RE-SKIN

D2.1 - Application context periodic update I

Funded by the European Union

Deliverable Information Sheet

Version	1.0
Grant Agreement Number	101079957
Project Acronym	RE-SKIN
Project Title	Renewable and Environmental-Sustainable Kit for building Integration
Project Call	HORIZON-CL5-2021-D4-02-02
Project Duration	42
Deliverable Number	D2.1
Contractual Delivery Date	31-08-2023
Actual Delivery Date	01-09-2023
Deliverable Title	Application context periodic update I
Deliverable Type	R
Deliverable Dissemination Level	PU
Work Package	2
Lead Partner	ENTPE
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History of changes

Version	Date	Comments	Main Authors
0.1	21-07-2023	First draft, establishing document structure	Joud Aljumaa Aldakheel (ENTPE)
0.2	27-08-2023	First version, incorporating input from all participants	Joud Aljumaa Aldakheel, Veronicca Gazzola, Yamna Soussi, Ghizlane El Mahiba, Hajar Benhmidou, Myriam Bahrar (ENTPE
0.3	28-08-2023	Quality review	R- Adhikari (POLIMI), A. Vallan (FPM)
1.0	01-09-2023	Final version addressing all further comments	Joud Aljumaa Aldakheel (ENTPE)

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Disclaimer

1. Executive summary

The main purpose of this deliverable is to provide a thorough and detailed account of the first periodic update pertaining to the application context in the target countries (T2.1-2.4) and to present the findings of the site risk assessment (T2.6) with a higher level of specificity.

The aim is to ensure that the document encompasses all the key elements that contribute to the understanding of the context, such as the status of the retrofit market, the existing regulatory framework, and any other pertinent factors. Additionally, the document aims to present a comprehensive overview of the site risk assessment, going beyond a mere summary of the results. It strives to include multi-hazard and multi-risk assessment maps, providing a visual representation of the various hazards and risks associated with each target country within the application context. In this deliverable, the risk maps are presented for Italy and Spain. In the next deliverable after acquiring the information on the other case studies locations the risk maps will be shown for France and Bulgaria.

2. Building Retrofit Market

The task describes the advancement of residential building energy retrofit in the target countries, to study the progress made in improving the energy efficiency of existing residential buildings. To achieve this, data is gathered from diverse sources, including official government websites, databases from across Europe, and international reports.
This comprehensive data collection allows for a thorough assessment of the retrofit and their impact on reducing energy consumption. The findings and insights derived from this task can play a crucial role in understanding the effectiveness of energy retrofit policies and strategies implemented in the target countries.

2.1. Residential Building Stock

Residential building stock focuses on the analysis and assessment of the housing within the target countries. This section aims to provide an understanding of the current state of residential buildings, including various aspects related to their structure, and energy consumption.

2.1.1. High-level Overview of the Building Stock

The stock of residential dwellings and buildings in the target countries consists of a variety of buildings typologies, though single- and multi-family buildings dominate. Other residential dwellings can be found in, for example, mixed-use buildings or institutional settings, such as care homes for the elderly. Each of the four target countries (Bulgaria, France, Italy and Spain) carried out a population and housing Census, as per their statutory requirement under EU Regulation (EU) 2017/712.

Table 1: Diverse dwellings in Bulgaria: Exploring housing unit distribution from the 2021 Census

Dwelling type	Number of Housing Units	Percentage of Total
Single-family	1,858,596	43.6
Multi-family	2,402,858	56.4
Total	4,261,454	

However, these figures do not tell the full story. Of the 4,261, 454 dwellings in Bulgaria, only 2,603,713 units are occupied. This means there is a staggering 39% vacancy rate. According to the preliminary Census, when compared to 2011, there are a greater share of vacant units, suggesting a worsening situation in terms of the use of the existing stock of potential homes.

Table 2: Diverse dwellings in France: Exploring housing unit distribution from the National Ministry

Dwelling type	Number of Units	Percentage of Total (*Num of Units*)
Single-family	20,714,250 (2,317,910,000 m^2)	55.4

Multi-family	16,673,300 (1,009,800,000 m^2)	44.6
Total	37,387,550 (3,327,710,000 m^2)	

Table 3. Dwellings in France by Usage

Dwelling usage	Number of Units	Percentage of Total
Owner-occupier	17,598,490	47.1
Private rental	7,629,980	20.4
Social rental	5,393,240	14.4
Secondary residences (e.g., holiday homes)	3,666,250	9.8
Vacant dwellings	3,099,590	8.3
Total	37,387,550	

Table 4: Diverse dwellings in Italy: Exploring housing unit distribution from the 2021 Census

Type of Dwelling	Number of Units	Percentage of Total
Total	35,271,829	
- of which: occupied	25,690,057	72.8
- of which: single-family	12,048,637	[34.2]
- of which: multi-family	13,641,420	[38.7]

Table 5: Diverse dwellings in Spain: Exploring housing unit distribution from the 2021 Census

Type of Dwelling	Number of Units	Percentage of Total
Total	25,976,305	
- of which: main residence	19,536,469	75.2
- of which: single-family	6,622,863	[25.5]
- of which: multi-family	12,913,606	[49.7]

2.1.2. Residential building stock by final energy consumption source

Energy consumption in residential buildings plays an essential role in environmental sustainability and resource management. This section explores the various energy sources utilized by dwellings.

- Share of fuels in final energy consumption, by Residential Buildings:

Table 6: Comparative analysis of fuel types across European Countries (2011-2021)

		2011	2016	2021	Change '21 v '11
Bulgaria	**Solid fossil fuels**	10.0	6.7	5.8	-4.3
	Natural gas	2.4	2.6	4.7	2.4

	Oil and petroleum	1.2	1.2	0.9	-0.3
	Renewables and biofuels	31.8	34.1	31.8	0.0
	Electricity	39.5	41.0	42.8	3.3
	Heat	15.1	14.4	14.1	-1.0
	Other fuels n.e.c.	0.0	0.0	0.0	0.0
France	**Solid fossil fuels**	0.1	0.1	0.1	0.0
	Natural gas	32.0	30.2	28.0	-4.0
	Oil and petroleum	15.8	12.4	9.9	-6.0
	Renewables and biofuels	17.3	20.8	24.0	6.7
	Electricity	32.1	33.5	34.6	2.5
	Heat	2.7	3.0	3.5	0.8
	Other fuels n.e.c.	0.0	0.0	0.0	0.0
Italy	**Solid fossil fuels**	0.0	0.0	0.0	0.0
	Natural gas	55.6	53.1	52.6	-3.0
	Oil and petroleum	9.5	7.1	5.9	-3.7
	Renewables and biofuels	14.5	19.6	21.3	6.8
	Electricity	18.6	17.2	18.0	-0.6
	Heat	1.8	2.9	2.2	0.5
	Other fuels n.e.c.	0.0	0.0	0.0	0.0
Spain	**Solid fossil fuels**	0.8	0.6	0.3	-0.5
	Natural gas	21.8	23.3	24.7	2.8
	Oil and petroleum	18.8	19.5	16.7	-2.1
	Renewables and biofuels	16.7	14.9	15.7	-1.0
	Electricity	41.9	41.8	42.7	0.8
	Heat	0.0	0.0	0.0	0.0
	Other fuels n.e.c.	0.0	0.0	0.0	0.0
EU-27	**Solid fossil fuels**	3.8	3.5	2.5	-1.4
	Natural gas	32.1	32.6	33.5	1.5
	Oil and petroleum	14.4	12.3	9.5	-4.8
	Renewables and biofuels	17.2	18.6	21.2	4.1
	Electricity	24.0	24.1	24.6	0.5
	Heat	8.4	8.8	8.6	0.2
	Other fuels n.e.c.	0.1	0.1	0.1	0.0

As shown in Table above, the four target countries are very diverse in terms of the sources of fuel used by their households in their final energy consumption.

If we look at the least sustainable fuels – gas, petrol, and solid fuels – then Bulgaria is the best performer, with just 11.4% of household energy needs coming from these sources. There is then a significant jump to 37.9% in France, and 41.6% in Spain. Italy stands out, with 58.4% of energy from these sources; above the EU average of 45.5%.

In terms of the use of renewables, Bulgaria also outperforms, with 31.8%. At 24%, France slightly outperforms the EU average, of 21.2%. Italy (21.3%) and Spain (15.7%) are below average in this regard.

2.1.3. The total stock of dwellings

Another import factor to consider, when it comes to the possible need for the renovation of a home, is its age. Dwellings built prior to 1990 were done according to a lower set of standards than today. Thus, buildings from that era, which have not already been upgraded, may be prime candidates for renovation.

Table 7: Bulgarian Residential Buildings Distribution Based on Construction Year

	%	Num of Buildings
Pre-1959	34.8	738,853
1960-1969	20.8	441,614
1970-1979	15.8	335,456
1980-1989	13.6	288,747
1990-1999	6.7	142,251
2000-2009	4.5	95,541
2010-2021	3.8	80,679
Total	100	2,123,142

Table 8: French Residential Buildings Distribution Based on Type And Construction Year

	Houses	Apartments	Other
pre-1919	2,998,629	1,304,482	30,413
1919-1945	1,825,088	1,053,184	20,097
1946-1970	3,110,718	3,651,276	51,095
1971-1990	5,318,934	4,222,940	96,610
1991-2005	3,071,396	2,151,180	76,408
2006-2017	2,314,437	1,941,124	73,191
Total	18,639,201	14,324,187	347,813

Table 9: Italy Residential Buildings Distribution Based on Construction Year

	Num of Buildings
Total	12,187,698
Pre-1919	1,832,504
1919-1945	1,327,007
1946-1990	7,332,087
1990-2011	1,696,100

Table 10: Spain Residential Buildings Distribution Based on Construction Year

	Num of Buildings
pre-1920	955,857
1921-1940	490,702
1941-1980	8,285,333
1981-1990	2,242,375
1991-2001	2,598,718
2002-2011	2,955,555

Based on the available figures, there is a significant part of the national housing stock in all four countries that predates 1990, especially in France and Italy, which both saw post-WWII construction booms in the 1950s and 1960s.

2.1.4. New construction of dwellings

This section focuses on recent developments in the residential building sector. It highlights the number of newly constructed dwellings each year.

Table 11: Annual new dwelling additions in selected European Countries (2016-2021)

	Bulgaria	France	Italy	Spain
2016	9,342	345,500	81,600	45,000
2017	8,384	346,900	80,600	54,000
2018	8,136	360,400	83,100	64,000
2019	12,105	390,000	86,500	78,000
2020	15,415	357,300	82,500	87,000
2021	17,868	386,600	87,300	91,000

2.2. Energy consumption by the residential sector

This section presents the energy usage within the residential domain of the target countries. It aims to provide valuable insights into the energy consumption of dwellings, understand the main drivers of variations, and explore the different end-uses of energy in residential settings.

2.2.1. Final energy consumption by the residential sector and by use

The final energy consumption within the residential sector, focusing on the overall energy usage and its distribution across various end-uses.

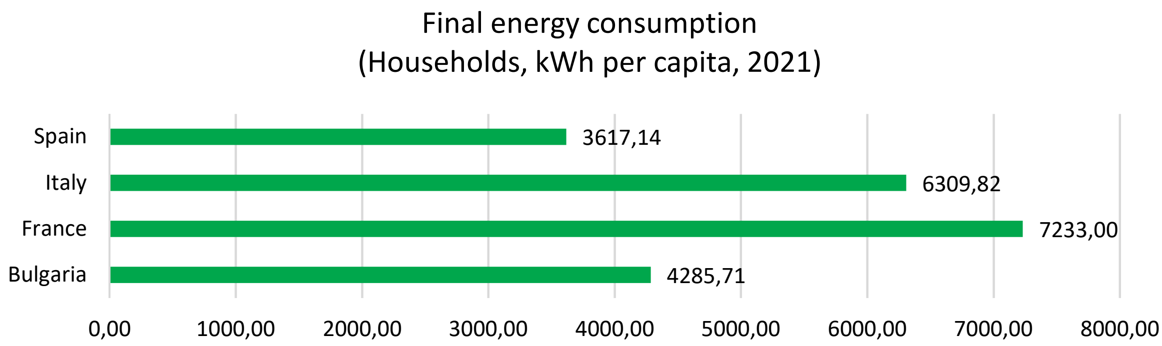

Figure 1. Final energy consumption by Household's Sector

In terms of assessing the final energy consumption of households, on a like-for-like per capita basis, we see that French and Italian households consume more than their Bulgarian and Spanish counterparts. However, while the data are on a per capita basis, a true like-for-like comparison is of course very difficult to develop. This is because other factors like climate, hours of sunlight, energy performance, and dwelling typology play an important role too.

