technology represents well the current market standard and fulfills the efficiency KPI fixed as goal (22.7%).

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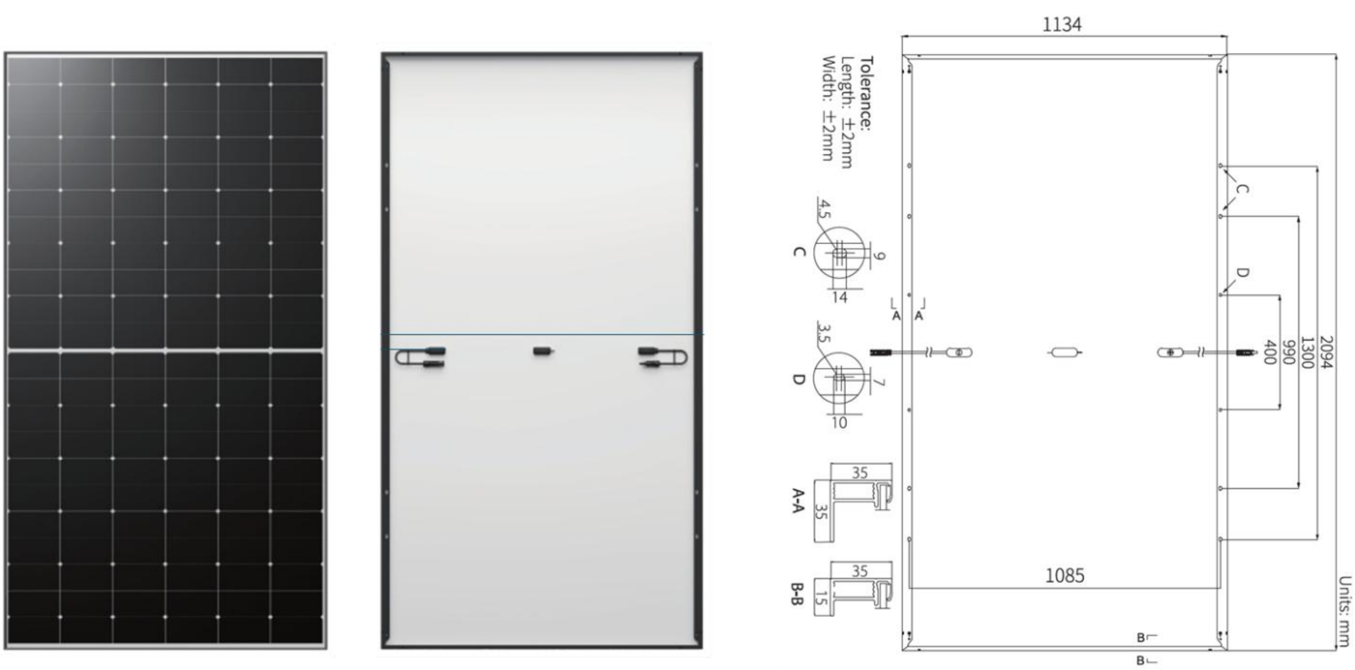

Figure 36 PV module selected as PVT electric layer: frontsheet (left), backsheet (centre) and measures (right).

- The ST absorber selected is the sheet and tube configuration (Figure 37), with a 1mm thickness aluminum continuous film where copper tubes are welded in a vertical comb configuration. The number of tubes per cell has been fixed to 2 according to performance-cost criteria. The frontsheet of the absorber is mechanised in order to open holes for the PV laminate connection boxes.

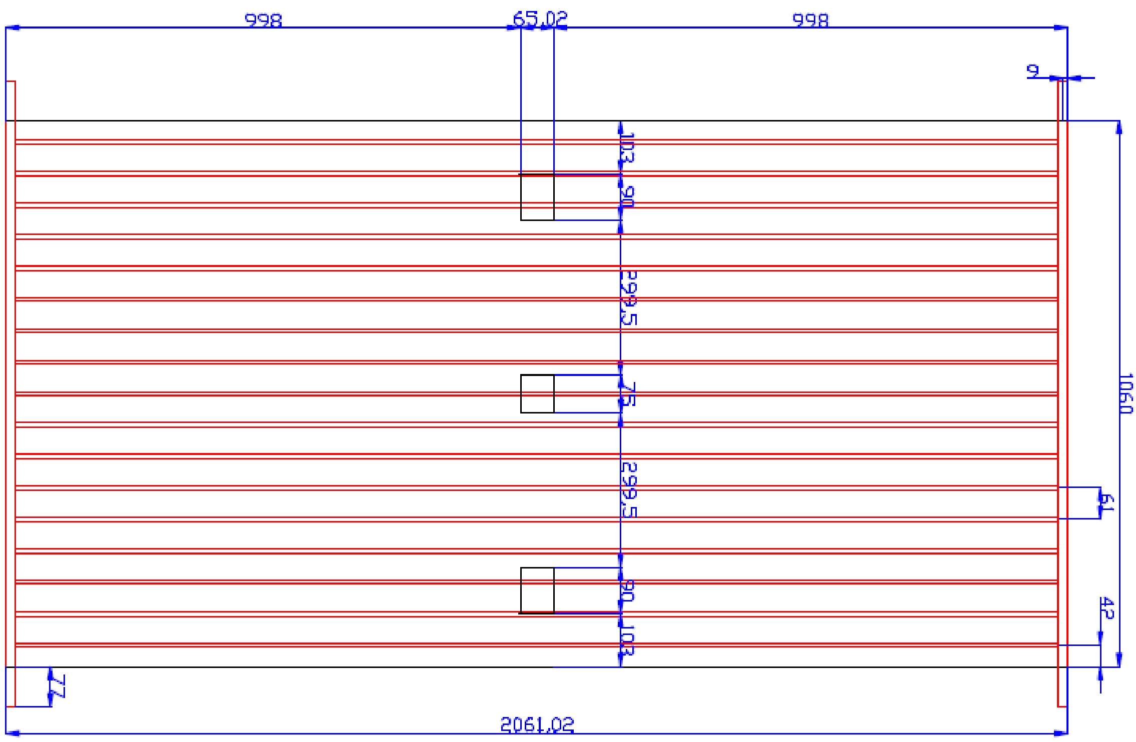

Figure 37 Measures of the ST absorber designed for PVT collector.

- For the interface between the PV laminate and the ST absorber two variants have been identified and are currently under IEC tests. The first is a conventional solar PV used EVA film for

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lamination, while the second one is one high conductivity silicon for adhesion. Both elements re appropriate for solar application.

Short-Term Steps

Within this activity, 3 main collaborators have been identified:

- PVT manufacturer: one of the most critical points of previously worked out initiatives was the impossibility to transfer the research to the industry. Thus, within META BUILD this transference has decided to be worked out form early development stage. Energy Panel SL, a solar assisted heat pump and PVT collector manufacturer has been contacted in other to stablish an agreement with TECNALIA, so they could include their restriction from the very beginning. Then, Energy Panel will be also part of the manufacturing of the units for the demonstrator.
- ST absorber manufacturer: in the same way as for the PVT collector assembler, TECNALIA reached an agreement with a ST collector manufacturer with demonstrated experience in the sector. Termicol SL has capabilities to customise absorbers to meet project needs. In the same way, they will be part of demonstrator units manufacture.
- Adhesive manufacturer: currently there are two different solutions for PVT collector assembly, lamination and adhesion. For the laminated solution, there is no additional critical point according to the industrial scale manufacturing, as this activity will be worked out with Energy Panel. However, for the adhesion, TECNALIA reached an agreement with Camel Solar, a company with a long experience in the field of adhesives with high thermal conductivity for solar applications. Camel will modify their adhesive recipe to optimise the energy performance while ensuring no solar degradation.

No agreement with PV module provider has been set up, as the current low-cost trend makes impossible to have European cost-effective PV module providers.

Sample manufacturing and IEC tests

Different type of PVT collector configurations have been defined, developed and manufactured (Figure 4) for IEC 61215 testing. These are mainly based on conventional PV module configuration and fiber reinforced polymer encapsulation, for both assembly mechanism direct lamination and high thermal conductivity adhesion. The samples are under testing sequence. The objective of the test is to test packaged collectors for stability against the relevant solar standard, studying the degradation under temperature cycling, outdoor exposure, UV preconditioning, humidity freeze, damp heat, and hail.

