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D2.2 - GUIDELINES FOR THE IMPLEMENTATION AND FINANCING OF EE MEASURES IN SUPERMARKETS

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TABLE OF CONTENTS

Horizon 2020
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Horizon 2020
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Terms, definitions and abbreviated terms

List of Acronyms			
Acronym	**Definition**	**Acronym**	Definition
AHU	Air Handling Unit	GHG	Greenhouse Gas
AI	Artificial Intelligence	HVAC	Heating, Ventilation, Air Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	LED	Light-Emitting Diode
ATM	Automated Teller Machine	LHV	Lower Heating Value
BIPV	Building-Integrated Photovoltaic	M	Month
BMS	Building Management System	PLC	Programmable Logic Controller
CHP	Combined Heat and Power	PV	Photovoltaic
COP	Coefficient of Performance	PVC	Polyvinyl chloride
DHW	Domestic Hot Water	R&D	Research and Development
EMS	Energy Management Software (or System)	RES	Renewable Energy Source
EPC	Energy Performance Contract	SME	Small-Medium Enterprise
ESCO	Energy Service Company	TRL	Technology Readiness Level
ESG	Environmental Social Governance	VFD	Variable Frequency Drive
EU	European Union	WP	Work package
EV	Electric Vehicle		

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1. Executive Summary

The SUPER HEERO project aims at providing a replicable financial scheme for energy efficiency investment in small and medium supermarkets, based on stakeholder and community engagement. Note that by supermarkets we refer to stores and shops offering a wide variety of food, beverages and household products: they are larger and have a wider selection of products than grocery stores but are smaller and more limited in the range of merchandise than a hypermarket or big-box market.

In D2.1 of the SUPER HEERO Project, delivered in December 2020 and available on the project website, building upon a high-level analysis of typical supermarkets' energy systems and equipment, a catalogue was created with the 42 most relevant and easy to replicate energy efficiency measures to be promoted by SUPER-HEERO renovation approach.

In the present D2.2 of the SUPER HEERO Project, guidelines for high-level design of all the 42 energy efficiency measures included in the catalogue are drafted. The guidelines are referred to the overall energy management of the supermarket, the improvement of energy supply, and the main areas of energy use in the supermarket, i.e. the HVAC (Heating, Ventilation, Air Conditioning) systems, lighting, products refrigeration and other areas.

After having drafted the guidelines for high-level design, practical examples are presented. Energy efficiency renovation packages have been created by selecting from the catalogue of potential energy efficiency actions the most suitable ones for supermarkets based on specific baseline conditions (old, medium, new) and geographical location (Northern or Southern Europe). To account for the budget availability of the supermarket, energy efficiency renovation packages have been created with different depth and consequently different investment needed.

Based on this approach, 18 renovation packages were created and analysed in order to evaluate the investment needed, the achievable energy savings and the consequent potential economic savings and pay-back time. All the values are presented per unit of area of the supermarket, in order to allow – with a certain degree of accuracy – extrapolation for supermarkets of different sizes. A case study based on data from a real supermarket is also presented and discussed.

Based on the results of the analysis, it is highlighted that a wide range of opportunities for renovation measures exist, characterized by an investment below or around 200,000 € (for a 400 m^2 supermarket) and a payback below 5-6 years. The study finds that "basic" renovation packages typically on "old" supermarkets have the best cost-benefit ratio, since they aim at taking "low-hanging fruits", whereas interventions on supermarkets with better starting conditions might be slightly less profitable but can be interesting and/or necessary to meet corporate sustainability targets. Benefits beyond energy efficiency to a wider set of sustainability metrics and linkages to Environmental Sustainability Goals and Corporate Social Responsibility are possible also thanks to the innovative financing measures being developed in the SUPER HEERO project which engage community members.