Table 12: Final Energy Consumption by Households, Use Type, Per Capita Basis in Terajoules (2021)

	Bulgaria	France	Italy	Spain
Total	0.0154	0.0260	0.0227	0.0130
Space heating	0.0082	0.0179	0.0152	0.0052
Space cooling	0.0001	0.0001	0.0002	0.0001
Water heating	0.0027	0.0027	0.0026	0.0025

Cooking	0.0013	0.0013	0.0015	0.0010
Lighting and electrical appliances	0.0032	0.0041	0.0030	0.0041
Other end use	0.0000	0.0000	0.0003	0.0001

Table 13: Percentage of Households Unable to Keep Their Home Adequately Warm

Country	%
Bulgaria	23.7
France	6.0
Italy	8.1
Spain	14.2

The percentage of households unable to keep their homes adequately warm (i.e., the share of the population who declare they cannot afford to keep their homes at a suitable temperature) shows that almost a quarter of households in Bulgaria declare such a financial constraint. This suggests that some of Bulgaria's better performance may be self-enforced, e.g., some households are intentionally going without heat.

2.2.2. Main drivers of the energy consumption variation of households

This section presents the variation of energy consumption of the target countries between 2 deferent years.

Table 14: Comparing Energy Consumption Changes: Shifts in Target Countries' Patterns (2000 vs. 2018/2019)

(Mtoe)	Bulgaria	France	Italy	Spain
Consumption 2000	2.19	40.5	27.6	12.1
Climate	-0.07	0.1	-1.3	0
More dwellings	0.6	8.1	4.6	5.2
More appliances per dwellings		4.2	4.5	0.6
Larges homes	0.35	0.6	-0.5	
Energy savings	-0.44	-16.5	-4.5	-6.1
Others	0.13	2.8	1.5	3.2
Consumption 2018 (except France is 2019)	2.23	39.9	32	14.9

2.3. Retrofit Market

Retrofit Market introduces a significant aspect of the construction and energy sectors, focusing on the practice of retrofitting existing buildings to improve their energy efficiency and sustainability.

2.3.1. Building systems for energy efficiency in France

Various building systems and technologies promote energy efficiency in the context of France (Data of 2020). Understanding these systems allows stakeholders to assess the most effective retrofitting approaches.

The following tables provide information on the number of available and stocked dwellings that utilize the system, along with their respective percentages in each of France's zones, and the distribution of building types. For each system, the available types are listed with their corresponding percentages of use in the various zones across France.

- Insulation:

Table 15: Building Insulation Analysis: Distribution by Zone, Building Type, and Insulation Methods

Zone	Number of data	Total insulation	Type of building		Insulation post				
			Single-Family	Multi-Family	Low Floor	Attic Lost	Rampants	ITE	ITI
H1	2461	62.6%	93.3%	6.7%	5.6%	27.4%	21.9%	26.3%	18.8%
H2	1430	36.4%	99.8%	0.2%	9.0%	45.3%	11.2%	19.1%	15.4%
H3	38	1.0%	89.2%	10.8%	9.1%	42.4%	21.2%	15.2%	12.1%

- Ventilation:

Table 16: Ventilation Analysis: Exploring Building Types and Ventilation Methods by Zones

Zone	Number of data	Total ventilation	Type of building		Type of ventilation			
			Single-Family	Multi-Family	Simple flux	Hygro B	Hygro A	Double flux
H1	2461	65.2%	94.6%	5.4%	30.6%	40.3%	15.3%	13.9%
H2	1430	34.1%	100.0%	0.0%	19.0%	68.6%	7.6%	4.8%
H3	38	0.7%	100.0%	0.0%	0.0%	40.0%	60.0%	0.0%

- Heating:

Table 17: Heating: Investigating Building Types, Heating Sources, and Generator Types by Zones

Zone	Number of data	Total heating	Type of building		Heating source before renovation					Heating source after renovation				
			Single-Family	Multi-Family	Wood	Electricity	Oil	Gas	Other	Wood	Electricity	Oil	Gas	Other
H1	1132	43.4%	92.6%	7.4%	10.4%	20.8%	30.4%	35.8%	2.5%	46.4%	9.2%	8.5%	35.9%	0.0%
H2	1424	54.6%	99.8%	0.2%	3.8%	61.5%	11.5%	15.4%	7.7%	78.2%	5.5%	0.8%	15.5%	0.0%
H3	50	1.9%	93.9%	6.1%	0.0%	64.3%	14.3%	21.4%	0.0%	84.0%	10.0%	0.0%	6.0%	0.0%

Type of heating generator	Percentage
Boiler	38.2%
Stove	49.9%
Pac	10.4%
Other	1.4%

Type of boiler generator	Percentage
Standard	4.50%
In condensation	63%
Air-Water	12.10%
Air-Air	9.70%
HPE	5.60%
Other	5.10%

- Domestic Hot water:

Table 18: Domestic Hot Water Analysis: Exploring Building Types and Domestic Hot Water Types by Zones

<table>
<tr><th rowspan="2">Zone</th><th rowspan="2">Number of data</th><th rowspan="2">Total heating</th><th colspan="4">Type of domestic hot water</th></tr>
<tr><th>Classic</th><th>CETI</th><th>CESI</th><th>SSC</th></tr>
<tr><td>H1</td><td>74</td><td>19.9%</td><td rowspan="3">1.4%</td><td rowspan="3">21.1%</td><td rowspan="3">68.4%</td><td rowspan="3">9.1%</td></tr>
<tr><td>H2</td><td>291</td><td>78.4%</td></tr>
<tr><td>H3</td><td>6</td><td>1.6%</td></tr>
</table>

2.3.2. Classification of Building Energy Consumption

Different buildings have varying energy needs based on their size, function, location, and occupant behavior. Categorizing buildings based on their energy consumption and the location countries is examined, while each country has its energy classification.

- France:

Table 19: France's energy classification of 2020

Energy Classification	Percentage
A	5.6%
B	7.8%
C	14.2%
D	30.4%
E	25.7%
F	11.6%
G	4.7%

- Italy:

Table 20: Italy's Energy Classification of 2021

Energy Classification	Percentage
A1	2.20%
A2	1.40%
A3	1.20%
A4	0.30%
B	1.40%
C	2.30%
D	14.00%
E	24.00%
F	29.60%
G	23.50%

- Spain:

Table 21: Spain Energy Classification of 2021

Energy Classification	Percentage
A	0.00%
B	1.00%
C	4.00%
D	11.00%
E	52.00%
F	11.00%
G	21.00%

- Bulgaria:

Table 22: Bulgaria Energy Classification of 2010

GHG Classification	Percentage
A	0.0%

B	0.0%
C	1.0%
D	8.0%
E	39.0%
F	34.0%
G	18.0%

2.3.3. Cost of renovation

This section explores the financial aspect of retrofitting buildings, focusing on the cost associated with systems. Understanding the cost implications of retrofitting is crucial for decision-makers and building owners, as it helps them evaluate the return on investment and assess the feasibility of implementing energy efficiency measures.

Table 23: Cost Analysis of Building Retrofitting: Evaluating Investment for Energy Systems

	Windows (Base = 2015)					Doors (Base = 2015)	Facade (Base = 2014)		Roof		Attic		Basement		Ground plate	Solar shading (Base = 2015)
	Single glazing	Double glazing	Double glazing with solar protection	Triple glazing	Triple glazing with solar protection	Average	Fixed costs	Variable costs	Fixed costs	Variable costs	Fixed costs	Variable costs	Fixed costs	Variable costs	Fixed costs	Average costs
	EUR/m²	EUR/m²	EUR/m²	EUR/m²	EUR/m²	EUR/m²	EUR/m²	EUR/m²cm	EUR/m²	EUR/m²cm	EUR/m²	EUR/m²cm	EUR/m²	EUR/m²cm	EUR/m²	EUR/m²
Bulgaria	60	117	130	171	241	379	25	0.57	49	0.51	7	0.54	12	0.43	11.70	267
France	195	283	308	350	469	1,087	71	1.64	142	1.47	21	1.56	34	1.23	33.56	765
Italy	164	246	268	311	420	696	46	1.05	91	0.94	14	1.00	21	0.79	21.50	490
Spain	137	211	231	273	370	675	44	1.02	88	0.91	13	0.97	21	0.76	20.84	475

	Cooling systems (Base = 2018_						Photovoltaics (Base = 2018)			
	Centralised chiller (whole building, replacement)	Centralised chillers (whole building, new installation)	Centralised multi-split system (whole building)	Centralised multi-split system (for appartment)	Mounted single-split/window AC	Movable AC systems	0-10 kWp	10-15 kWp	15-20 kWp	>20 kWp
	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR
Bulgaria	60,755	537,560	28,019	8,626	1,221	379	1,904	1,997	2,091	2,184
France	72,530	574,329	28,607	9,214	1,809	379	2,356	2,385	2,413	2,442
Italy	76,486	573,644	31,053	9,721	1,575	417	2,273	2,350	2,427	2,504
Spain	85,386	640,393	29,650	9,287	1,512	398	2,176	2,249	2,322	2,394

	Space heaters (base = 2015)	Other heat emitters than radiators	Radiators	Ventilation		Domestic hot water systems		Lighting
	Average	Average	Average	Central	Local	Central	Decentral	Average
	EUR	EUR/m²	EUR	EUR/m²	EUR	EUR	EUR	EUR/m²
Bulgaria	4,232	12	154	13	557	2,206	821	6
France	9,074	34	392	37	1,989	3,332	1,084	16
Italy	4,968	22	229	23	288	1,364	165	10
Spain	5,289	21	137	23	291	1,525	287	10

3. Economic and Regulatory Context and Smart Grids Interaction Rules

This part serves as a review of current guidelines, incentives, and opportunities related to energy retrofit practices and smart grids within the European Union and the four project target countries. The main objective of this task is to remain up to date with the regulations and changes throughout the project's duration. This deliverable will only focus on reviewing some regulatory and economic aspects at the EU and national levels, alongside identifying smart grid initiatives and opportunities. More detailed information, analysis, identification of gaps, areas of alignment, and propositions of the amendments will be presented in future deliverables.

3.1. Retrofit Practices Guidelines and Regulations

The building sector account for over one-third of total worldwide final energy consumption and a quarter of global energy-related emissions are attributed to the building sector [1]. Therefore, it is crucial to re-evaluate buildings' energy and environmental performances for all energy applications[2]. Energy is used for various purposes in buildings, including HVAC systems, service water heating, lighting, and household electric and electronic appliances.[3] However, older existing buildings tend to be less efficient than new ones [4]. For this purpose, buildings' energy retrofitting is considered a key measure to reduce global worldwide energy consumption [5]. It offers significant potential to improve building energy performance by reducing end-use consumption, ensuring higher comfort levels, saving costs, and mitigating greenhouse gas emissions[2]. Recent energy retrofit projects benefit from technological advancements, innovative building techniques, and affordable cost-effective renovation solutions that incorporate energy efficiency and renewable energy sources[6]. Various regulations and guidelines have been put in place to facilitate retrofit practices in the building sector[7]. The following table presents some types of these guidelines.

Table 24.Energy Retrofit Guideline Types

Guidelines	Definition
Energy performance standards	Governments set energy performance standards that buildings must meet after retrofitting. These standards specify the required energy efficiency or desired reduction levels in energy consumption.[8]
Building codes and permits	Building codes incorporate energy-efficiency measures and technologies to apply to meet energy performance standards[9]. While permits are necessary for energy retrofit projects to ensure that the retrofits adhere to safety, environmental, and energy efficiency standards.[10]
Energy audit and monitoring	Some regulations mandate energy audits before retrofit to identify the savings potential and adequate practices to apply. While monitoring activities are for after retrofit to assess the building's energy performance and retrofit measures' effectiveness.[11,12]

Mandatory Disclosure	In certain countries, building owners are required to disclose the energy performance or consumption of their properties to potential renters or buyers. This is usually done through mandatory disclosure in the form of Building Energy Performance Certificates.[13]
Binding targets	Governments frequently set targets for enhancing energy efficiency in the building sector as time progresses.[14] These objectives instill a sense of urgency and foster long-term strategizing motivating stakeholders to adopt energy retrofit measures in order to achieve the desired outcomes.

3.1.1. Guidelines and regulations at the European level

Building energy retrofit is a key element in Europe's commitment to climate mitigation and sustainability promotion[15]. To attend this objective, the European Union set ambitious binding targets, strong strategy and guidelines aimed at reducing the energy consumption of both existing and new buildings and minimizing their environmental impact[14].