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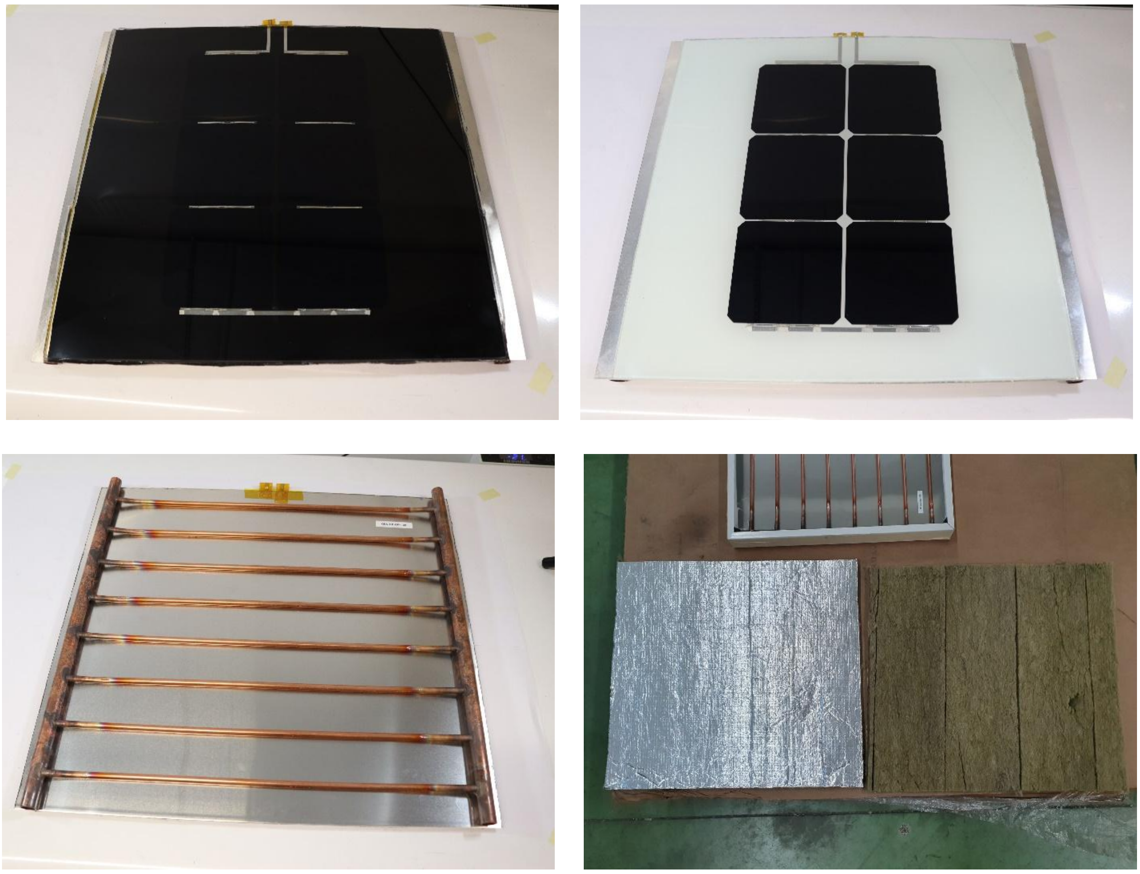

Figure 38 Samples manufactured for IEC standard test sequence. Conventional PV module laminated to absorber (top left), fiber reinforced polymer encapsulated and glued to absorber (top right), sheet and tube absorber (bottom left) and PVT assembly.

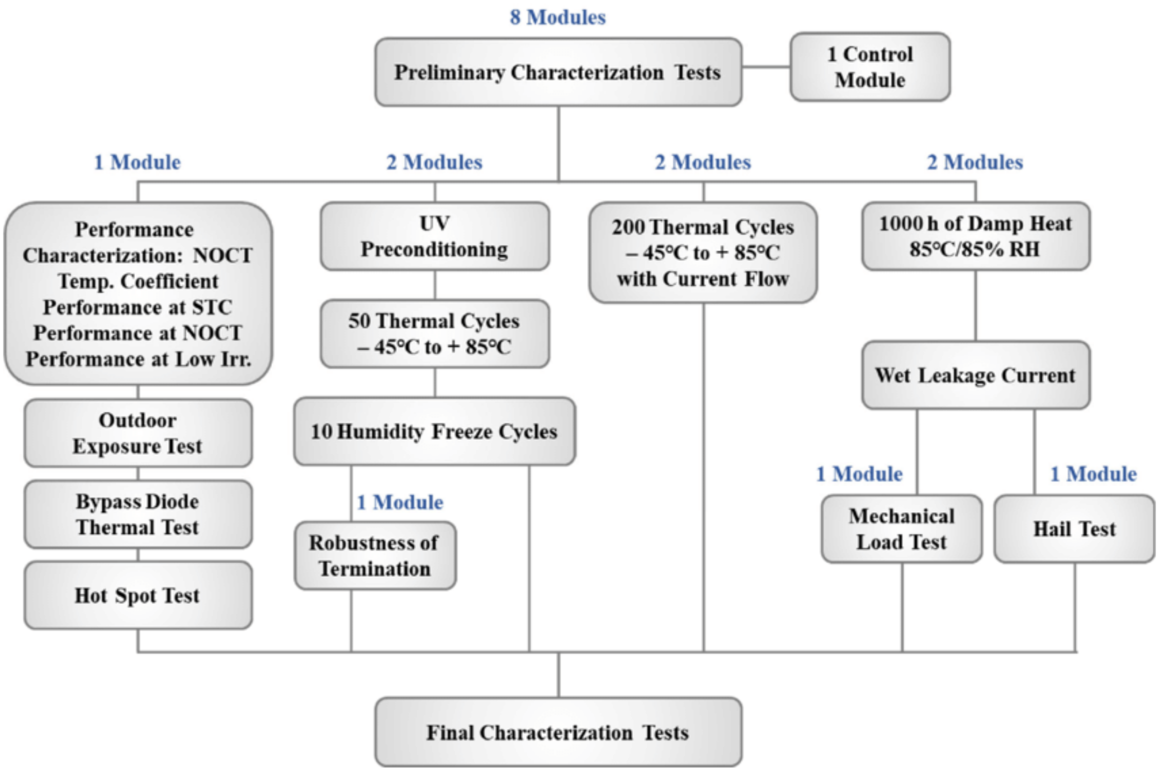

Figure 39 IEC 61215 testing sequence.

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Study of demonstrator collector needs

For the definitive demonstrator configuration, different case studies have been analysed, and a final selection has been carried out. The criteria used for setting up the solar field layout has taken into consideration the following items:

- In case all the PVT configurations pass the IEC test and the scaling is feasible, at least 3 different configurations should be installed. A current pre-selection considers: the one manufactured with conventional PV modules, the one based on fiber reinforced polymer, and for one of them it would be ideal to have the two assembly variants: laminated and glued.
- The rooftop occupation should be optimised, trying to maximise solar generation, prioritising winter performance, while not affecting other potential future rooftop uses.
- To facilitate integration of the solar field with other demonstrator technologies, such us heat pump.
- To have hydraulically compensated circuits and facilitate connection to electric balance of system components.
- Additionally, a pure PV reference will be added in other to analyse the generation gap of the PVT approach.

Among all analysed layouts, the option D of Figure 40 seems to be the most suitable one in terms of rooftop occupancy, solar generation potential in annual, winter and intra-daily point of view. The solar field will be finally installed in an east-west configuration with a tilting of 10˚.