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2. Introduction and Methodology

The SUPER-HEERO project aims at providing a set of innovative and replicable financial schemes for energy efficiency investment in small and medium supermarkets, leveraging, when possible, stakeholder and community engagement. Note that by supermarkets we refer primarily to self-service shops offering a wide variety of food, beverages and household products: they are larger and have a wider selection of products than grocery stores but are smaller and more limited in the range of merchandise than a hypermarket or big-box market. This is because small to medium sized supermarkets are most likely to have the potential to benefit from energy efficiency measures but also face the greatest challenges securing the know how or financing for such measures. As an extension of the project core concepts, the project also foresees an expansion of these concepts to other sectors, other types of retail points, and potentially hypermarkets.

The approach relies on three main instruments: engineered Energy Performance Contracts (EPC), product as a service model for technology providers engagement and community-based crowdfunding/cooperative initiatives. For holistic interventions or even a simple one, these innovative financing schemes may be combined into a hybrid composite solution (e.g. crowdfunding to finance an EPC also employing as a service for part of a holistic intervention).

Using the innovative financing schemes coupled to technology packages and process for implementation, SUPER-HEERO will enable upfront cost reduction and engagement of additional investment sources, while bringing direct economic and environmental savings for the supermarket, as well as cascade to the final customer, the engaged ESCOs and utilities, and technology providers.

The main objectives of the project are:

- develop and engineer an innovative scheme for energy efficiency investment in small and medium supermarkets based on stakeholder and community engagement;
- compile a portfolio of ad-hoc energy measures for supermarkets and elicitation of requirements and high-level design based on case studies for segmentation;
- implement the innovative financial instruments for energy efficiency investments in two relevant pilot case studies;
- define a structured strategy and methodology for the replicability of the financial scheme at regional and national level;
- identify barriers and needs to support the development of regulatory and policy frameworks that allow the uptake of innovative financial schemes for energy efficiency investment.

The expected impacts of the project are instead the following ones:

- 88 Stores engaged to implement mechanisms with a total floor of 29,560 m^2;
- primary energy saving of 7,094 GWh/y;
- reduction of the greenhouse gases emission of 6,807 tCO_2e/y;
- 4.7 million Euro of investment in energy efficiency measures triggered;
- delivery of innovative financing schemes that are operational and ready to be implemented.

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The Super-HEERO work plan is structured in 6 work packages (WP) and each of them is divided into tasks. This report represents the second delivery of WP2 (Energy Efficiency Renovation Actions for Supermarkets) first task (Task 2.1 – Energy efficiency measures and guidelines for supermarkets).

2.1 Purpose of the Document

The present deliverable, D2.2 of the SUPER HEERO project, following the catalogue of energy efficiency measures presented in D2.1 (a publicly available renovation catalogue at the project website), includes the guidelines for high-level design of energy efficiency actions in supermarkets, analysing potential renovation packages under the technical and financial perspective, depending on different baseline and boundary conditions of the supermarket.

The overall approach adopted in the present document is outlined in Figure 2.1: starting from the catalogue of energy efficiency measures, guidelines for high-level design are defined, renovation packages are created based on different conditions/requisites of supermarkets' clusters, the technical and financial performance of the proposed renovation packages is analysed and, to conclude, a case study is presented.