At the core of the EU's strategy lies the **Energy Performance of Buildings Directive** (EPBD), revised in 2018, it mandates all member states to adopt measures that promote energy performance for both existing and new buildings. For retrofit ,the EPBD set minimum energy performance standards with a consideration to systems upgrades or renewable energy sources [16]. One of the targets set by EPBD related to the European Green Deal's "Renovation Wave" strategy is to double the annual energy renovation rate of buildings by 2030 from 1% to 2% of the building stock[17]. Furthermore, the EPBD set out that and all new public buildings had to be Nearly Zero Energy Building (NZEB) and all new buildings must meet the NZEB standards after 2020[18].

The **Energy Efficiency Directive** (EED), alongside the EPBD, plays a key role in guiding retrofit practices. Amended in 2018, it promotes energy efficiency in various sectors, aiming to achieve a binding target of at least 32.5% energy consumption reduction by 2030. The building sector is a key focus of EED, it encourages member states to enhance energy performance through renovation practices, including adopting energy-efficient technologies, improving envelope insulation, implementing renewable energy systems, and utilizing smart technologies. By prioritizing energy retrofitting, the EED strive to decrease overall energy consumption and greenhouse gas emission from buildings[19].

The EU's **Renewable Energy Directive** (RED) supports building energy retrofit by promoting renewable energy sources in buildings to reduce fossil fuel reliance. It targets 32% of the EU's total energy consumption from renewable sources by 2030, encouraging their integration into retrofitted buildings for heating, cooling and electricity. RED fosters self-consumption models, where energy-efficient buildings generate their own renewable energy, aligning with NZEBs and a decentralized energy production approach. Strict sustainability standards for bioenergy ensure environmentally friendly retrofit practices, making RED a potential catalyst for extensive energy renovation efforts to achieve EU climate neutrality by 2050, reinforcing the European Green Deal's ambition[20].

Introduced in 2020 as a core component of the European Green Deal, the EU's **Circular Economy Action Plan** aims to promote sustainable production and consumption patterns for a cleaner and more competitive Europe[21]. Emphasizing the closure of product lifecycles, this approach has notable implications for building retrofit practices. In addition to improving energy efficiency, retrofitting focuses on employing sustainable materials that can be repurposed and recycled at the end of their lifecycle. For instance, the plan encourages circular management of construction and demolition waste, which accounts for approximately one-third of all waste in the EU, by promoting recycling and minimizing landfill use[22].The EU's **Eco-Design Directive** showcases its commitment to environmental sustainability, aiming to promote the energy efficiency and environmental performance of products throughout their lifecycle. For retrofit projects, selecting energy-efficient systems and products is crucial, and this directive plays a key role by setting mandatory ecological requirements in line with the EU's energy consumption reduction and circular economy objectives. Moreover, in alignment with the European Green Deal's goals, the directive encourages the adoption of energy-efficient solutions in retrofit projects to facilitate the transformation of the building sector and decrease overall greenhouse gas emissions[23].

3.1.2. Guidelines and regulations at countries level

Country-level regulations and guidelines are crucial in promoting energy efficiency across the EU, addressing environmental, architectural, and socioeconomic aspects in each member state. Local entities ensure energy retrofit practices adhere to these regulations, aligning with the directives and ambitious energy transition targets set by the EU. These national-level efforts bring these objectives to life and make a meaningful impact. Within the context of the RE-SKIN project, we will present a summary of regulations and guidelines specific to energy retrofit practices in Italy, Bulgaria, France, and Spain in the following sections.

3.1.2.1. Guidelines and regulations in Italy

Italy is actively progressing towards the EU's targets, focusing on achieving NZEBs standards[24]. To support energy efficiency and sustainability in building sector, Italy has implemented a comprehensive set of regulations and guidelines[25]. The primary framework for achieving these goals is the National Energy Strategy (Strategia Energetica Nazionale or SEN), introduced in 2017. This strategy aims to reduce overall energy consumption by 30% and enhance energy efficiency by 10% in the building industry. Moreover, it sets targets to increase renewable energy's share to 28% of total energy usage and 55% of electricity usage by 2030, encompassing the building sector[26]. Italy has established energy regulations at both national and municipal levels. Municipal regulations, such as the Regolamento Edilizio, is crucial in promoting energy retrofitting and considering regional characteristics. It provides guidelines for building permits, covering various requirements like minimum unit size, gross floor area (GFA), and garage and ceiling dimensions. Italian municipalities have been updating their Building Regulations over the past two decades to align with urban planning and EU energy efficiency policies[27].

3.1.2.2. Guidelines and regulations in France

In the French context, energy retrofit practices are governed by the Energy Transition Law for Green Growth and Environmental Regulation RE2020. In 2015 this Law has set targets to reduce greenhouse gas emissions by 75% by 2050, with a focus on buildings' energy efficiency improvement. Another objective is reducing final energy consumption by 50% by 2050, with an intermediate target of 20% reduction by 2030[28]. The legislation also emphasizes renovating 500,000 buildings annually for better energy efficiency, showcasing France's commitment to extensive retrofitting initiatives[29].The RE2020 building code is dedicated to new buildings, mandating adherence to Nearly Zero-Energy Building standards. It emphasizes bio-sourced materials and reducing energy consumption during the building's life cycle, including operational and embodied energy. While for new constructions, it indirectly influences retrofit practices by encouraging energy-efficient and low-carbon technologies, aligning with France's energy efficiency targets[30]. Additionally, the Energy Performance Diagnosis (DPE) is a mandatory disclosure in France for properties being sold or rented, promoting transparency and efficiency through a thorough energy usage assessment[31].

3.1.2.3. Guidelines and regulations in Spain

Spain's regulatory framework for energy efficiency and sustainability in the building sector centers on energy retrofit practices. The Technical Building Code (CTE) revised in 2019 is a key regulation driving the adoption of retrofits, comprising the Basic Document of Energy Saving (DB-HE) and Basic Document of Health (DB-HS). The DB-HE outlines specific criteria for limiting energy demand, improving energy efficiency in installations and lighting, and utilizing solar energy for hot water and electricity. Following the DB-HE's guidelines, retrofit measures can include efficient insulation, reduced thermal bridges, double-glazed windows, and materials enhancing thermal mass, aligning existing buildings with new construction's energy performance standards under the CTE[32]. Under Royal Decree 235/2013, the Spanish government introduced the Energy Performance of Buildings Certificate (EPB) for existing and new buildings[33]. Royal Decree 56/2016 further supports retrofitting practices by promoting energy audits and emphasizing energy management systems[34], highlighting Spain's commitment to sustainability and advancing energy retrofit goals.

3.1.2.4. Guidelines and regulations in Bulgaria

In Bulgaria, energy efficiency regulations for buildings, drawn from the EU Energy Performance of Buildings Directive, set minimum energy standards for new and majorly renovated properties. These regulations also require the issuance of Energy Performance Certificates (EPCs) for construction, sale, or leasing, ensuring an assessment of the building's energy performance. Regular inspections of heating, cooling, and ventilation systems are compulsory. Notably, the Bulgarian government has set parameters for Nearly Zero-Energy Buildings (NZEB), prioritizing public buildings, and devised a long-term renovation strategy targeting energy efficiency and decarbonization by 2050, in line with the broader aims of the Energy Efficiency Act (EEA).[35,36]

3.2. Economic Retrofit Subsides and Grants

The European Union offers incentives to promote sustainability, energy efficiency, and climate action. The Horizon Europe initiative, with a budget of 95.5 billion dollars from 2021 to 2027, aims to support research and innovation for sustainable economic growth and job creation[37]. It promotes enhancing building energy efficiency through design, construction, and retrofitting projects, aligning with the European Green Deal and other strategies. Moreover, the program encourages international collaboration among member states to share best practices and work towards common goals[38]. The EU's LIFE program, similar to Europe Horizon, runs from 2021 to 2027 with a budget of $5.4 billion, supporting projects focused on environmental protection, climate change mitigation, and EU climate policies. It particularly benefits energy retrofit initiatives, promoting a transition to a resource-efficient, low-emissions economy. The program aids projects related to energy efficiency, renewable energy usage, and infrastructure improvement[39].The Energy Efficiency Directive (EED) is another regulatory incentive that encourages energy retrofit practices by facilitating financing facilities and creating a demand for energy retrofit projects. It supports SMEs in implementing energy efficiency measures and mandates central governments to purchase only highly energy-efficient goods, services, and buildings[19]. EU also provides tax incentives, like reduced VAT rates and tax credits, to encourage energy efficiency and energy retrofit practices. These incentives vary among EU countries. Additionally, the EU promotes information exchange, training, and procurement to encourage environmentally friendly practices in businesses[40].

3.3. Smart grids Initiatives and strategies

Smart grids are a transformative innovation in the energy sector, enabling real-time monitoring and informed energy consumption decisions. They enhance demand and supply efficiency, integrate renewable energy sources, and reduce wastage[41]. Implementing smart grids in retrofit projects is crucial as they offer valuable insights for targeted interventions, reduce grid dependency, lower energy costs, and enhance the economic viability of energy retrofit projects.[42]

In 2009, the Commission established a task force to accelerate the deployment of smart grids in the European Union. The task force comprises five expert groups addressing smart grid standards, cybersecurity, privacy, and data protection. Expert Group 1 ensures the compatibility of smart grid systems and technologies, leading to updated technical standards. Expert Group 2 focuses on privacy and security in smart metering systems in line with the General Data Protection Regulation. Expert Group 3 facilitates demand side flexibility in the EU, crucial for smart grid deployment. Expert Groups 4 and 5 concentrate on smart grid infrastructure deployment and industrial policy implementation, respectively[43].

The European Union adopted the "Third Energy Package" in 2009 to promote the liberalization of gas and electricity markets. The package contained measures that encourage the use of smart grids. One important measure required 80% of electricity consumers to have smart meters by 2020. These meters are the devices that enable real-time monitoring of energy usage, promoting energy efficiency and accurate billing. For the actual Update, only the gas part of the third energy package rules from 2009 is still in force[44].

“Bridge” is an initiative launched by the European Commission in 2016 under Horizon 2020 and Horizon Europe. It aims to address interconnected energy concerns by bringing together projects focused on smart grids, energy storage, islands, and digitalization. As of 2021, Bridge has financed a total of 93 projects, of which 58 are still ongoing. The investment has exceeded 1 billion dollars, with 860 million dollars coming from EU support. These projects have involved approximately 1000 organizations from 40 different countries [45].

The "European Technology and Innovation Platform Smart Networks for Energy Transition (ETIP SNET)" is a significant initiative established in 2016. It recommends research and innovation initiatives for the EU's energy transition, identifying policy and funding obstacles in the energy sector. ETIP SNET envisions smart energy networks, involves stakeholders, and provides guidance. The ETIP SNET R&I Roadmap 2022-2031 serves as a blueprint for fully decarbonizing the European energy system by 2050, developed with input from over 350 energy experts representing EU stakeholders[45].

The European Union is actively promoting smart grids in the building sector through various initiatives. These efforts focus on optimizing energy consumption, reducing carbon emissions, and improving sustainability.

4. Technological and Performance Benchmarking Process

4.1. State-of-the-art in building integrated energy systems based on literature review

4.1.1. Background and objective

This task's objective was to establish a comparative analysis of the expected technological characteristics and key energy performance parameters of the proposed retrofit package, both with standard retrofit solutions and with future retrofit best practice. This data will then be compared with the controlled data from the demonstration cases, to assess the real cost-effectiveness of the RE-SKIN renovation package.

4.1.2. Solar photovoltaic systems

When it comes to solar energy, buildings need both heat and electricity, and both can be supplied by solar systems. The following figure illustrates the different solar systems, depending on the technology used and the energy produced (**Errore. L'origine riferimento non è stata trovata.**).