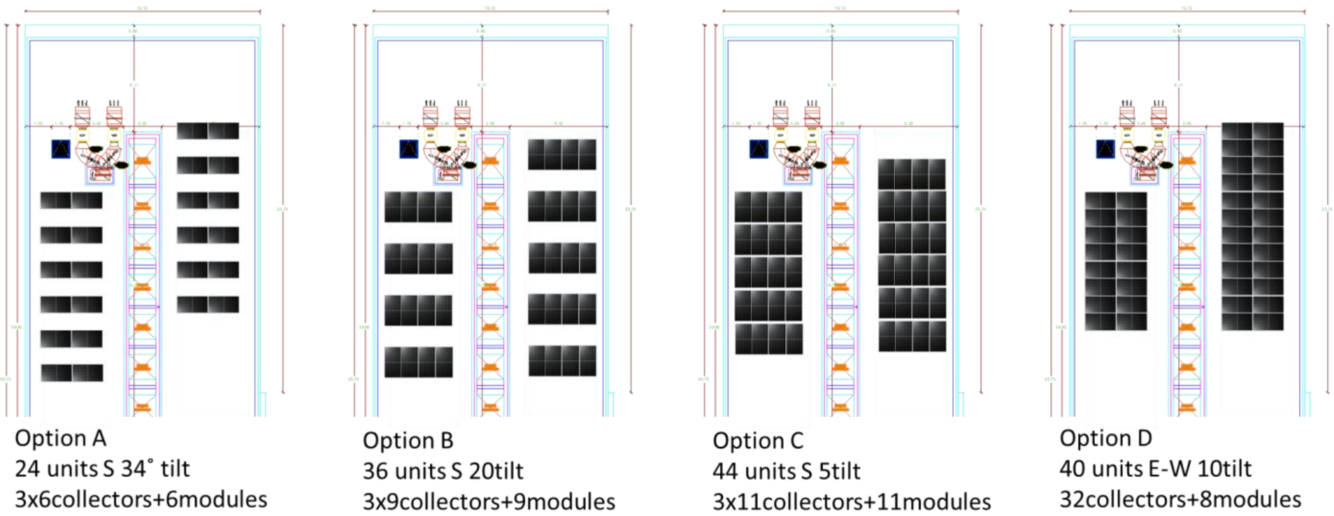

Figure 40 Different solar field layouts for the rooftop

4.1.5 Future steps

The future steps are the ones below:

1. Obtain a valid solution according to IEC 61215 standard for small samples.
2. Upscale the solution for a 2.2m2 device.
3. Manufacture prototypes for the demonstrator.

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4.2 Air-based PVT

4.2.1 Overview

This section presents the development of the air-based solar photovoltaic-thermal panels (PVT-a), performed by ENDEF within the META BUILD project. This panel type can produce thermal energy and electricity simultaneously by combining, in the same component, the photovoltaic and solar thermal technologies, using air as the heat transfer fluid (HTF). Thanks to this combination, the overall energy production is maximised per unit of surface area, compared to the single photovoltaic (2), (3).

The following subsections describe the current PVT-a system development by ENDEF in a previous I+D project, indicating its status and main issues that must be addressed to improve the product performance, the core of the innovation in the context of META BUILD, as well as the main advances did in the first project year and the future steps.

4.2.2 Starting status, description and constraints

The project is based on ENDEF's existing experience in hybrid-photovoltaic PVT panels and their integration with HVAC systems. Currently, ENDEF manufactures two types of liquid-based PVT panels, one glazed and another unglazed, commercially available. Besides, since 2023, ENDEF has had an air-based PVT panel whose absorber component is based on a new design, protected by the patent EP 3 809 591 A1. This first air-based PVT panel developed by ENDEF has undergone validation in relevant environments at two demonstration sites, with performance results published in a scientific journal (4).

The basic concept of the ENDEF's air-based PVT panel is illustrated in Figure 41.(a). It uses air as heat transfer fluid, the layer configuration has a frontal PV layer or PV laminate, a rear air chamber, a back insulation and a closing back sheet. Using a fan, the inlet air circulates through the rear chamber, getting temperature thanks to the incident solar irradiance and the heat generated on the back side of the PV layer. The heated air is finally sent to the system demand, while at the same time, electricity is also produced through the PV-laminate.

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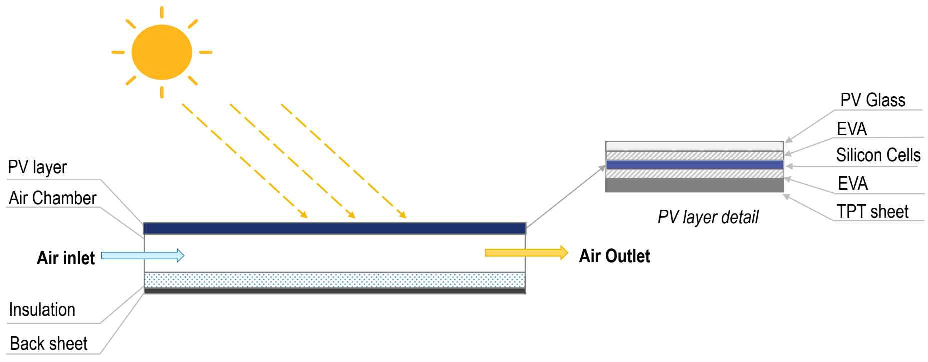


(a) Air based PVT concept

(b) Base PVT-a bench integrated by 5 PVT-a panels

Figure 41 PVT-air-based current ENDEF concept

Compared to water, air as HTF reduces the complexity and costs associated with PVT installations, making possible the implementation of systems where air can be used directly or indirectly for different applications such as ventilation, heating and drying (5). As a restriction, air has a lower heat capacity than water. Therefore, the air-based PVT system requires an optimal design to maximise global energy production while limiting the pressure drops.

The current model of ENDEF's PVT-a panel is focused on applications for flat roofs, using a base PVT-bench integrated by 5 PVT-a panels arranged in a vertical position, as Figure 41.(b) shows. In the context of WP3 – "Technologies enabling electrification", ENDEF will redesign the PVT panel to standardise their installation for different roof types while the energy production will be optimised, and the pressure drops will be reduced.

4.2.3 Core innovation technology

The development of the air-based solar photovoltaic-thermal panels (PVT-a) within the META BUILD project will be focused on redesigning the current PVT-a panel to develop and standardise two configurations: a system for flat roofs and a system for tilted roofs. For each configuration, a new PV laminate will be chosen to fit the final design (whether frameless or not, glass-glass, with a back sheet, etc.), and the thermal absorber will be adjusted considering the specific restrictions linked to these configurations and the materials.

The mechanical re-design process will be conducted using 3D-tool software, which allows detailed design for all the components selected to accurately design the layout of each component, including the PV laminate, absorber elements, support structures, closure sheets, air collector ducts, as well as all fixing and closing elements. An internal ENDEF's simulation tool will be used to conduct initial energy simulations to consider different design parameters such as the air chamber height, the air mass flow rate and the insulation thickness. Once the mechanical design is completed, the electrical design will be carried out to collect the electrical production of each PVT-a panel.

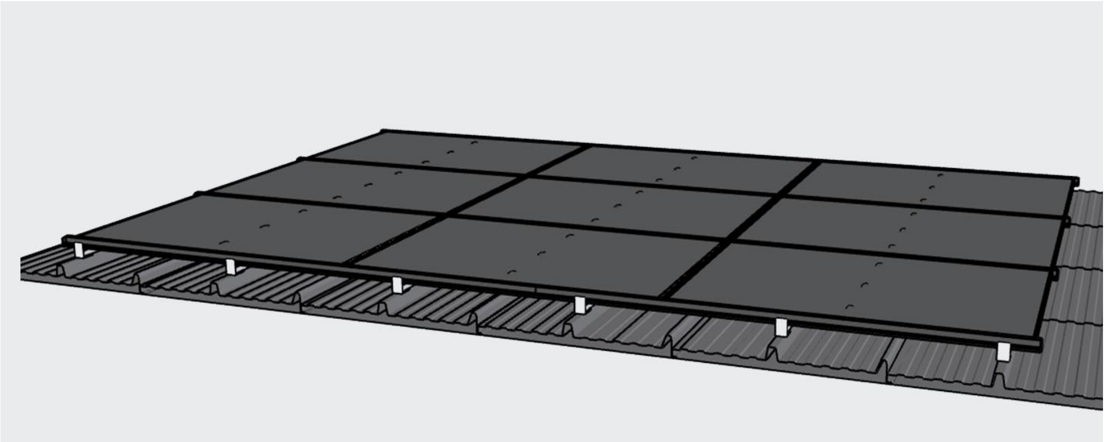
To evaluate the energy performance of the re-designed air-based PVT panels; an energy performance testing will be carried out in the ENDEF facilities, following the procedures described in the ISO 9806-2017 norm (6). To do this, two small energy performance testing installations will be conducted for each type of PVT-a system (tilt roof and flat roof). According to the tests performed, the PVT-a performance curves for different solar mass flow rates and environmental variables (solar irradiance and wind velocity) will be provided for simulation purposes of integrated solutions to be performed in the context of WP2 – "Electrified thermal energy demand integrated solutions & demonstration strategy".