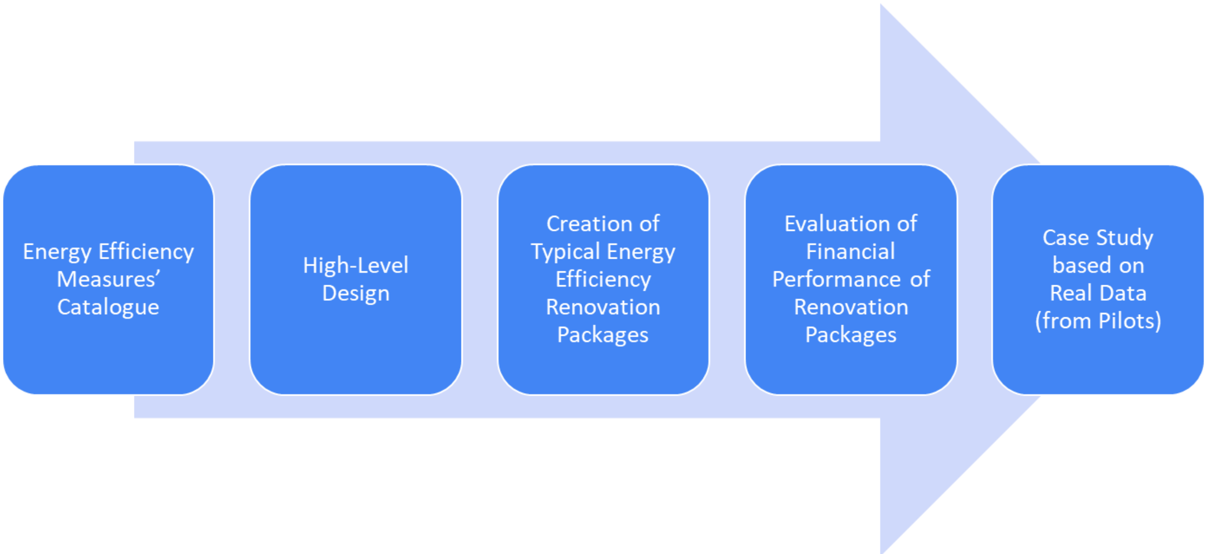

Figure 2.1: Overall Approach to the Analysis

2.2 Structure of the Document

The present Deliverable is articulated into the following sections:

- Chapter 1 presents the executive summary of the report;
- Chapter 2 provides the introduction;
- Chapter 3 presents the guidelines for high-level design of the identified measures;
- Chapter 4 illustrates the potential pathways to energy efficiency of supermarkets based on different starting and boundary conditions;
- Chapter 5 contains a case study of high-level design based on real supermarket data;
- Chapter 6 draws the conclusions of the study.

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3. Guidelines for High-Level Design

In line with the approach followed in D2.1, based on the analysis of typical supermarkets' energy balances, this section focuses on the guidelines for high-level design of energy efficiency interventions related to the following six key areas:

- overall energy management;
- energy supply;
- heating, ventilation, air conditioning;
- lighting;
- product refrigeration;
- other areas.

As a general approach to energy efficiency of supermarkets, it is worth recalling that the best practice follows the main steps outlined in Figure 3.1: starting from low-hanging fruits, i.e. the improvement of energy management and devices operation and maintenance, it is then possible to act to reduce the energy demand through the optimization of the existing systems, then to focus on the increase of the energy conversion efficiency. After the energy demand is optimized through these three steps, the possibility to cover the residual demand with energy self-produced from renewables or cogeneration can be considered. To conclude, monitoring the performance of the devices and systems and evaluating potential further actions for a continuous improvement are always useful steps.