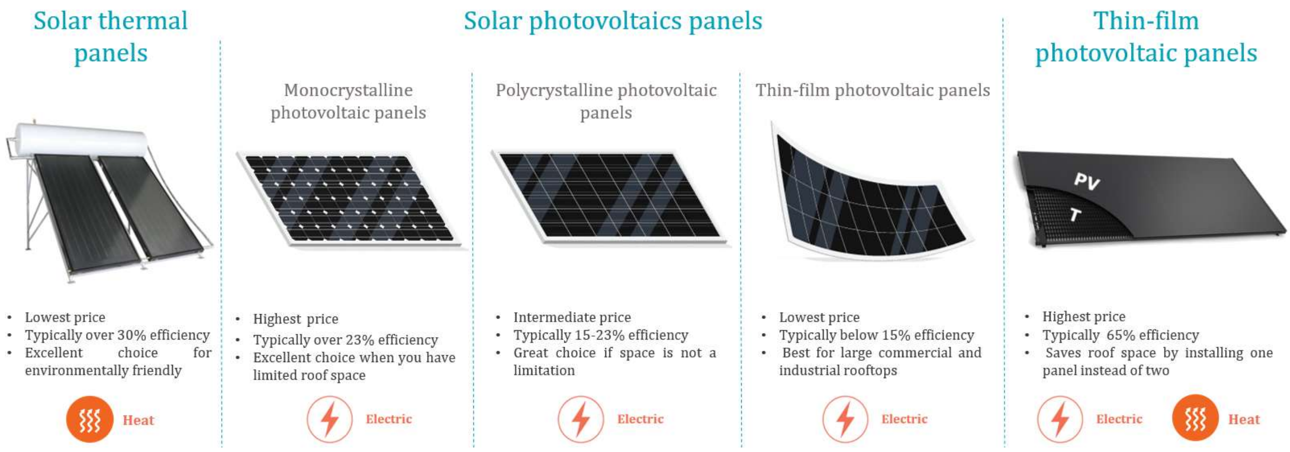

Figure 2. Various solar systems

One of the most common types used is represented by the Photovoltaic Thermal collectors (PVT) systems since they combine the advantages of photovoltaic cells and solar thermal collector into a single system (also used in RE-SKIN project). PVT systems produce both thermal and electrical energy at a lower cost than using separate PV and thermal collectors. They can be used in district heating, drying, desalination, and energy generation for buildings. Furthermore, standalone solar energy systems incorporate PVT with seasonal energy storage, especially valuable in areas without viable grid connections or where energy sales aren't financially competitive.

4.1.3. Solar-assisted DC Heat Pump

By design, the heat pump enables heat to be transported from a cold environment to a warm environment and vice versa. In addition, it is an energy-saving device, consuming little energy in relation to that which it releases based on its thermodynamic mechanisms of refrigerant evaporation, condensation, compression and expansion over a closed cycle. Heat pump performance depends mainly on evaporator source temperature, while solar energy can thermally assist heat pumps by raising evaporator temperature with solar thermal collector. We can identify between two main types: solar-assisted direct-expansion heat pumps and solar-assisted indirect-expansion heat pumps. In direct systems, the solar collector and the heat pump are combined into a single unit and the refrigerant circulates through the solar collector. In this way, they generate heat from the air or sun using an open or insulated collector-evaporator. In this context, these systems can be classified as direct expansion solar-air serial heat pump (**Errore. L'origine riferimento non è stata trovata.**a), direct expansion solar-air dual source heat pump (**Errore. L'origine riferimento non è stata trovata.**b) and direct expansion solar-air parallel heat pump (**Errore. L'origine riferimento non è stata trovata.**c).

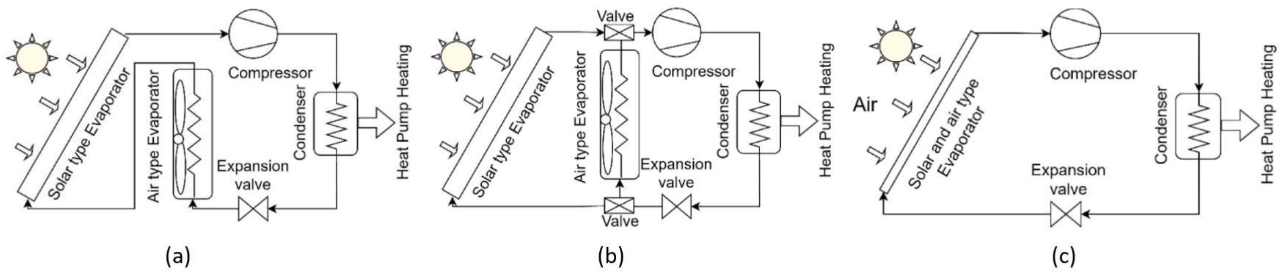

Figure 3. Illustration of Solar-assisted Direct Expansion Heat Pump Types

However, in indirect systems, the solar energy absorbed by the solar thermal collector is transferred to a heat transfer fluid, usually an antifreeze water solution and then the thermal energy is used for heating space directly or serving as heat source for heat pump. In this case, the solar heat transfer fluid cycle and the heat pump refrigerant cycle are separate, each cycle can meet the heating demand independently on ambient conditions. This system can be divided into three types - series, parallel and dual source - depending on their configuration to meet the heating demand, as shown in **Errore. L'origine riferimento non è stata trovata.**.

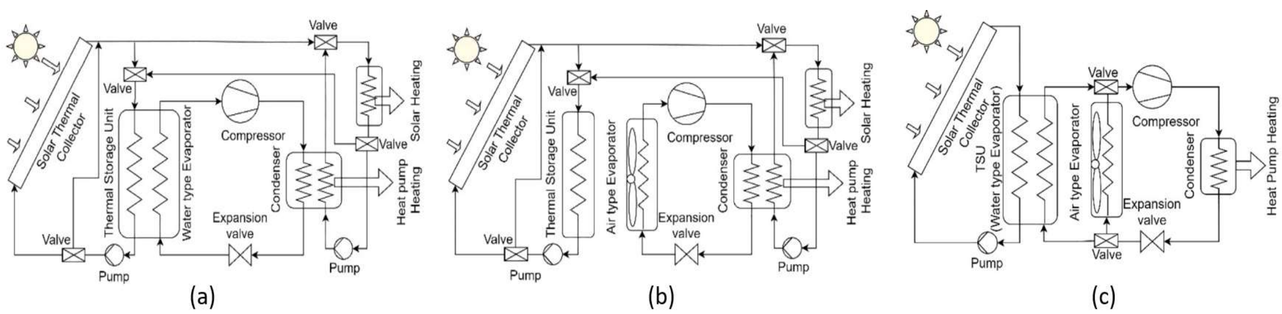

Figure 4. Illustration of Solar-assisted Indirect Expansion Heat Pump Types

Unlike solar panels, photovoltaic panels do not use light to generate heat, but rather electricity. Consequently, based on the same principle as solar-assisted direct expansion heat pumps, direct expansion photovoltaic-thermal collectors are installed instead of the heat pump evaporator. Photovoltaic cells installed on the collector generate electricity, while cooling pipes attached to the back of the photovoltaic cells with the collector plate absorb the photovoltaic cells' heat. In this way, excess heat from the evaporator-collector helps the heat pump as a high temperature heat source, while the electricity produced by the photovoltaic cells feeds the compressor's power input. furthermore, depending on the type of solar-assisted indirect expansion heat pump, the heat output may be used either for direct space heating or as a heat source for the evaporator. However, such systems require the use of insulated photovoltaic panels to reach high temperatures.

4.1.4. Battery storage systems

One of the main shortcomings of renewable energies is the difficulty of matching supply to demand. In fact, the sun doesn't always shine when the community needs electricity during peak periods. One of the best ways of stabilizing the power grid and providing a more regular supply is to use storage systems, namely electrochemical batteries, buildings can shift their electricity consumption from day to night. In addition to lower electricity tariffs, storage also reduces peak consumption. This type of battery is an energy storage system based on a chemical reaction, with two electrodes immersed in a liquid called electrolyte. Figure 5 illustrates the different electrochemical battery systems with their description and examples available on the market.

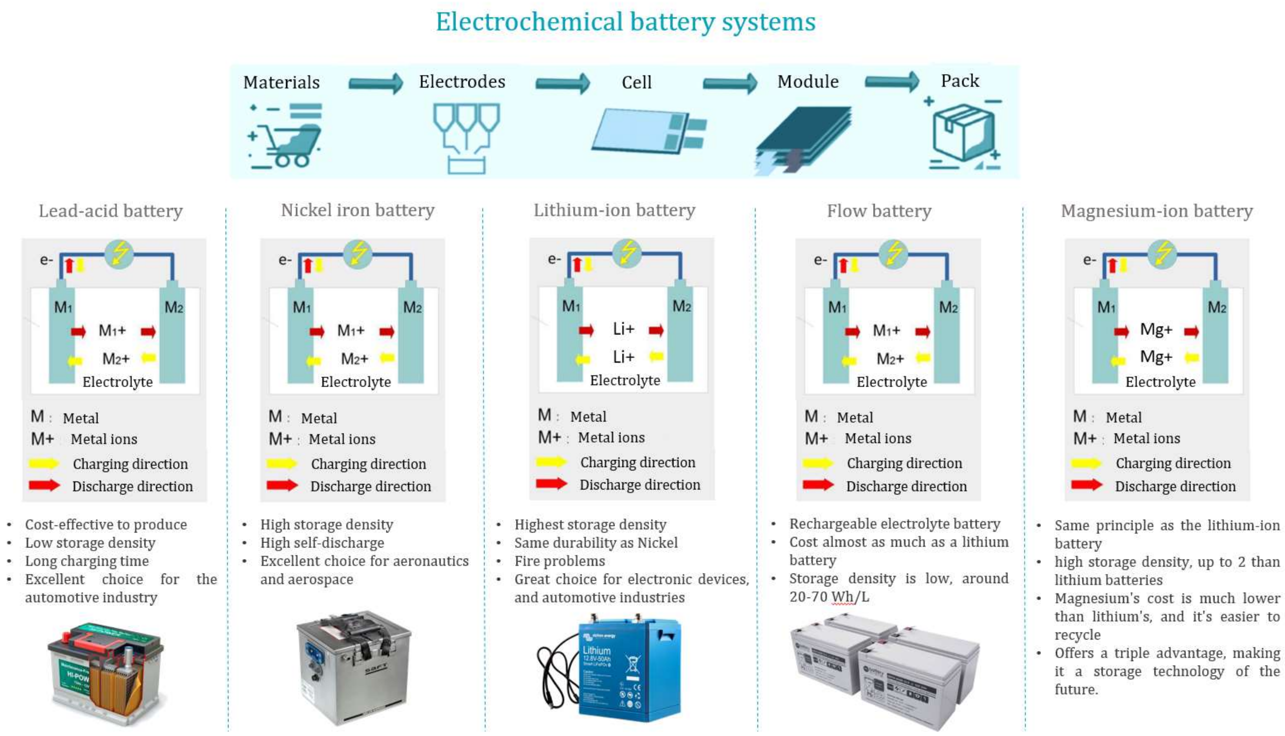

Figure 5. Various Electrochemical Batteries Systems

4.1.5. HVAC systems

The HVAC system (heating, ventilation and air conditioning) is an all-in-one system installed inside a building to ensure good air quality, healthy air flows and occupant comfort by ensuring that air circulates inside and is exhausted outside the building. Therefore, the choice of heating systems is important in terms of energy efficiency and the financial burden on a particular budget. To this end, the following figure illustrates the different centralised and decentralised heating systems and water heating depending on the different energy sources to be used.

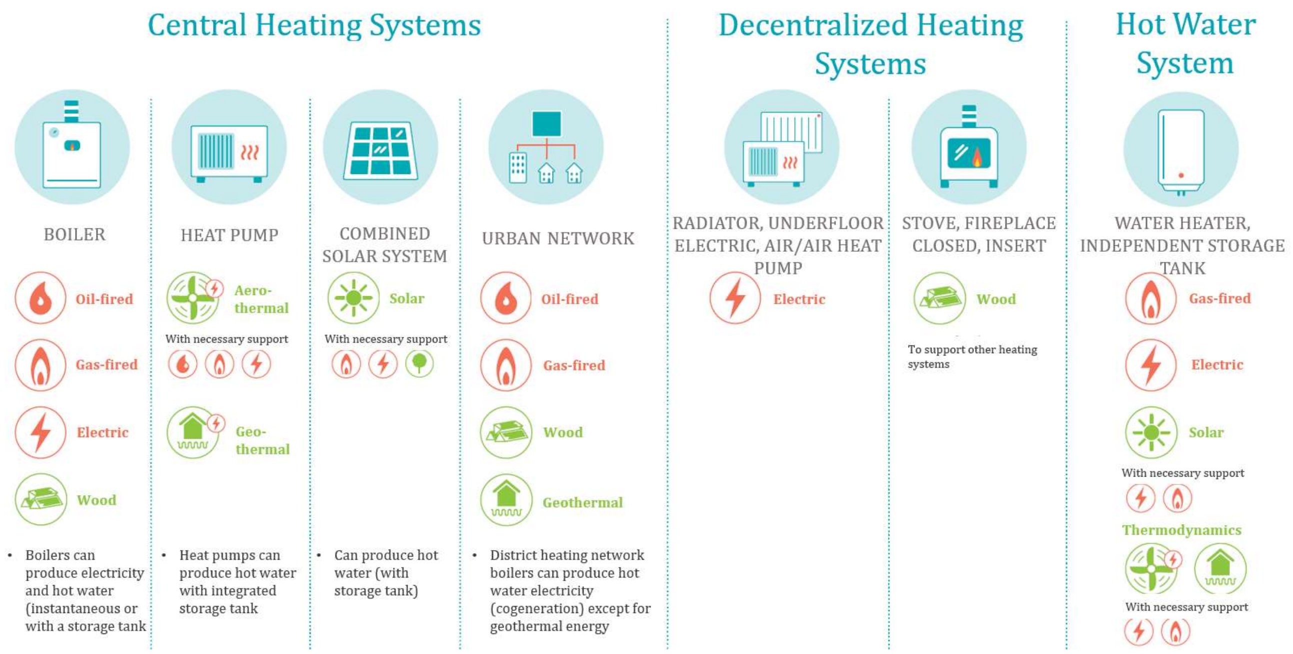

Figure 6. Different Heating and Water Heating Systems

In addition, air conditioning systems can be distinguished according to the nature of the refrigerant and heat transfer fluid used, the centralized or decentralized refrigerant preparation method and also the nature of the environment to be treated, whether it has several zones or a single zone. Figure 7 illustrates the various air-conditioning systems available, according to their utilization mode.