4.2.4 Technology progress and status

The development of the two PVT-a systems for flat and tilt roofs, indicated in the previous subsection, has been focused on a re-design process, this includes the following activities:

- Definition of initial configuration approach for each system type, PVT-a tilt roof and PVT- a flat roof
- Selection of configuration option, considering the current PVT-a ENDEF's system, the literature review and as well as the manufacturing process.
- Selection of the materials and components, including the PV laminate, the absorber components, the back sheet enclosure, the structure components and complementary fixing elements.
- The initial mechanical design, by implementation of 3D models in a software package, to verify the configurations and the suitability of the chosen materials.
- Sensitivity analysis using an internal ENDEF's software tool to evaluate the preliminary energy performance according to key parameters in the design, including the air-chamber height and the air mass flow rate range.
- Final mechanical designs for both PVT-a systems (tilt roof and flat roof). This included assembly proof, with two PVT-a panels, to give feedback to the mechanical design for the PVT-a system for the tilt roof.
- Electrical design according to the final mechanical design.

Both PVT-a systems (tilt roof and flat roof) were redesigned with moderate slopes and horizontal distribution in order to provide better architectural integration and lower pressure drops compared to the current ENDEF's PVT-a system. Figure 42 illustrates the final configuration adopted for each type of solution. Additionally, as part of the re-design process for each PVT-a system (tilt roof and flat roof), a sensitivity analysis was performed using ENDEF's in-house software, to evaluate the incidence of key parameters, such as channel height, air flow velocity, and back sheet insulation thickness in the energy performance. Taking these results into account, the final design was adjusted.



(a) PVT-a system for tilt roof

(b) PVT-a system for flat roof

Figure 42 View of the mechanical design performed for the two types of PVT-a system

The **PVT-a system for tilt roof** (Figure 42 (a)) is composed of a set of 9 panels, arranged in a matrix with 3 rows and 3 columns, supported by structures fixed to existing building roof. The air enters the PVT-a system in the bottom zone of the PVT-a matrix, flowing upwards, through the air chamber between the building roof and the PV laminate. The outlet air is collected by duct located in the top zone of the PVT-a matrix. Depending on the space available on the roof, one or more PVT-a matrix can be installed, and the individual ducts must be connected to a general collector duct, which finally will be connected either to the heated room or to an HVAC system.

The **PVT-a system for flat roof** (Figure 42 (b)) has a set of 4 panels, arranged horizontally, with a common insulated rear back sheet, forming an air chamber between the PV laminate and the rear back sheet. This air chamber is divided into several transversal channels, through of which the air flows. This set of panels is supported by a structure installed on the flat roof, using standard slopes of 15 and 30°C. In this system, the air enters in the left side of the system, then flows through the air chamber and finally is collected with a duct on the back side of the final panel. Depending on the available space, one or more sets of PVT-a panels can be installed. Likewise, to the PVT-a system for tilt roof, each individual duct will be connected to the main collecting duct, which can be integrated into an HVAC system or connected to the heated room.

4.2.5 Future steps

The next steps for the product development will be focused on performing the energy performance test for both PVT-a system types (tilt roof and flat roof) in ENDEF's facilities. The corresponding activities are

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structured in two main phases, the first phase will be centred on the PVT-a system for tilt roof, to be performed in the first 6 months of 2025; and the second phase will be focused on the PVT-a system for flat roof that will be conducted during the last 6 months of 2025.

The activities include the energy performance bench design, the manufacturing of the PVT prototypes, the installations of the tech bench, and the measurement and analysis issues. The test will be conducted following the procedures described in the ISO 9806-2017 norm[2]. The corresponding testing results will be used to obtain validated energy performance curves for different solar mass flow rates and environmental variables (solar irradiance and wind velocity).

4.3 Second Life batteries

4.3.1 Overview

This document will present the state of the nation of the second life batteries technology at the end of December 2024, starting with a presentation of our initial state of development, the initial studies that were carried out to guide us in this new development cycle, as well as the different challenges faced until now and the first results obtained and the next steps.

4.3.2 Starting status, description and constraints

Presentation of the battery demonstrator (10.2kWh)

As a proof of concept, a modular battery made from second-life 18650 cells from e-scooters has been designed, assembled and tested (Figure 43). The battery is a 48V system with up to 8 modules of 1.3kWh each connected in parallel (Figure 44). The technical specifications of the battery and the module are presented in Table 8.

Table 8 Technical specifications of battery and the module

	Battery Pack (10.2kWh)	Single Module (1.3kWh)
Electrical configuration	1s8p modules	13s18p cells
Total cells	1872	234
Min Voltage	42.9 V	42.9 V
Nom Voltage	47.5 V	47.5 V
Max Voltage	53.3 V	53.3 V
Continuous discharging current	180 A	22.5 A
Continuous discharging power	8.55 kW	1.07 kW
Continuous charging current	108 A	13.5 A
Continuous charging power	5.13 kW	0.64 kW
Usable capacity	216 Ah	27 Ah
Usable energy	10.2 kWh	1.3 kWh
Communication	CAN bus (DB9), Touch screen, GUI	
BMS	Passive balancing, Master-Slave configuration	

[2] CEN, CENELEC, Solar energy. Solar thermal collectors -Test methods. EN ISO 9806:2017, (2017) 130.

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Firstly, the pack with two modules was assembled for initial testing. For the assembly of the modules, 1025 cells were selected based on their OCV values. Following a multi-stage sorting procedure, 468 cells were selected to be used in the modules. The selection process included sorting based on the visual appearance of the cells, voltage equalisation results, and EIS measurement results at certain frequencies.

After the selection was done, the cells were welded together using busbars. The welding process involved testing different welding pulse parameters such as the duration and intensity of the pulse to find the optimal parameters to have a strong weld point without damaging the cells. These parameters need to be optimised during each battery assembly as the busbar and the material of the cell-can might not always have the same properties.

The assembled battery with two modules has been tested by charging and discharging using the HMI presented in Figure 45. The tests showed that Module 1 has a capacity of 30.68Ah while Module 2 has a capacity of 26.1Ah. After several testing cycles, Module 2 went into voltage unbalance and was disconnected from the battery (bricked) by the BMS protection. This showed that the cell selection thresholds were not tight enough.

To summarise, the drawbacks of using cylindrical cells are the following:

- Busbar welding needs parameter optimisation that adds extra time and complexity.
- Cell selection criteria needs tighter thresholds and can become time-consuming.
- Assembly time of the modules is significant.
- Cell voltage unbalance leads to long balancing times and can eventually brick the module.

Figure 43 The 10.4kWh proof-of-concept battery

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Figure 44 The modules inside the battery

Figure 45 The battery HMI

High level requirements from the Grant Agreement

Based on the grant agreement, two second life batteries have to be provided in the framework of the META BUILD project:

- 60kWh BESS made from second-life cells from micromobility for Austrian pilot coupled with 155kW PV panels.
- 12kWh BESS made from second-life cells from micromobility for Italian pilot coupled with 20KW PV panels.

Present the initial risk with the regulation not being set in stone

The recently released 'IEC 63330-1:2024 Repurposing of secondary batteries - Part 1' (7) gives the general requirements for the repurposing of Li-ion batteries. However, for the 'IEC 63330-2 Repurposing of secondary batteries - Part 2: Classification of batteries to be repurposed - Safety and performance estimation methods', developmental work has just begun (11/2024). Thus, it is not clear yet if the developed BESS will meet the requirements set in IEC 63330-2 Part 2 at the time of installation.

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4.3.3 Core innovation technology

Integrating a battery energy storage system (BESS) with photovoltaic (PV) systems enhances energy efficiency and reliability. Solar panels generate variable energy, often exceeding demand during peak sunlight hours. A BESS captures this surplus energy, enabling its use during periods of low solar output, such as nighttime or cloudy conditions. This improves self-consumption, reduces grid dependency, and enhances energy security by providing backup power. Additionally, coupling BESS with PV mitigates intermittency, stabilises energy supply, and supports grid integration of renewables. The system reduces energy costs and carbon emissions, offering a sustainable and efficient solution for energy management and grid resilience.

A small-scale BESS, up to 100 kWh, made from second-life cells, can compete with one made from first-life cells in cost-sensitive and sustainability-focused applications. Second-life cells offer significant cost savings, often 30–50% cheaper, and align with circular economy principles by reducing waste. Second-life cells generally have lower energy density, and a reduced cycle life compared to first-life cells. However, this is not critical for applications with low to medium energy demands or shorter daily cycling, such as grid balancing or load shifting.

After the deployment of the BESS in the two pilots, real-time data will be collected for further optimisation of charge and discharge profiles, as well as protection settings.

4.3.4 Technology progress and status

Preliminary study

Considering the vast variety of battery type processed by Circu Li-ion, a preliminary study was carried out focused on ideating on the building blocks of the BESS and defining the design and technical specifications of these blocks. The starting point was taken to be reclaimed cells from battery packs used in micromobility devices such as e-scooters and e-bikes, as it was with the first BESS internally conceived. These cells would be contained in submodules, several of which will be connected together to form a module, which, along with the Battery Management System (BMS) would be the final building blocks of the complete BESS. What follows in this section is an overview of the design and technical specifications chosen for each individual building block of the BESS.

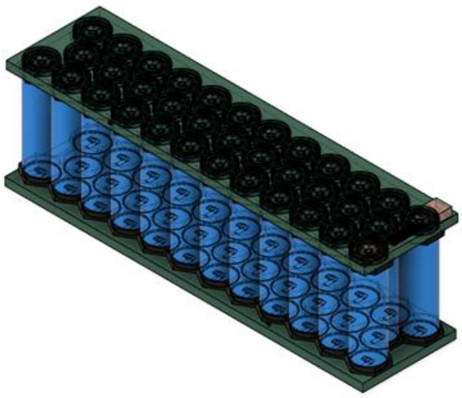

Figure 46 Proposed design of submodule consisting of reclaimed cells from micromobility battery packs

The proposed design of the **submodule** consisted of 30 to 40 second-life micromobility cells all connected in parallel and held in place using ABS holders (spacers) similar to the ones used in micromobility battery packs. The parallel configuration of the cells was decided in order to reduce the impact of non-welded connections on cell performance. Furthermore, we also wanted to have as little welding as possible in the submodule in order to make cell replacement in the case of a failure easier. The control circuitry PCBs and the power carrying cables would be placed on the spacers and would therefore essentially sandwich the cells. It was also decided that the cells used would exclusively have a state-of-health (SoH) greater than 95%. Furthermore, the maximum operating voltage of the submodule would be 4.1V, while the lower cut-off would be 3V. Lastly, the ideal C-rate of the module would be 0.2C, while the maximum allowed C-rate would be 0.5C. The exact cells chosen for this submodule would be chosen in order to support these requirements in the best way possible. All of these specifications are summarised as presented below:

- 30 – 40 cells connected in parallel and held in place using ABS holders (spacers) similar to the ones used in micromobility packs.
- PCBs mounted on top of the spacers on either side of the cells and these PCBs will accommodate all the necessary electrical and protection circuitry needs.
- Cells with SoH values greater than 95% +/- 0.2%.
- Maximum voltage: 4.1V, cut-off voltage: 3V.
- Ideal C-rate: 0.2C, peak C-rate: 0.5C.

Figure 47 Proposed design of modules containing 12 submodules

Having done the preliminary ideation on the technical specifications of the submodule, the **module** design was also put on paper. It was decided that each module would contain 12 of the submodules mentioned in the previous subsection connected in series (12s configuration). This configuration was chosen due to its convenience to be used with commercially available BMS's. The rated voltage of the module was decided to be 44V, while the rated C-rate and peak C-rate was the same as the sub-modules, i.e., 0.2C and 0.5C respectively. In terms of voltage and temperature sensing, the modules would contain only general voltage monitoring, as the cells of the submodules are in parallel, and ideally there would be two temperature measurements per submodule. To perform this measurement and control, each BMS of the module must be capable of communicating with the master BMS. Furthermore, due to the high capacity of the submodules, balancing leads that can ideally handle 1A of current would be needed, with 500mA being the minimum requirement. Lastly, all of this would be housed in a 19-inch rack to limit the need of engineering development and ease procurement/supply chain hassles that may arise due to a bespoke housing. A summary of these specifications is presented below:

- Each module will contain 12 submodules in 12s configuration.
- Rated voltage: 44V.
- Rated C-rate: 0.2C, peak C-rate: 0.5C.
- General voltage monitoring.

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- Ideally two temperature measurements per submodule.
- Slave BMS's capable of communicating with master BMS.
- Ideally 1A balancing leads, 500mA minimum.
- 19-inch rack for housing.

Keeping in mind the technical specifications of the submodule and modules, a **BMS design for the BESS** was theorised. It was decided that the BMS would be in a master/slave configuration, with each slave BMS connected to a submodule and would be required to perform voltage and temperature measurements and cell balancing on the submodules. On the other hand, the master BMS will be associated with the BESS as a whole and collect all the necessary data from the slave BMS's and control the processes related to those data. Lastly, the master BMS will also communicate with the Energy Management System to ensure efficient and safe operation of the BESS.

With these functional requirements, we found some major challenges and blockers attached. These were related to the complexity associated with the large number of thermal sensors that were required (12 for one module due to there being one thermal sensor required for each submodule), and due to the complexity associated with controlling the slave BMS's connected in parallel. In light of these challenges, a thorough analysis of the options available to us was carried out. This included developing an in-house BMS, buying a commercially available BMS, or outsourcing the development of the BMS. The findings of the analysis are presented briefly below:

- <u>Option 1: In-house development of the BMS:</u>
  - Using cells from micromobility packs (cylindrical 18650 cells) will require PCB development.
  - 2 simple passive PCBs – development time: 200 hours each.
  - 1 custom PCB for slave BMS - development time: 1000 hours.
  - 1 custom PCB master BMS – development time: 1500 hours.
  - This would amount to a total of 2700 hours of work for the first version. It is estimated that the beta and final version would require a further 1000 hours of development. This would add up to around 130-150k € just for PCB development.
- <u>Option 2: Buying a commercially available BMS:</u>
  - Given our constraint on the number of thermal sensors required and the capability of the BMS to handle parallel operation of the modules, our options are narrowed down to one BMS model, the n-BMS from Lithium Balance. But although their slave unit (CMU) can integrate 12 temperature sensors, it is not clear if they can support parallel connection of modules.
- <u>Option 3: Outsourced development (BMS PowerSafe):</u>
  - This option was explored as a workaround to the high cost of in-house development, and the inflexibility of off-the-shelf solutions. For this, several BMS manufacturers were contacted in order to find ones that would be willing to develop a BMS for us. Out of these, BMS PowerSafe showed considerable interest in working with us and talks with them were initiated.

Reconsideration

Having explored our options with regards to BMS development and procurement, it was clear that we either had to procure an off-the-shelf BMS, or outsource development. But within these two solutions, there weren't a lot of options to be considered. On top of this design challenge due to reclaimed micromobility cells, we were faced with an additional hurdle. Since the cells would need to be removed from their first-life devices to

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be used in our BESS, they would require to be certified again to be deemed fit for re-use, adding an extra layer of complexity.

In order to work around these hurdles, it was decided that the development be continued by using second-life EV modules as the building blocks of the BESS and do away with the submodule to module to BESS structure. This would limit the need for additional certification because the cells from the second-life EV modules will retain their certification from the OEM owing to the fact that they will not have to be removed from the modules for use in the BESS. Furthermore, using second-life EV modules also simplifies the BESS design by removing the need for submodules. So instead of submodules making up modules, which then makes the BESS, the only building block of the BESS will be the second-life EV modules. Lastly, the BMS design with the second-life EV modules will also be much more straightforward as opposed to the previous design due to the simpler overall BESS design and use of more standardised building blocks as opposed to building blocks developed in-house.

The next step was to select second-life EV modules that would fit closest to the technical specifications of the modules mentioned in the previous section. For this, extensive testing was carried out, the details of which can be found in the next section.

Module testing and selection

To support us in the selection of EV modules, Circu Li-ion acquired a testing machine from the company Neware. Specifications of the machine were established after a careful market study to be able to test all the available modules on the market.

Specifications are the following:

- Maximum DC voltage: 200V.
- Maximum DC current: 100A.
- Number of channels: 4.
- Temperature measurement: 8 K-type thermocouples.

This machine was commissioned on site in August 2024 and has been used to perform diagnostics on modules recovered from EV packs.

Between August and December (up until the date of this report), a total of 90 modules have been fully diagnosed for a total of 232kWh. To put things into perspective, a standard diagnostics cycle requires 1080 hours of test with an average test time of 12 hours per module to which 200 hours of data processing needs to be added.

Based on our initial assessment, selected modules need to have the following specification:

- Direct voltage measurement on the module and no communication protocol.
- Similar state of health, capacity, and internal resistance.
- Same battery pack model, and ideally year of production to avoid major refresh and changes in their designs.

Considering the testing and the results obtained, the following modules have been found suitable for use:

- Volkswagen MEB modules with the following configuration: 12S2P, 8S3P, 8S2P.
- Stellantis EMP2 6S1P modules.
- Stellantis CMP 6S2P modules.
- Jaguar IPace 3S4P modules.