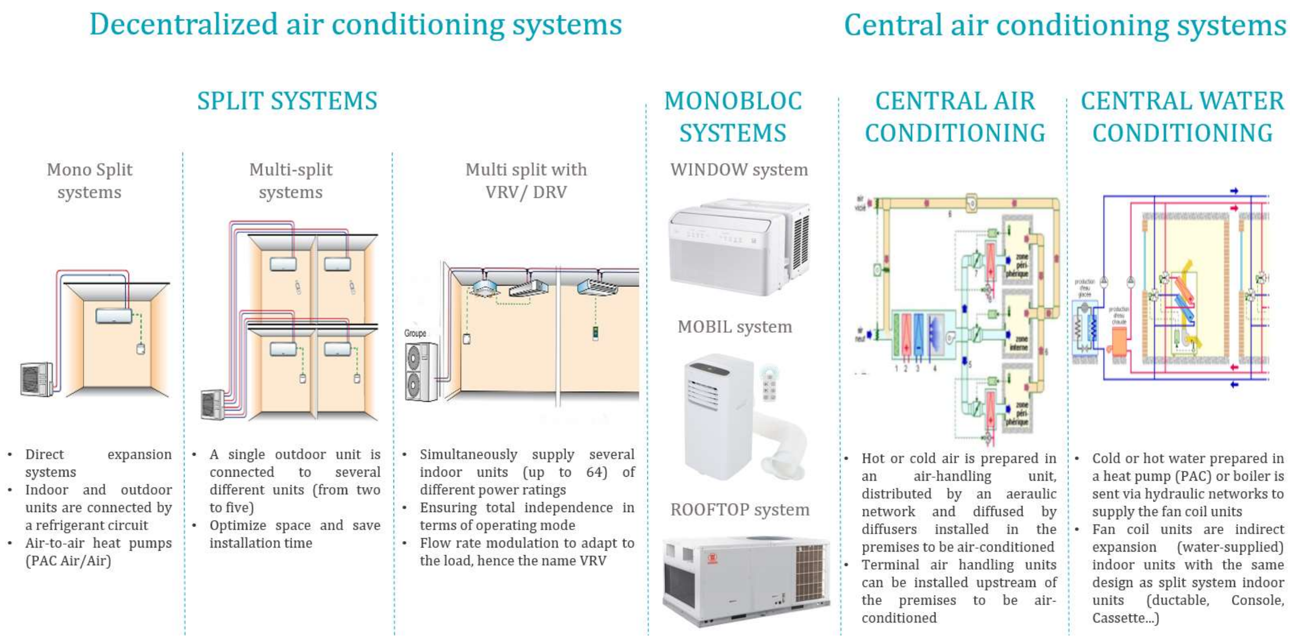

Figure 7. Different air-conditioning systems.

4.1.6. Building automation systems

Building automation and control systems (BACS) include all the products, software and engineering services required to support the energy-efficient, cost-effective and safe operation of building services systems, by means of automatic controls and by facilitating the manual management of these building services systems (**Errore. L'origine riferimento non è stata trovata.** 8). These are centralized control systems for technical systems.

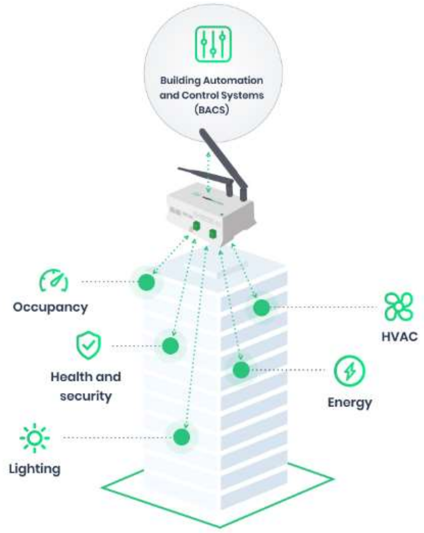

Figure 8. Building Automation and Control Systems (BACS)

4.2. Comparison with the state of the art: standard renovation solutions and the upcoming best retrofit practices

State of the art	RE-SKIN
BIPVT systems	
• Intermittency in the production of photovoltaic panels. • Climate and location dependency. • Photovoltaic panels are expensive custom-made elements or custom-framed panels. • Photovoltaic panels require a large surface area to ensure good energy production. • Photovoltaic panels are installed close to the roof's thermal insulation, which causes the panels to overheat.	The system of photovoltaic panels that will be used in the RE-SKIN project represent improvements on a previous project carried out by the ZH and POLIMI partners, including reconditioned photovoltaic panels manufactured by RINOVA. These panels will be made from recycled aluminum profiles, which guarantee waterproofing and facilitate the use of different-sized components with different characteristics, thus avoiding the need for a customized design. In addition, the structure will include a layer of bio-sourced insulation. Moreover, the system can generate electricity and thermal energy.
Solar-assisted DC Heat Pump	
• Heat pumps can cause noise pollution (decibels are very low, equivalent to a refrigerator in operation). • Regular maintenance. • Conversion losses and additional system complexity.	The direct current from the panels will feed directly into the heat pump, avoiding conversion to alternating current, thus increasing the efficiency of the system. The air heat exchanger will be of the ducted type, with the possibility of an air intake in the cavity of the hybrid solar roof: during heating modes, whenever the air from the hybrid roof is warmer than the outside air, it will be sent to the evaporator, increasing the coefficient of performance.
Battery storage systems	
• Battery systems require regular maintenance, otherwise they can simply fail over time, requiring reinstallation from scratch. • Batteries very expensive to buy and to run every year, to ensure your own energy autonomy.	As part of the RE-SKINproject, the recycling of batteries is included, in particular the reuse of electric vehicle batteries that are no longer suitable for the automotive sector but are still effective for the building sector. An intelligent charger for electric vehicles will also be integrated into the RE-SKIN system, with a direct current charging and control unit

• Contain hazardous chemicals, making them more dangerous in the event of an accident. • Few intelligent charging systems have been developed, with the ability to manage the charging process according to the hourly energy rate, the availability of renewable energies and the needs of the user.	integrated into the MIMO converter, and an associated charging station to be installed close to the building. Using the capabilities of the RE-SKIN cloud platform, the system will define the best charging profile, considering several factors, such as the available photovoltaic power, the building's electrical load, the energy tariff
HVAC systems	
• In central air-conditioning systems, fan coil units generally operate on alternating current and require a high-water temperature in heating mode and a low water temperature in cooling mode. • Considerable losses on the distribution system, particularly in older buildings, with a high risk of condensation during cooling due to inadequate pipe insulation, reduced production efficiency for heat pump coupling. • Units may be difficult to access for maintenance and repair. This can lead to higher maintenance labor costs.	Based on the results of HEART, previous H2020 project, RE-SKIN's intelligent fan coil represents a revolutionary technology for the following reasons: it integrates a direct-current compressor to increase the thermal output from the centralized direct-current heat pump, according to the energy demand of each room. As a result, heat loss from existing distribution pipes is minimized, and condensation in cooling mode is avoided; Condensation can be drained directly into existing heat distribution pipes, avoiding the need to connect units to the building's drainage system. units to the building's drainage system.
Building automation systems	
• Control and monitoring systems often focus on a single building system, such as a heating system, or a small subset of systems. • Interfaces to these systems are based on proprietary solutions that are not easy to use for building owners, and therefore make it difficult to keep track of the performance of all the systems.	The chosen RE-SKIN project's intelligent control system will function as a single control and monitoring layer for all building systems, independently of the manufacturer or protocol. Technically inexperienced users will be able to access several aids as a voice control and the check of the current status and history of each subsystem. In addition, automated processes will continuously check for dysfunctions, unexpected events, and alerts.

5. Site Risk Assessment

5.1. State-of-the-art on multi-hazard and multi-risk assessment

The field of risk assessment is rapidly growing with contributors from many natural and social sciences areas recognizing worldwide *Risk* as function of [47]: 1) *Hazard* (process/ phenomenon/ human activity that may cause impacts in terms of potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time), 2) *Exposure* (the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social or cultural assets in places that could be adversely affected, 3) *Vulnerability* (conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, asset or system to the impacts of hazards) and 4) *Coping Capacity or Resilience* (ability of people, organizations and systems, using available skills and resources, to manage adverse risk conditions)[48]. Nowadays, considering the complex conditions of many territories exposed to and affected by a number of different types of risks (i.e., Natural and climate related, Technological, Na-Tech)[49], the risk assessment requires a multi-risk analysis approach that could account for the possible interactions among the multiple threats (*multi-hazard*), including cascading events and interactions at the vulnerability level (*multi-vulnerability*). Even if the relevance for adopting this kind of approach emerges from international organizations at a range of spatial scales, including the European level [50,48] (Sendai Framework 2015-2030), performing quantitative multi-risk assessment using the methodologies available today presents many challenges[51, 52, 53]. Actually, current approaches are more focused on the qualitative assessment of the multi-risk with detailed analysis of natural hazard conditions and related interactions[54]. Moreover, direct and indirect damage are not estimated taking into account a multi-vulnerability analysis[51] with regard to both *physical vulnerability* of the element exposed to all hazards and *functional vulnerability* that is not necessarily only the outcome of physical disruption, but it may also occur as a result of extended power or telecommunication outages that may affect external lifelines on which assets rely for their functioning (*systemic vulnerability*). Damage to lifelines, vital services, may affect the functionality in many ways, due to power or telecommunication outages, or impeding the workforce from reaching the site for ordinary or extraordinary operations particularly in case of extreme events. Therefore, the problem of assessing multi-risks cannot be limited to the facility itself and its immediate surroundings; it must instead comprehensively consider the geographic area where it is located. A territorial perspective must be therefore adopted, considering risks at the relevant spatial scale to capture the interconnection between different territorial assets, other critical infrastructures, and environmental conditions. Finally, the multi-risk assessment requires a huge amount of data to be collected, analysed and aggregated in order to provide a rigorous multi-risk information at the different territorial levels[55]. Starting from the emerging current lacks, an analytical methodology must be proposed to assess multi-risk conditions - by a multi-dimensional and systemic approach – considering not only the level of vulnerability of different territorial assets exposed to multi-hazards, but also the recognition of “protection” factors that - in the case of accidental events involving (directly or indirectly) territorial infrastructures - may be implemented at different territorial levels (as proposed in[56]).

5.2. Mapping and Multi-risk assessment In Target Countries

In this section, preliminary data and information are gathered to characterize - at different spatial levels (local/municipal and territorial/national/regional/provincial) - the areas where the four pilot case studies are located in terms of: 1) presence of potential hazardous phenomena/risks, 2) availability of urban and territorial planning tools for risk assessment/management, 3) availability of dataset/database providing data/information about hazard level.

5.2.1. Multi-hazard and multi-risk assessment in Italy

In Italy, the risks in terms of Civil Protection are identified by Legislative Decree No 1 of 2 January 2018, “*Civil Protection Code*”. They are: seismic, volcanic, tidal, hydraulic, hydrogeological, adverse weather events, water deficit and forest fires (Article 16). In addition, there are other risks for which civil protection action can be carried out, such as chemical, nuclear, radiological, technological, industrial, transport, environmental and sanitation risks and uncontrolled re-entry of space objects and debris. In 2021, the Civil Protection Department (in compliance with the European Commission's requirements) issued a summary of the relevant elements of risk assessment and management capacity, focusing on prevention and preparedness measures.