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Figure 48 Examples of EV modules in stock

All these modules present the advantage of having a direct voltage measurement port used in their first life for balancing, but also present the same drawback: these voltage measurement pins are protected by internal fuses and cannot be replaced. Which means that a BMS (battery management system) with compatible current requirements has to be used. This proved more challenging than expected as most EV modules use fuses between 75 and 150mA while most aftermarket BMS use balancing currents starting from 200mA.

As such, the following modules are considered as an option:

- Stellantis EMP2 14S1P.

This module type does not present a direct voltage measurement but allows direct access to each individual cell connection. Furthermore, an aftermarket BMS can be connected to it, making it a viable option to be used in the BESS.

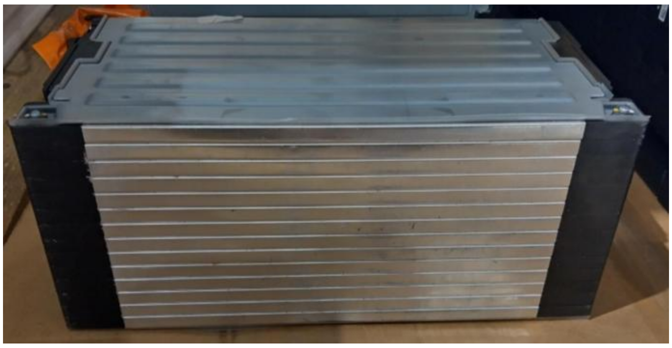

Figure 49 Stellantis EMP2 14S1P

- Mitsubishi Outlander PHEV modules.

These modules present several advantages, the first one being the absence of welding between the cells. Instead, the cells are connected using treaded connectors and bolts, allowing for a reuse of the cells and busbar in a new assembly. Being quite rare, this model of modules is only considered as an alternative option.

Figure 50 Mitsubishi Outlander PHEV modules

A total of 117kWh of modules among the tested 232kWh matched our initial screening in terms of SOH (greater than 95%) and a direct voltage measurement (or easily adapted). These modules were set aside for this project.

Additional modules will later be tested and assessed for the application.

Specifications from pilots

Austrian pilot:

- Usable capacity: 60kWh.
- Available power: 20-30kW.
- Availability time: 2-3 hours.
- Battery room availability: Can be made if required.
- Installation place: Indoors.
- Compliance: VDE-AR-E 2510-50, IEC 62619, IEC 62485-1, IEC 62485-2.

Italian pilot:

As of writing D3.1, only high level specification are available for the Italian pilot (see deliverable D5.1 – “META BUILD Front Runners: Report of designing and demonstration activities”). In later stages of the pilot implementation and maturity, more information will be made available (D3.2 – “Technologies for enabling electrification and business models, 2nd technology release”).

New regulation for second-life batteries

Here, it is worth making a point about the recently introduced regulations. Before the release of the IEC 63330-1, no safety standard existed for second life batteries. But with the introduction of this standard, quite a few things need to be kept in mind.

The points addressed in this standard are the following:

Information needed by CIRCU LI-ION:

- The manufacturer of the battery.
- The chemistry.
- Manufacturing date.
- When available the serial number and dismantling procedure.
- Operating range (voltage, current, temperature).
- History of critical failure.
- State of health.

- Remaining useful life.
- For EV modules/packs: “State of certified energy” or SOCE, remaining capacity expressed in energy (kWh or Wh) at a defined time.
- History of storage conditions.
- History of repairs.

Data we need to be provided by CIRCU LI-ION:

- Operating range (voltage, current, temperature)
- Expected lifetime in second-life conditions
- The expected performance of the battery such as capacity, resistance, et cetera. It cannot exceed initial specifications.
- The safety design of the system design (example changing from a pack to cells or from a 12S to an 8S) needs to be reassessed and certified again.

Some examples are being presented to explain the impact of this new standard on the work being done.

An EV battery pack is usually composed of modules. These modules are themselves composed of cells connected together. To take concrete examples, if we take the pack for second life application, and it meets the criterium fixed by the original manufacturer in terms of capacity, resistance and expiration date, and we don’t modify its safety system, the system will keep its original certification. As an absolute rule, the second life application cannot be more demanding than the first life one. This works with modules and cells as well. Now if we extract the modules and reassemble them into another battery, the modules will still be certified, but the final battery will have to retake all the safety tests.

Safety tests needed to obtain the UN38.3 - which is only one of the safety standards, are:

- Altitude testing/low pressure test.
- Thermal testing by making sudden temperature variation from -2°C to +75°C.
- Vibration testing to simulate the vibrations the batteries will be subjected to during transportation.
- Impact testing.
- Short circuit testing (internal and external).
- Over-charge.
- Over-discharge.

Each of these tests is considered destructive, implying the need to create at least 7 batteries to re-obtain the certification. Any failure at any of these steps implies the need to pass all of them again. No design change is allowed between each test.

This new standard, as well as some requirements from the Austrian demo leads to the need of an adjustment in our approach.

Indeed, the cost factor unfortunately needs to be taken into account, even at the prototype stage. The cost of obtaining such certification at the moment would negatively impact the development. Owing to the nature of our operations, CIRCU LI-ION receives battery packs randomly, leading to the need of diversifying our supply chain to use different modules, which leads to the need to obtain the UN38.3 certification several times (once for every type of module we could use). In addition to the UN 38.3, other certifications specific to stationary storages would also need to be obtained.

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This certification issue, coupled by the need to secure so called production scraps (fully assembled and functional batteries, but scrapped) – which are difficult to come by as they are highly sought-after by second life storage companies, thus making them difficult to secure, adds further complexity to the situation.

It is also worth mentioning that the IEC 63330-2's focus on testing for second life applications has only just begun to be worked on by the technical committee and is expected to be released around February 2026. Implications from this, will be reviewed and assessed, to identify the potential risks that pose in the approach of building the batteries form recovered cells.

To mitigate proactively the implications, it has been decided to adapt our approach and focus on two possibilities. The first one is to work with full, unmodified battery packs. The second would be to acquire an already CE-rated system (also called racks) from some companies we already worked with on various other projects and use modules their systems is certified for. This would derisk the delivery of the batteries while keeping the CE certification, but is currently seen as a backup solution.

Utilisation of EV battery packs as stationary Storage

The main challenge involved in using an EV battery pack as stationary storage lays in the ability to communicate with the battery pack. Indeed, for safety reasons, EV packs are by default "locked". This means that even connected to a load they cannot be charged or discharged.

Based on our experience with Micro-mobility battery packs, we identified that the first step was to find a way to communicate with the battery pack. Some batteries are simpler than others to unlock. This is for example the case of the Renault Zoe first generation for which the unlocking only requires the application of 12V, and a component called the service plug.

Figure 51 Renault ZOE Gen1 22kWh unlocking setup

Once these two conditions are fulfilled, the battery pack can be used as an energy storage device. This pack being rather easy to unlock is an appealing candidate, but even in its bigger version will not present enough capacity to fulfil the full needs of the Austian pilot which will require several batteries. Considering the most common version of this pack is the 22kWh variant, a considered option is to connect three of these packs for a theoretical total of 66kWh. The high-level architecture for this BESS could look as indicated in Figure 52.

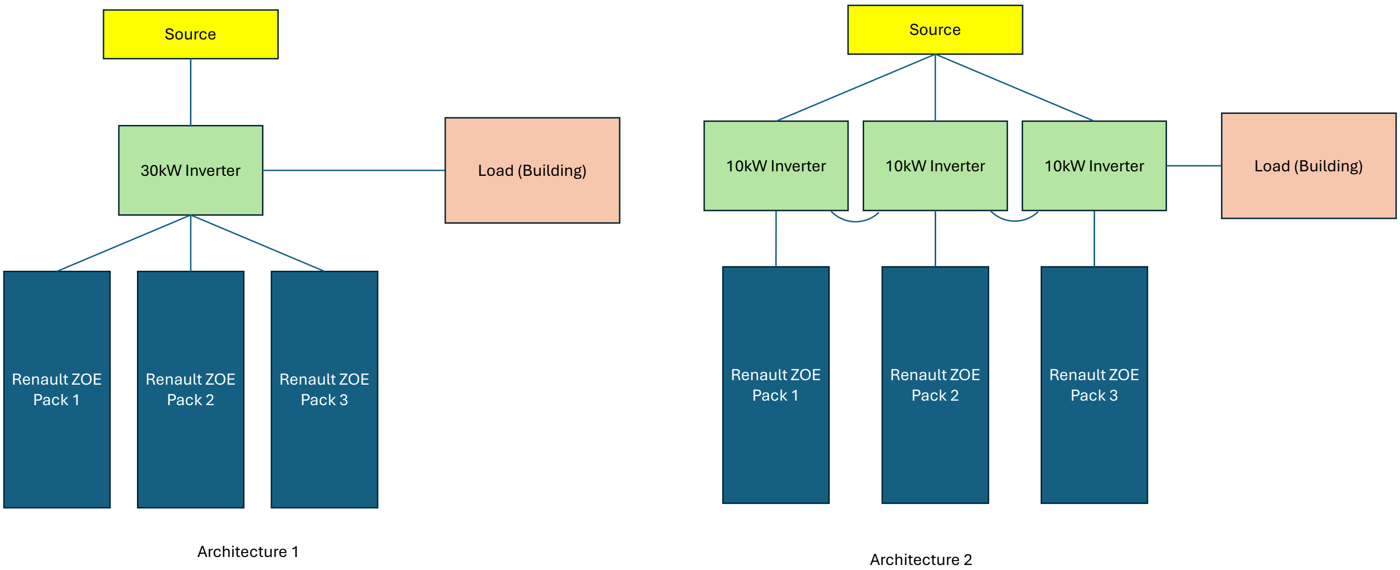

Figure 52 High-level architecture considered for the 60kWh BESS

One possible architecture is with three batteries all connected to one separate inverter each. The connection of the three batteries to the same inverter could be possible, but this option is still under study as the three batteries will likely have different states of health (remaining capacity), which might generate an unbalance in the system.

The other challenge presented by the Zoe Batteries is from a technological perspective. The Zoe is part of the first wave of Li-ion car batteries. Its system is, by today's standard, quite simple, if not outdated. The battery is air-cooled, which can, in some cases, create an internal unbalance between the modules (difference of capacity); the possibility to monitor each cell's voltage is also limited, and safety standards are not as good as in newer packs.

The second battery pack we managed to unlock was the BMW i3 pack. This pack presented many more challenges.

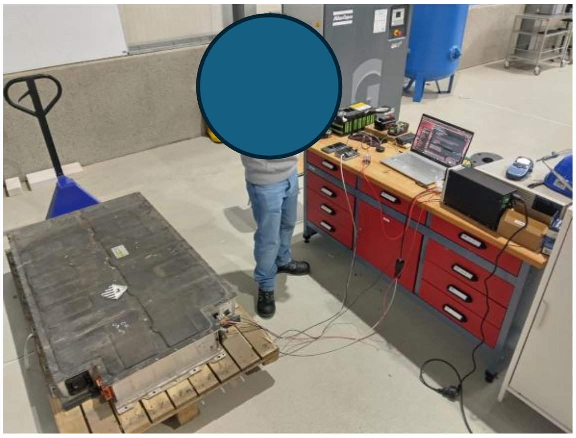

Figure 53 Unlocking test on BMW i3 battery pack

The unlocking of this battery pack requires 'true communication' with the BMS (battery management system) to unlock the main contractor. This simple communication is required to find first the proper communication protocol, then to figure out which combination to send to the BMS to activate the contactor. To this end, a so called "sniffing" system was used, allowing us to record on another car using this battery pack, and after a

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series of trial and error to find the proper sequence, with the proper frequency to unlock the pack. Because this battery pack is more modern than the Zoe, the BMS can provide more information, such as the last known state of health of the battery, the number of cycles, but also, more importantly for us, each individual cell voltage.

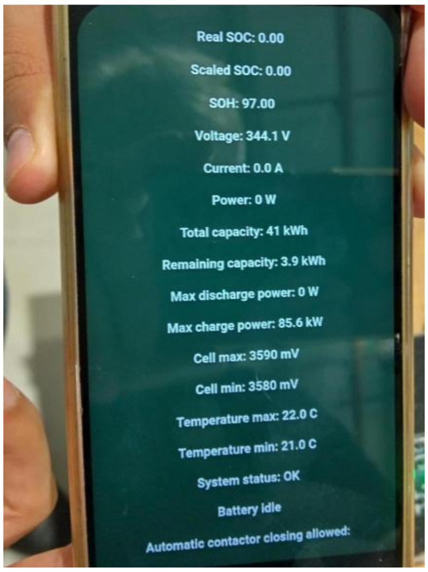

Figure 54 Presentation of the Android app used to monitor the pack values

For ease of use, a small android app was internally developed to allow the monitoring of these parameters. Like for the Zoe pack, the I3 pack will not be enough by itself to fulfil the energy requirement of the Austrian pilot. As this battery pack exists in several configurations, ranging from 22 to 44kWh, using a high voltage architecture similar to the one proposed for the Zoe, i.e., mainly focused on the 22kWh pack, is at this point considered as a viable option.

Other batteries that are considered to be unlockable and usable at this moment, are still in the process of being sourced. The next step for this path will be to start sourcing one or several inverters to fully test the concept with one or several of the battery pack candidates.

4.3.5 Future steps

The next steps for the 60kWh battery will be the following. We first try to source a compatible inverter with the two batteries we know can be unlocked and as soon as possible start the connection to it for further testing. This testing will involve:

- Testing the compatibility of the batteries with the inverter. As mentioned, one of them requires constant communication to allow the charge and discharge.
- Performance testing, during which we will assess the thermal behaviour of the battery during the charging and discharging process.
- And versatility. Because the exact charge and discharge profiles are unknown, the system needs to be tested in different conditions to assure its suitability with the final use case.

In parallel, we'll continue sourcing new battery candidates to test our unlocking methodology and give us the best chances of success. Furthermore, we'll continue keeping an eye on the future release of the IEC 63330-2 to avoid any last-minute legal issues.

Backup solution

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As mentioned already at the end of the section 04.3.4, the backup is to acquire from one of our partners an already certified system without the batteries. In this case our focus would be to test known compatible batteries according to their specifications to ensure the certification of the system stays valid. This path will be assessed in the upcoming months to be fully ready to react in case of a complete failure of our own attempt to manufacture these batteries. Furthermore, considering the absence of proper specifications from the Italian pilot at the time of writing this document, the abovementioned option will likely be pursued. With their requirements and specifications being completely different from the one we intend to deliver to the Austrian pilot, starting a full internal development from scratch for the Italian pilot today might expose us to too many uncertainties.

5 Solutions Database for Replication

META BUILD aims to develop and demonstrate replicable, high-efficiency technological solutions for decarbonising the EU building stock. The project contributes to this goal by creating a solutions database that serves as a reference for analysing and replicating META BUILD technologies in diverse building archetypes and climatic conditions across Europe. This section outlines the structure and initial steps undertaken to achieve this objective.

5.1 Methodology for Developing the Solutions Database

The methodology for developing a holistic Solutions Database has been separated into three initial steps for paving the way for enhancing the replicability of META BUILD solutions.

5.1.1 Identification of Representative Building Archetypes

The first step focuses on defining building archetypes that reflect the diversity of the EU building stock in terms of usage, climatic conditions, and structural characteristics. This involves:

- **Statistical Analysis of Building Characteristics:**
    - **Building Categories:** Buildings will be categorised based on use (e.g., residential, commercial), construction age, and size.
    - **Climate Associations:** Archetypes will be linked to prevalent EU climate zones (e.g., Mediterranean, Continental, Oceanic) using climate classification systems.
    - **Predominant Building Types:** For example, single-family homes dominate rural areas in countries like Sweden and Finland, while multi-family apartment buildings are typical in urban centres across Southern and Central Europe, such as Spain and Germany.
- **Preliminary Archetype Definition:**
  A multi-family building in Valladolid, Spain, has been identified as a reference archetype. This building features standard characteristics representative of Southern European urban residential architecture, with accessible technical schematics, historical energy data, and localised climate data.

This step ensures that the database encompasses the diversity needed for scalable replication of META BUILD technologies.

5.1.2 Data Collection and Compilation

The second step involves systematically gathering comprehensive data for each identified archetype, ensuring alignment with project requirements. Key data categories include:

- **General Building Information:**
    - Location, use type, construction age, and size of the building.
- **Energy Metrics:**
    - Historical energy consumption data, peak demand trends, and renewable energy production (e.g., solar PV system outputs).
- **HVAC Systems:**
    - Specifications of heating, ventilation, and cooling systems in use, including operational profiles and energy performance metrics.
- **Architectural Schematics:**
    - Floor plans, energy flow diagrams, and other technical layouts essential for understanding building operation.

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- **Climate Data:**
    - Historical weather data and localised climate conditions for each archetype.