With regard to Italian pilot case study, which is located in Lombardy Region (Northern Italy) in the western area of Milano city (Baggio neighbourhood) (Figure 9) characterized by several natural and man-made hazards. In particular, the Civil Protection Plan of the Metropolitan City of Milan (2021) describes the main hazards: 1) *Seismic* (Seismic Risk Rescue Plan); 2) *Hydraulic and hydrogeological* (Flood Risk Management Plan - PGRA); 3) *Forest fire* (Regional Forest Fire Prevention Plan - AIB); 4) *Installations at major accident risk*; 5) *Transport of dangerous substances* and 6) *Electricity and essential services blackout risk*. Then, about *extreme weather events risk* (i.e., heavy rainfall, windstorms, drought and heat waves), on the basis of past events data analysis (ARPA Lombardia, Regional Agency for the Protection of the Environment), it can be concluded that the consequences of Climate Change are increasingly being felt in the metropolitan area of Milan, such as the increasing average temperature, more frequent extreme climatic conditions (due to both the intensification of winds and precipitation), and the reduction in annual average rainfall precipitation. Finally, with regard to *pandemic risk*, it's a territorial risk potentially impacting the entire Lombardy Region. In particular, it could have a direct impact on the health of workers and/or limit their movement when emergency measures are designed to reduce infections.

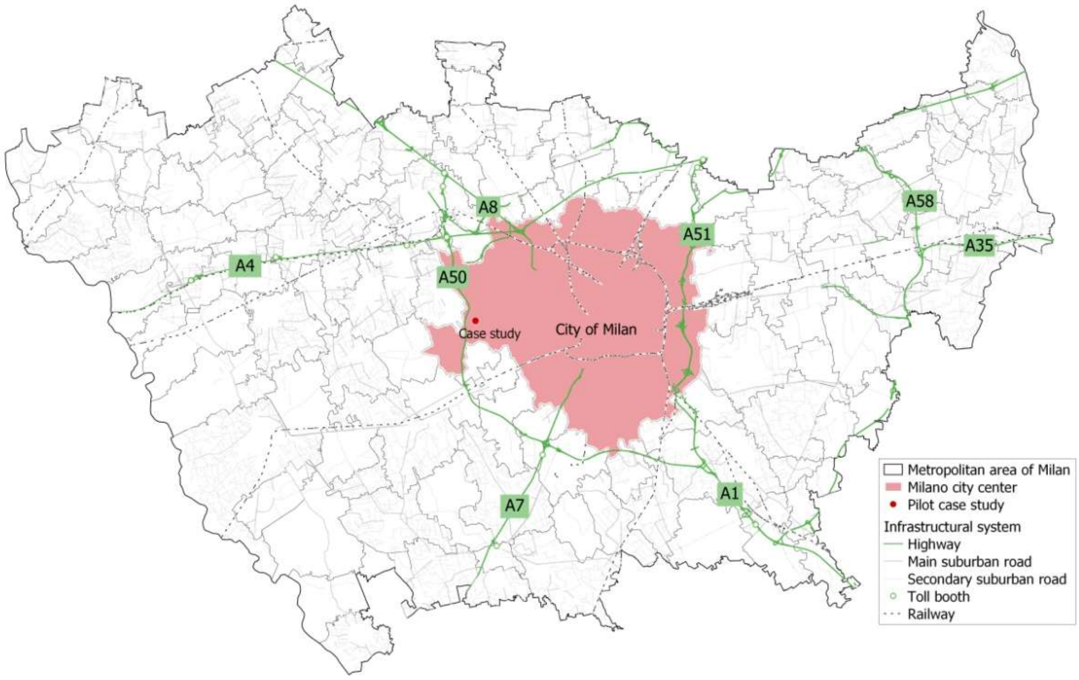

Figure 9. Territorial Framework of the Pilot Case Study
Source: elaboration by the authors

To map multi-hazard conditions, Lombardy Region provides several territorial layers on the own Geoportal (www.geoportale.regione.lombardia.it/) and Open Data portal (www.dati.lombardia.it/) as represented in Figure 10.

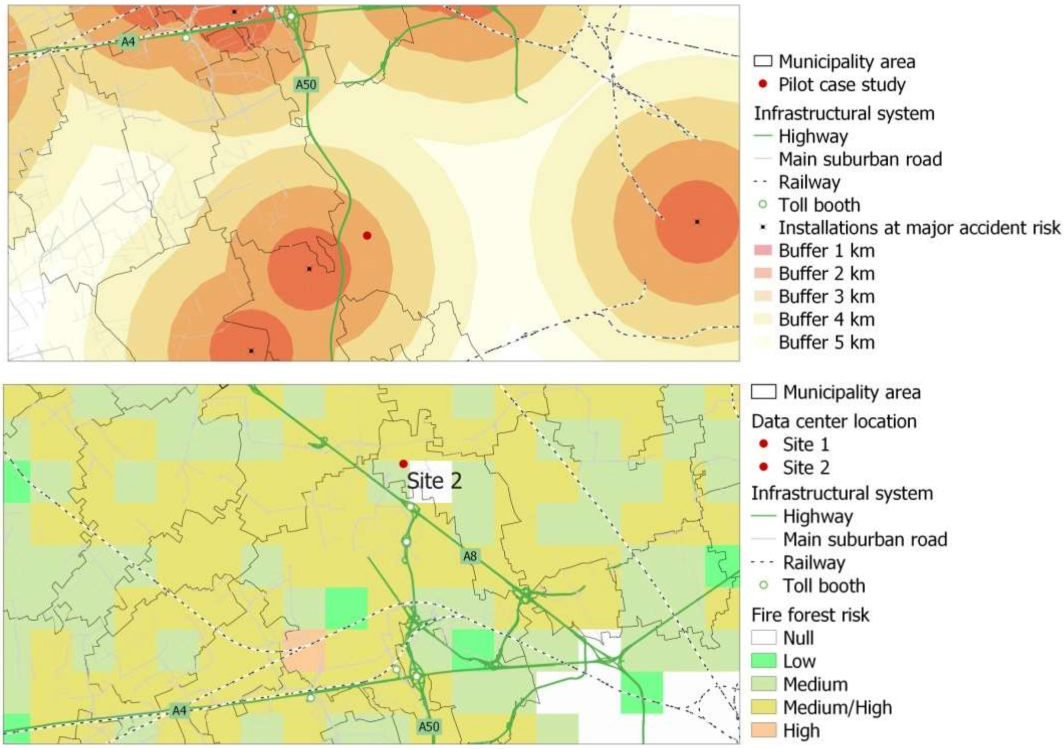

Figure 10. Some Examples of Hazard Maps (Installations at Major Accident Risk and Forest Fire) Related to the Territorial Context of the Italian Pilot Case Study
Source: Elaboration by the Authors

5.2.2. Multi-hazard and multi-risk assessment in France

About the territorial context of the French pilot case study, no data and information are collected considering the proposal to select another pilot building to analyze in the context of the project. Information will be added in the next deliverable, after the identification of the new French case study.

5.2.3. Multi-hazard and multi-risk assessment in Bulgaria

About the territorial context of the Bulgarian pilot case study, no data and information are collected considering the proposal to select another pilot building to analyze in the context of the project. Information will be added in the next deliverable, after the identification of the new Bulgarian case study.

5.2.4. Multi-hazard and multi-risk assessment in Spain

The Spanish pilot case study is located in Langreo, a municipality in the Northern Spain, in Asturias Region. Here, the *Plan Territorial de Protección Civil del Principado de Asturias* (PLATERPA) (approved by Decree 69/2014 of 16 July) describes the different natural and man-made territorial hazards/risks. The natural risks are synthesized in the following Table. The Principality of Asturias provides and collects all the geographical information of the Principality of Asturias in a "Territorial Information System and Spatial Data Infrastructure of Asturias (SITPA-IDEAS) (https://ideas.asturias.es/). The main aim of the dataset is to provide an overview of the susceptibility of the Asturias Region to certain potentially natural hazardous processes.

Table 25. List And Brief Description of The Natural Hazards/Risks Related to the Territorial Context of the Spanish Pilot Case Study

Natural hazard	Brief description
Seismic	In the Principality of Asturias, the territory is divided into two sectors from the point of view of seismic acceleration and intensity values, which mark the seismic hazard. In any case, it is an area that presents the lowest values of the country.
Geodynamic & gravitational movements	The area is vulnerable to different geodynamic and gravitational phenomena, in particular to: surface slippage, large mass movements and rock falls.
Meteorological	In relation to heavy rainfall, storms and hail there are different data sources as the Emergency Service of the Principality of Asturias (SEPA), the State Meteorological Agency (AEMET) (www.aemet.es/es/serviciosclimaticos/datosclimatologicos/),the Sociedad Asturiana de Estudios Económicos e Industriales (SADEI) (www.sadei.es/sadei/territorio-y-medio-ambiente/climatologia_163_1_ap.html).
Flood	The Royal Decree 903/2010 of 9 July about the "Assessment and management of flood risks" transposed into Spanish law the provisions of the Directive 2007/60 of the European Parliament and of the Council of 23 October 2007, on flood risk assessment and management. The areas most at risk of flooding are defined as "Areas of Significant Flood Risk" (ARPSIs) identified in the "National Flood Zone Mapping (SNCZI), developed by the Ministry with environmental competence. This information can be obtained from several sources as the National Flood Mapping System Viewer - Inventory of dams and reservoirs (https://sig.mapama.gob.es/snczi/index.html?herramienta=DPHZI) or Mapas de peligrosidad y de riesgo de inundación del primer ciclo (2011) y del segundo ciclo (2019) of the Cantabrian Hydrographic Confederation. In general, cartography is developed from flood hazard maps that include 3 scenarios, Low/Medium/High probability of flooding.
Forest fire	The high occupation of forest areas in the Principality of Asturias, associated with the Climate Change phenomena, increases the risk of such events.

5.3. Risk Assessment of RE-SKIN Components

To identify the risks associated with RE-SKIN components, a questionnaire to assess the risks associated with RE-SKIN components was developed and circulated among partners developing and working on the systems. The questionnaire aimed at enhancing the security, reliability, and efficiency of the systems by identifying vulnerabilities to various hazards. It considered direct and indirect impacts of hazards on the systems and subcomponents. The main goal is to identify weaknesses and susceptibilities and find ways to mitigate potential hazards. By understanding vulnerabilities and implementing suitable measures, the systems can become more resilient and better prepared to withstand potential impacts, minimizing damages or disruptions. This approach helps in developing effective risk mitigation strategies and improving overall service provision. The following diagram summarizes the different levels of risks considered in RE-SKIN systems.

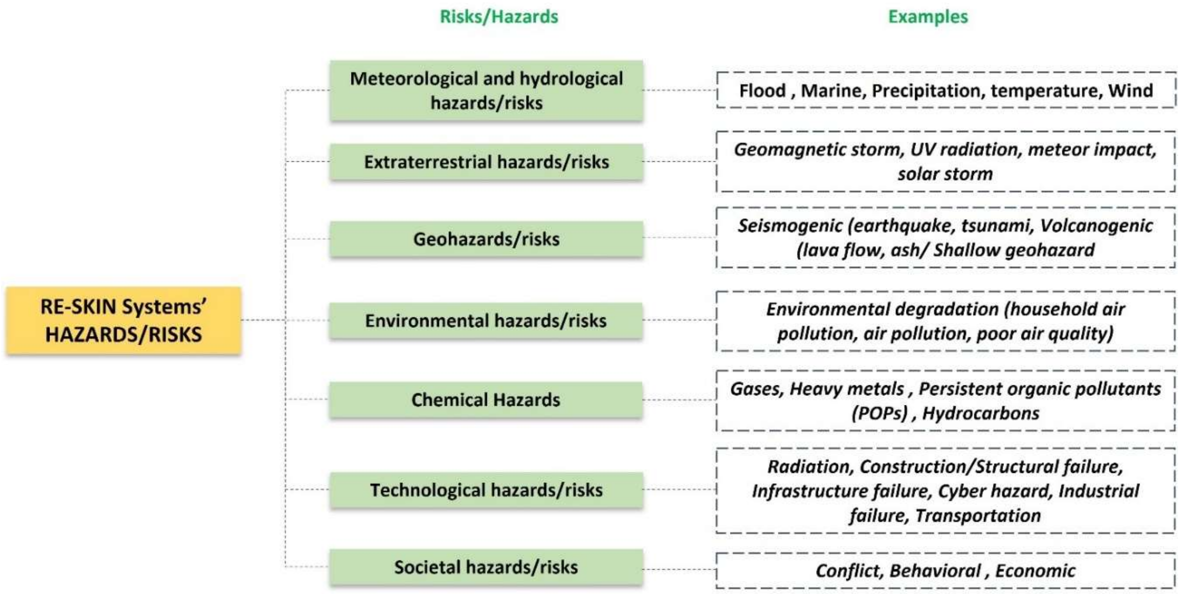

Figure 11. RE-SKIN System: List of Possible Hazards

The following sections shows the hazards within each system in the project.

5.3.1. Hydronic air-to-water DC heat pump

Risks for the Hydronic air-to-water DC heat pump were identified, including geohazards, meteorological and hydrological hazards, and technological hazards, along with corresponding protection measures. Secondary system impacts due to these hazards, such as water heating issues in the buffer tank and smart fan-coil units, were also addressed.

1. Summary of risks for Hydronic air-to-water DC heat pump:

Hazard: Geohazard (Earthquake)

- *Potentially Damaged/Impacted Subsystems:* Compressor, blower motor, fan blades, electrical, and hydronic connections.
- *Type of Physical Damage/Impact:* Risks include oil and refrigerant leaks from compressor vibration, blade breakage, motor malfunction, and damage to electrical and hydronic connections.
- *Protection Factors/Mitigation Measures:* Proper installation following the installation guide. Secure refrigerant lines and electrical connections.

Hazard: Meteorological and Hydrological (Flood)

- *Potentially Damaged/Impacted Subsystems:* Heat exchangers and electrical components (e.g., heat pump control board).
- *Type of Physical Damage/Impact:* Risks include destruction of electrical components and contamination of the heat pump with dirt, debris, and pollutants.
- *Protection Factors/Mitigation Measures:* Implementation of flood barriers and installation of the heat pump in an elevated location.

Hazard: Technological Hazard (Infrastructure Failure)

- *Potentially Damaged/Impacted Subsystems:* Compressor and coils.
- *Type of Physical Damage/Impact:* Risks include improper compressor shutdown during power outages, leading to overheating and damage, as well as freezing and subsequent cracking of coils during power restoration.
- *Protection Factors/Mitigation Measures:* Provision of a backup power source, such as a generator.

2. Summary of Hazards and Secondary System Impacts:

Hazard: Geohazard, Technological hazards, Meteorological and hydrological hazards.

- *Secondary system potentially affected:* Buffer tank/DHW tank, Smart fan-coil units.
- *Type of Damage:*
- Water in the buffer tank cannot be heated up.
- Smart fan-coil requires certain level of water temperature, but water temperature cannot reach the target temperature.
- This kind of malfunction of heat pump would not cause physical damage of the tank and fan-coil unit, but it can cause error of whole heating and cooling system.
- *Protection Factors/Mitigation Measures:* Installation of a backup heating method for the buffer tank.

5.3.2. BIPVT roof system

An overview of the hazards faced by the BIPVT roof system and the corresponding protection measures implemented to mitigate potential damage or impact on the subsystems is presented. Then, a summary of the hazards Summary of Hazards and Secondary System Impacts is shown.

1. Summary of risks for BIPVT roof system:

Hazard: Hailstorm

- *Potentially Damaged/Impacted Subsystem:* Glazed surface.
- *Type of Physical Damage/Impact Suffered by the Subsystem:* Glass breakage, which can occur due to the impact of hailstones.
- *Protection Factors/Mitigation Measures:* Ensuring the use of high-quality glass to enhance its resilience against hailstones.

Hazard: Strong Winds

- *Potentially Damaged/Impacted Subsystem:* Attacks on the system due to the wind force.
- *Type of Physical Damage/Impact Suffered by the Subsystem:* Failure to hold attacks caused by strong winds.

- *Protection Factors/Mitigation Measures:* Conducting a tightness check based on the wind regulations specific to the country of installation. This measure aims to ensure the system's stability and ability to withstand high wind pressures.

2. ***Summary of Hazards and Secondary System Impacts:***

Hazard: Strong Winds

- *Secondary System Potentially Affected:* Electrical systems.
- *Type of Damage Suffered by the Secondary System:* Absence of power from renewable sources, likely due to disruptions in the BIPVT's ability to generate electricity during strong winds.
- *Protection Factors/Mitigation Measures:* The system will be connected to the public network, which can serve as a backup power source during periods when the BIPVT's power generation is affected by strong winds.

Hazard: Hailstorm

- *Secondary System Potentially Affected:* Heat Pump (HP).
- *Type of Damage Suffered by the Secondary System*: Lowering of the heat output of the HP, as it won't receive the usual support of hot air derived from the BIPVT during a hailstorm.
- *Protection Factors/Mitigation Measures*: Ensuring the use of high-quality glass to enhance its resilience against hailstorms.

5.3.3. Electrical storage – Batteries

The various hazard impacts and the associated protection measures for the Electrical Storage – Batteries are discussed, particularly focusing on lithium battery cells and their electrical components. Protection measures are shown where they can minimize potential damages and ensure its efficient and safe operation under different hazard scenarios.

1. ***Summary of risks for Electrical storage system:***

Hazard: Meteorological and hydrological (flood) Hazard

- *Potentially Damaged/Impacted Subsystem:* Lithium Battery cells and electricals flooded.
- *Type of Physical Damage/Impact Suffered by the Subsystem:* Short circuit with possible fire and production of H2, leading to equipment loss.
- *Protection Factors/Mitigation Measures:* Prevent water from easily entering the battery room and battery enclosure to avoid flood-related damage.

Hazard: Marine Hazard

- *Potentially Damaged/Impacted Subsystem*: Battery terminals and related electronics.
- *Type of Physical Damage/Impact Suffered by the Subsystem:* Corrosion due to exposure to salt water or saltwater mist, leading to functionality loss or even thermal runaway self-igniting fire.
- *Protection Factors/Mitigation Measures:* Enclose the system in a maritime-grade IP65 enclosure to protect it from marine environments.

Hazard: Infrastructure failure- Power Outage for more than one day in a row

- *Potentially Damaged/Impacted Subsystem:* Lithium battery cells.

- *<u>Type of Physical Damage/Impact Suffered by the Subsystem:</u>* Self-discharge below a recoverable limit during prolonged power outages.
- *<u>Protection Factors/Mitigation Measures:</u>* Ensure that batteries are electrically disconnected from even small loads during long power outages and periodically recharge them to maintain their functionality.

Hazard: Transportation Hazard

- *<u>Potentially Damaged/Impacted Subsystem:</u>* Lithium batteries.
- *<u>Type of Physical Damage/Impact Suffered by the Subsystem:</u>* Various potential damages and risks like thermal runaway, fire, and explosion.
- *<u>Protection Factors/Mitigation Measures</u>*: Adhere to international and national transportation norms and rules for the safe transportation of lithium batteries.

Hazard: Behavioral- thief or vandalic acts

- *<u>Potentially Damaged/Impacted Subsystem</u>*: Battery system.
- *<u>Type of Physical Damage/Impact Suffered by the Subsystem:</u>* Loss of system or system functionality due to theft or vandalism.
- *<u>Protection Factors/Mitigation Measures:</u>* Implement classical anti-theft and anti-vandalism measures to protect the battery system from such acts.

2. ***Summary of Hazards and Secondary System Impacts:***

Hazard: Loss of functionality (battery no more working) in combination with loss of mains (grid) power.

- *<u>Secondary System Potentially Affected:</u>* Communication and dataloggers.
- *<u>Type of Damage Suffered by the Secondary System:</u>* Possible loss of information.
- *<u>Protection Factors/Mitigation Measures:</u>* Install an electrical back up system.

5.3.4. Building Envelope - Façade cladding/Windows

Hazards and their potential impacts on different subsystems of the building envelope (façade cladding and windows), and the corresponding protection factors and mitigation measures were collected. Moreover, it provides a summary of the potential hazards and their impacts on different systems and secondary systems in the project.

1. ***Summary of risks for Building Envelope Façade Cladding and windows:***

Hazard: Meteorological and hydrological (precipitation-related)

1. *<u>Potentially damaged/impacted Subsystem</u>*: Outer layer.
- *<u>Type of physical damage/impact suffered by the subsystem:</u>* Corrosion.
- *<u>Protection factors/mitigation measures:</u>* Anti-corrosion coatings, regular cleaning and maintenance, proper drainage systems, weather-resistant materials, appropriate sealants, and design considerations.

2. *<u>Potentially damaged/impacted Subsystem:</u>* Insulation.
- *<u>Type of physical damage/impact suffered by the subsystem:</u>* Moisture can cause degradation of the insulation material and promote mold growth.

- *Protection factors/mitigation measures:* Using water-resistant insulation, proper ventilation, using proper drainage systems, regular inspection, and maintenance, and incorporating design considerations.

3. *Potentially damaged/impacted Subsystem*: Substructure.

- *Type of physical damage/impact suffered by the subsystem:* Moisture exposure may cause corrosion and compromise the substructure's structural integrity.
- *Protection factors/mitigation measures:* Proper coating application, regular cleaning and maintenance, installation of a drainage system, use of water-resistant materials, proper ventilation, and air circulation, incorporating design considerations.

Hazard: Meteorological and hydrological (temperature-related)

1. *Potentially damaged/impacted Subsystem:* Sandwich panel and substructure.

- *Type of physical damage/impact suffered by the subsystem: Thermal expansion and contraction, thermal fatigue, exposure to acute temperatures, and moisture condensation, can lead to cracking, failure, reduced strength, and durability.*
- *Protection factors/mitigation measures: Use of materials with appropriate thermal coefficients to minimize stress due to temperature changes.*

2. *Potentially Damaged/Impacted Subsystem:* Glass.

- *Type of Physical Damage/Impact:* Loss of insulating capacity and increased air permeability, leading to higher energy consumption for cooling/heating.
- *Protection Measures*: Testing and enhancing the resilience of external construction components in the system against degradation caused by temperature changes.

Hazard: Meteorological and hydrological (wind-related)

- *Potentially damaged/impacted Subsystem:* Sandwich panel and substructure.
- *Type of physical damage/impact suffered by the subsystem:* Wind uplift could lead to damage or failure of the cladding system.
- *Protection factors/mitigation measures:* Use of wind-resistant materials. Proper installation so the system is securely fastened. Reinforcing the sandwich panel and substructure with additional supports or braces can increase their wind resistance. Regular maintenance and design considerations.

Hazard: Meteorological and hydrological (flood)

- *Potentially Damaged/Impacted Subsystem:* Glass.
- *Type of Physical Damage/Impact:* Water penetration into areas not designed to be wet.
- *Protection Measures:* Testing and controlling internal drainage channels to prevent water penetration.

Hazard: Extraterrestrial (UV radiation)

- *Potentially damaged/impacted Subsystem:* Outer layer.
- *Type of physical damage/impact suffered by the subsystem:* Sunlight exposure can cause material degradation.
- *Protection factors/mitigation measures:* UV-resistant coatings or films. UV-resistant materials for the outer layer. Regular cleaning and maintenance to remove dirt and debris that can accelerate UV damage. Incorporating design considerations to reduce the amount of direct sunlight on the outer layer.

Hazard: Geohazard (earthquake)

- *Potentially damaged/impacted Subsystem:* Substructure.
- *Type of physical damage/impact suffered by the subsystem:* Structural deformation, detachment of connections, material and fatigue failure, and impacts from falling debris.
- *Protection factors/mitigation measures:* Incorporating flexible joints and connections in the substructure to allow for movement during an earthquake. Properly anchoring the substructure to the foundation to prevent it from shifting or collapsing.

Hazard: Environmental (air pollution)

- *Potentially damaged/impacted Subsystem:* Outer layer.
- *Type of physical damage/impact suffered by the subsystem:* Air pollution may degrade materials over time.
- *Protection factors/mitigation measures:* Regular cleaning and maintenance. Using weather-resistant materials. Design consideration.

Hazard: Environmental (wildfires)

- *Potentially damaged/impacted Subsystem:* Sandwich panel and substructure.
- *Type of physical damage/impact suffered by the subsystem:* Cladding may spread fire to other building elements.
- *Protection factors/mitigation measures:* Use of fire-resistant materials for the substructure and outer layer.

Hazard: Societal (behavioral)

- *Potentially damaged/impacted Subsystem*: Outer layer.
- *Type of physical damage/impact suffered by the subsystem:* Damage by vandalism or falling objects, affecting its appearance and structure.
- *Protection factors/mitigation measures:* Using impact-resistant materials for the outer layer. Regular maintenance and repair. Installing protective barriers.

Hazard: Conflict - Behavioral violence

- *Potentially Damaged/Impacted Subsystem:* Glass.
- *Type of Physical Damage/Impact:* Glass breakage due to behavioral violence.
- *Protection Measures:* Enhancing the resilience of the glazing to withstand impact, possibly using reinforced glass or protective films.