  Existing data from META BUILD front-runner buildings will be leveraged to streamline data collection processes, ensuring consistency and completeness.

5.1.3 Development of the Solutions Database

The database will be designed as a practical, user-friendly tool for organising and sharing information. It will include:

- **Standardised Templates:**
  Templates will be developed to present data consistently across archetypes, simplifying interpretation and comparison.
- **Scalable Entry Formats:**
  The database will allow the straightforward addition of new archetypes as the project progresses, ensuring adaptability for future needs.

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6 Novel Market Structures and Business Models

Integrating low-carbon, electrified technologies into the EU building sector demands innovative market structures and business models that meet regulatory and market needs. META BUILD is focusing on benchmarking advanced technologies, refining their performance, and designing scalable frameworks for their deployment. This section outlines the structure and methodology to achieve these four objectives.

6.1 Objectives and Scope

1. **Benchmark Integrated Packages:** Evaluate HPs, RES, and storage solutions against current EU market demands and anticipated trends.
    - *Purpose:* To identify how META BUILD technologies compare with existing solutions and determine areas for improvement.
    - *Approach:* Assess technical performance, compliance with EU regulations, and market feasibility, leveraging data on commercial solutions.
2. **Refine Solutions:** Use benchmarking insights to enhance the technical and economic performance of technologies developed within the project and presented in sections 3 and 4.
    - *Purpose:* To ensure technologies meet real-world requirements.
    - *Approach:* Collaborate with stakeholders to adjust design parameters and validate them through simulations and pilot tests.
3. **Explore Novel Market Structures:** Investigate and design market frameworks that support service-oriented business models to facilitate the deployment of integrated packages.
    - *Purpose:* To identify market pathways for META BUILD technologies.
    - *Approach:* Analyse trends, engage stakeholders, and design scalable structures adaptable to diverse EU contexts.
4. **Develop Suitable Business Models:** Create tailored models addressing the needs of specific market segments.
    - *Purpose:* To ensure scalability and economic viability.
    - *Approach:* Define value propositions, analyse costs and benefits, and align with policy incentives.

6.2 Methodology

The methodology for achieving the META BUILD market objectives is split into five stages and are cited below.

6.2.1 Benchmarking of Integrated Packages

- **Objective**: Compare the performance and suitability of META BUILD's integrated solutions (HPs, RES, and storage) against EU market demands, current commercial technologies, and regulatory frameworks to identify strengths, gaps, and areas for improvement.
- **Steps**:
    - **Data Collection:** Gather comprehensive data on EU regulations, performance metrics of comparable commercial solutions, and specific building sector requirements. For example, data for HPs could include energy efficiency ratios and refrigerant types, while RES data might cover photovoltaic efficiency and inverter performance.

- **Performance Metrics:** Define KPIs such as COP for HPs, round-trip efficiency for storage, and energy yield per kW installed for RES. These metrics ensure meaningful comparisons and align with EU priorities.
- **Market Segmentation:** Segment the EU market by factors such as building types (e.g., residential, commercial), geographical zones, and energy needs. For instance, HP adoption potential may differ between southern and northern Europe due to climate variations.
- **Gap Analysis:** Identify performance gaps between META BUILD technologies and current market offerings to prioritise areas for refinement.

6.2.2 Feedback and Refinement of Solutions

- **Objective**: Impulse improvement of technical and economic performance of technologies developed within the project and presented in sections 3 and 4.based on benchmarking outcomes.
- **Steps**:
  - **Workshops with Stakeholders**: Engage project partners responsible for buildings, such as those managing pilot sites, to gather practical insights.
  - **Iterative Development:** Adjust design parameters of abovementioned technologies to better align with identified market needs and regulatory requirements.
  - **Validation Testing:** Use numerical analysis simulation models to test refined solutions under real-world scenarios.

6.2.3 Exploration of Novel Market Structures

- **Objective**: Investigate and Design the market to support packaged service business models, enhancing the integration of META BUILD technologies into the EU building sector.
- **Steps**:
  - **Market Trends Analysis**: Study emerging models like energy-as-a-service or hybrid ownership for RES and storage systems. For example, explore how subscription models for HPs could work in urban rental markets.
  - **Stakeholder Engagement**: Collaborate with end-users, policymakers, and energy providers to identify barriers to adoption, such as upfront costs or policy mismatches.
  - **Framework Development**: Propose adaptable models, such as combining thermal storage with solar PV leasing, offering modular solutions for varied building sizes.

6.2.4 Development of Suitable Business Models

- **Objective**: Create tailored business models that address the needs of specific target groups, ensuring economic viability and scalability.
- **Steps**:
  - **Target Group Identification**: Segment the market into key groups, such as customers into residential, commercial, and public building operators. For instance, residential users may prioritise energy savings, while public buildings may value sustainability certifications.
  - **Value Proposition Design**: Define the unique value offered by integrated packages for each segment, emphasising energy efficiency, cost savings, and sustainability. Such as cost savings through integrated RES and storage systems or improved grid flexibility for commercial properties.
  - **Cost-Benefit Analysis**: Evaluate the economic feasibility of business models through detailed cost assessments and market simulations. Use lifecycle cost analysis to evaluate business models. For example, assess the ROI of a combined heat pump and battery storage package for a typical single-family home.

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6.2.5 Marketability Assessments

- **Objective**: Provide valuable inputs to the "Solutions Adoption, Replication, Scalability & Exploitation" efforts by assessing META BUILD technologies' market readiness and supporting large-scale replication and exploitation plans.
- **Steps**:
  - **Front Runners Evaluation**: Analyse performance and user acceptance from Front runners' sites, such as customer feedback.
  - **Feedback Integration**: Identify key takeaways for improving scalability, ensuring results align with replication objectives. For instance, create a collaboration framework within the project on policy implications of deploying integrated solutions.
  - **Deliverable Inputs**: Compile findings into structured inputs for replication tasks, emphasising actionable insights like business model adaptability across regions.

6.3 Initial Steps

1. **Kick-off Workshops**:
   - Organise workshops with building stakeholders, including pilot site managers and policymakers, to identify critical success factors and gather preliminary insights.
   - Establish working groups to oversee benchmarking, business model development, and market structure exploration.
2. **Data Acquisition**:
   - Collect data on EU building typologies, energy usage patterns, and regulatory requirements.
   - Gather technical specifications and performance data for technologies from project partners.
3. **KPI Definition**:
   - Define KPIs specific to energy efficiency, scalability, cost-effectiveness, and environmental impact.
   - Align KPIs with META BUILD's overarching goals and EU decarbonisation objectives.
4. **Preliminary Benchmarking**:
   - Conduct an initial comparison of META BUILD's integrated packages against leading commercial solutions to identify performance benchmarks.
   - Highlight areas requiring immediate attention and refinement.

By systematically addressing these steps, the project will create a robust framework for assessing market readiness and developing innovative, scalable business models to support META BUILD's exploitation objectives.

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7 Conclusions & Next Steps

The META BUILD project has made significant progress in developing and demonstrating technologies that enable the electrification of buildings and support the transition to a decarbonised energy system. This deliverable, D3.1 – "Technologies for enabling electrification and business models, 1st technology release", has provided a comprehensive overview of the work carried out in the WP3 – "Technologies enabling electrification", focusing on the first release of these technologies and their associated business models.

The legislative and regulatory conditions for heating and cooling systems across six countries with Front Runner are being thoroughly analysed. This analysis ensures that the developed technologies align with national regulations and facilitate entry into the reference markets.

The deliverable presents several innovative heat pump technologies that are designed to address the thermal demand of diverse building types within different climatic conditions. Additionally, it reports the advancements of the project about the development of PVT systems and second-life batteries. These technologies enhance the integration of renewable energy into buildings and support grid stability. Moreover, it goes further to present a methodology and outline for creating a solutions database that serves as a reference for analysing and replicating META BUILD technologies in diverse building archetypes and climatic conditions across Europe.

Finally, the deliverable discusses the novel market structures and business models suitable for the exploitation of META BUILD's technologies with a detailed methodology and description of the initial steps that have been taken.

The future steps for WP3 – "Technologies enabling electrification" in the META BUILD project will be to continue the development of the presented technologies, which include testing in labs, numerical simulations, and integration at pilot sites. In addition, the WP will also work on expanding the solutions database to include more building archetypes and climatic conditions, facilitating the replication and scalability of the technologies across Europe. Finally, the project will create a comprehensive framework for assessing market readiness and developing innovative, scalable business models to support META BUILD's exploitation objectives.

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