2. ***Summary of Hazards and Secondary System Impacts:***

Hazards: Meteorological and hydrological (flood), Marine (if nearby), Temperature-related, Societal (behavioral).

1. *Secondary System Potentially Affected:* Whole system.

- *Type of Damage Suffered by the Secondary System:* Wet or damp areas can cause growth of mold that are hazardous to the health of residents.
- *Protection Factors/Mitigation Measures:* Improved drainage and sealing between outer surface and residential areas to prevent moisture-related issues and draft wind problems.

2.Secondary System Potentially Affected: Steel roofing with bio-sourced back insulation.

- *Type of Damage Suffered by the Secondary System:* The damage to the façade cladding could affect the roof's insulation, causing a loss of thermal performance or system failure.

- *Protection Factors/Mitigation Measures:* Improved insulation material and continuous check.

5.3.5. Multi-input/multi-output converter (MIMO)

The potential hazards and their impacts on the Multi-input/multi-output converter (MIMO) system, along with the respective protection factors and mitigation measures are discussed below. Moreover, a summary of the timely actions and measures to address various hazards and secondary systems affected are presented to ensure the efficiency and functionality of the MIMO system and its related subsystems.

1. ***Summary of risks for MIMO:***

Hazard: Meteorological and hydrological hazards/risks

- *Potentially Damaged/Impacted Subsystem*: AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
- *Type of Physical Damage/Impact*: Delays in manufacturing of the mentioned subsystems.
- *Protection Measures:* Acquiring all parts as soon as possible to mitigate manufacturing delays.

Hazard: Technological hazards/risks, Societal hazards/risks

- *Potentially Damaged/Impacted Subsystem:* AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
- *Type of Physical Damage/Impact:* Delays in manufacturing due to technological issues and societal factors or delays in other RE-SKIN systems.
- *Protection Measures:*

1. Acquiring all parts as soon as possible to mitigate manufacturing delays.
2. Making an early prototype and testing all possible scenarios to identify and address technological issues.

2. ***Summary of Hazards and Secondary System Impacts:***

Hazard: Meteorological and hydrological hazards/risks, societal hazards/risks:

- *Secondary Systems Potentially Affected:* AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
- *Type of Damage Suffered by Secondary Systems:* Delays in manufacturing.
- *Protection Measures*: Acquiring all parts as soon as possible to mitigate manufacturing delays.

Hazard: Technological hazards/risks:

- *Secondary Systems Potentially Affected*: AC-DC converter, DC-DC converter, 48V DC-DC converter, PV optimizers.
- *Type of Damage Suffered by Secondary Systems*: Delays in manufacturing due to technological issues or delays in other RE-SKIN systems.
- *Protection Measures:*

1. Acquiring all parts as soon as possible to mitigate manufacturing delays.
2. Making an early prototype and testing all possible scenarios to identify and address technological issues.

5.3.6. Smart Control System

The potential hazards, impacts, and protection measures for the Smart Control System are summarized below. It highlights the importance of implementing specific protection measures to address potential technological hazards, infrastructure failures, and cyber risks in the Smart Control System.

1. ***Summary of risks for the Smart Control System:***

Hazard: Technological Hazard: Infrastructure failure - Potentially Damaged Subsystem: Storage

- *Type of Physical Damage/Impact:* Data loss.
- *Protection Measures*: Critical datasets are stored in cloud services to ensure data preservation even in case of infrastructure failure.

Hazard: Technological Hazard: Infrastructure failure - Potentially Damaged Subsystem: Network

- *Type of Physical Damage/Impact*: Critical system errors and complete system shutdown.
- *Protection Measures*: Software components are designed to avoid hard dependencies on other services or devices whenever possible, reducing the risk of system errors and shutdowns.

Hazard: Technological Hazard: Cyber hazard - Potentially Damaged Subsystem: The entire system

- *Type of Physical Damage/Impact*: Breach of data privacy and possible monetary costs originating from malicious users controlling the building systems.
- *Protection Measures*: Adopting the Security by Design methodology to strengthen the system's defenses against cyber threats and ensure data privacy.

2. ***Summary of Hazards and Secondary System Impacts:***

Hazard: Technological (infrastructure failure, Cyber hazard)

- *Secondary Systems Potentially Affected:* Possibly all of the systems connected to the network that require some interaction with the Smart Control System.
- *Type of Damage Suffered by Secondary Systems:* Degradation of functionality or complete shutdown in the most severe cases.
- *Protection Measures:* Adopting the Security by Design methodology to strengthen the system's defenses against cyber threats and ensure data privacy.

5.3.7. Overall risks associated with RE-SKIN Systems

To summarize the previous risks associated with the systems/subsystems, including direct and indirect risks, the following diagram has been developed to summarize these relationships.

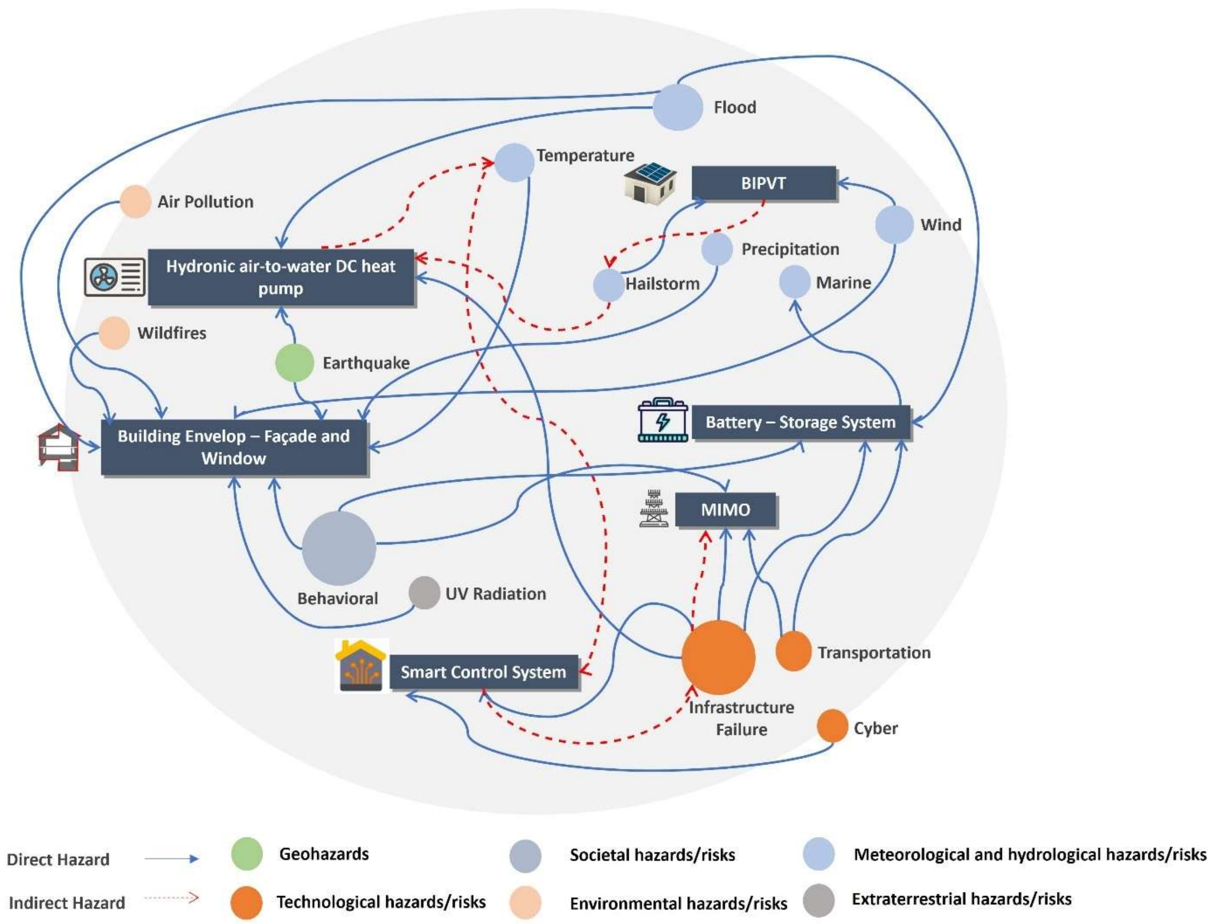

Figure 12. Summary of Hazards on RE-SKIN Systems and their Interconnection

5.4. Testing of RE-SKIN systems

Information on the testing capability/lab for risk assessment for each partner has been carried out. It showed the testing capability of partners, testing locations and systems to be tested and if any action is required from another partner. The following Table shows the result of this analysis.

Table 26. Testing Capability of Partners and Components in RE-SKIN Project

Partner/System	Testing Capability	Testing Location	System to be tested	Action Required
Heliotherm – Heat Pump	Yes	Helioeatherm testing facility.	Heat pump performance and endurance under various weather conditions.	N/A
Solar – Storage System	Yes	In-house testing facilities in Amsterdam and North Holland.	Quality of the recycled battery cells and the whole battery system.	N/A

PSC- MIMO	No	N/A	N/A	N/A
Garcia Rama – Façade System	Need other partners to perform testing	Testing will be carried out at DTI facilities.	N/A	N/A
Solar- Storage System	Need other partners to perform testing	N/A	Some fire testing on battery cells and the whole battery system might be required by local authorities before installation, and related testing facilities might be needed.	Identify a testing partner to perform testing on Storage system
CITIC- Smart Control System	Yes	CTIC laboratories	Integration tests and risk assessment of the Smart Control System (SCS) in conjunction with other building systems.	N/A

5.5. Risk Related Standards Associated with RE-SKIN Systems

The main standards to consider in the context of risk assessment for each system and the different subcomponents of the considered system are identified in the following Table.

Table 27. Main Hazards/Risks Standards for RE-SKIN Systems

System	Component/ Subcomponent	Main Standards	Details
Heat Pump	Heat Pump	EN378	European standard for refrigerating systems and heat pumps, providing safety and environmental requirements
Façade system	Insulating Sandwich Panels	NF standard EN 14509	European standard for insulating sandwich panels used in construction
	Outer Layers Steel coils hot dip galvanized	NF EN 10346 and NF EN 10143	. Standards for outer layer coatings and materials used in sandwich panels
	Outer Layers pre-lacquered	XP P 34-301 and NF EN 10169+A1	

	Outer Layers hot coated with the "ZM Evolution" coating	NF EN 10143	
	Outer Layers coils can be made of stainless steel	NF EN 10088-2	
	Insulation minimum tensile strength of 50 kPa	NF EN 1607	Standards for insulation material properties in sandwich panels
	Insulation minimum compression strength of 70 kPa	NF EN 826, NF EN 14509	
	Fixings- External exposures	NF P 34-205-1 (Appendix A)	Standards for selecting and using fixings and accessories in construction
	Fixings- internal atmospheres	NF DTU 43.3 P1-2 (5.1.1.4)	
	Sealing Products	Silicone Mastic with SNJF Façade Label	Specific type of sealant (silicone mastic) with SNJF façade label
	Surface Mass	NF EN 14509 (Appendix D)	Standards for surface mass (weight) tolerances of sandwich panels
	Thermal Performance	Th-U Opaque Wall Fascicle guidelines	Guidelines for calculating thermal performance of opaque walls
	Acoustic Performance	UNE-EN 10.140-2	European standard for determining the acoustic performance of buildings
	Reaction to Fire	NF EN 13501-1 (fire reaction classification of B-s2,d0 for AM 03 foam and B-s1d0 for AMC 01 foam with organic coatings having a PCS less than or equal to 4 MJ/m².)	European standard for fire reaction classification of construction products
	Miscellaneous Accessories	NF P 34-205-1 (DTU 40-35 reference)	Standards for production of miscellaneous accessories in construction
	Curtain Walling	hEN 13830	European harmonized standard for curtain walling products

	Windows and Doors	hEN 14351-1	European harmonized standard for windows and doors
Storage System	Battery Transport	Battery cells manufacturer specifications + International lithium batteries and battery cells dangerous goods regulations	Manufacturer specifications and international regulations for transporting batteries
	Battery Storage	Battery cells manufacturer specifications + Local authority norms and rules	Manufacturer specifications and local regulations for storing batteries
	Battery During Operation		Manufacturer specifications and local regulations for operating batteries
	Battery Systems	PGS 37-1 (Operation of Battery Energy Storage System), PGS 37-2 (Storage of Battery Storage Systems) (specific to the Netherlands)	Dutch norms for the operation and storage of battery energy storage systems in the Netherlands

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