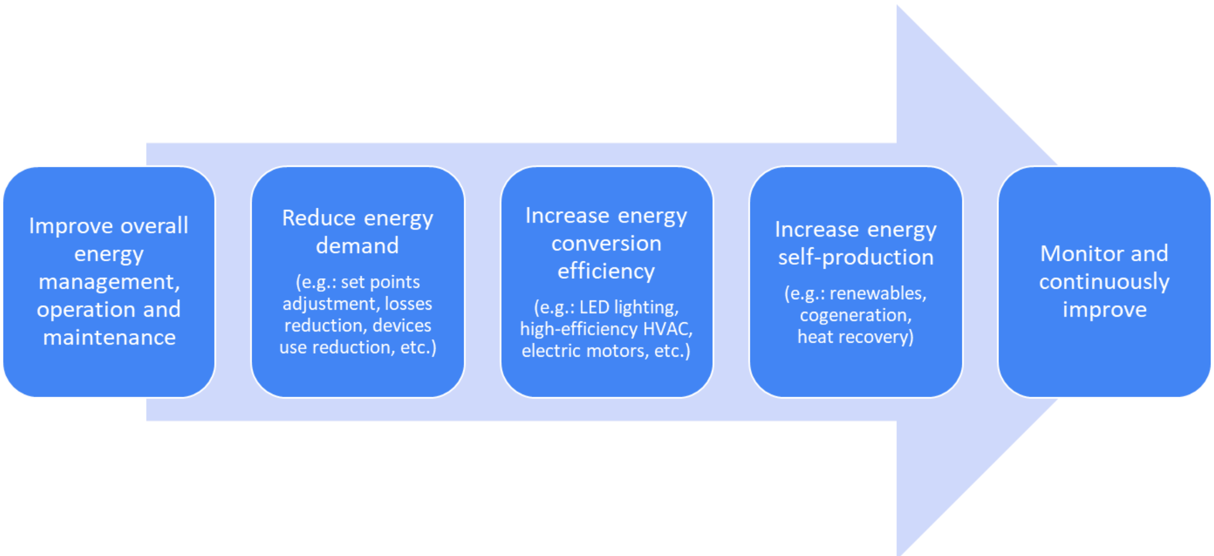

Figure 3.1: Adopted Approach to Energy Efficiency

3.1 Overall Energy Management

Energy management plays a key role on the overall optimization and potential reduction of the energy consumptions of the supermarket; it includes the actions aimed at keeping consumption levels under control, monitoring included, as well as the adoption of energy management systems and of the most

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suitable operation and maintenance routines to ensure that all energy-related devices work at the highest possible efficiency, i.e. delivering the requested service with the minimum possible energy consumption. These activities are related to all areas and devices in the supermarket.

The main opportunities for improvement identified for this field are:

- energy audit and implementation of an energy management system;
- monitoring of electricity consumption at main switchboards;
- blockchain enabled smart meters;
- artificial intelligence for smart electric load management;
- microclimate design and simulation using nature-based solutions;
- building and urban area dynamic energy simulation;
- asset management software;
- regular maintenance of energy users.

3.1.1 Energy Audit and Implementation of Energy Management System

An energy audit is a structured activity that aims at analysing the energy consumptions and flows of the site under assessment and the characteristics of the energy users with the aim of evaluating energy flows in the site and identifying opportunities for energy efficiency.

Large retail companies can be subject to the obligation to carry out an energy audit on some of their supermarkets, introduced by the EU Energy Efficiency Directive 2012/27/EU, whereas other companies may be willing to carry out such an analysis to identify opportunities for the reduction of their environmental impact and energy supply costs.

The key steps for a high-level design of an energy audit are:

- ✓ **estimate the energy demand** using monitoring mechanisms or consulting the electricity bills in order to understand the supermarket power needs and design;
- ✓ **monitor the energy consumption on spot areas**;
- ✓ **assess the technical characteristics of the installed energy systems** (refrigeration, HVAC, lighting, logistics, etc.) and of the building envelope (walls, windows, doors, etc.);
- ✓ **prepare surveys to make to the supermarket personnel**;
- ✓ calculate **energy performance indicators** and compare them with available **benchmarks**;
- ✓ make a **gap analysis** versus energy efficiency best practices of the sector and
- ✓ assess the **pre-feasibility** of a number of energy efficiency actions including technical and **economic evaluation**.

The energy audit may be a starting point for the implementation of an **energy management system**, i.e. a set of procedures for the monitoring, management and continuous improvement of the conditions of the supermarket under the energy perspective.

The energy management system can be realized and certified according to the ISO 50001 technical standard, thus potentially improving the corporate image, in addition to the identification of energy saving opportunities.

The implementation of an energy management system, the appointment of an **energy manager** and the continuous adoption of energy-related good practices is then expected to keep the energy efficiency level

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as high as possible, thus achieving further improvements compared to the execution of an energy audit alone.

3.1.2 Monitoring of Electricity Consumption at Main Switchboards

Monitoring of electricity consumption is one of the basic solutions to identify opportunities in energy management and improvement actions that can be implemented with low or no investment at all. Indeed, monitoring of electricity consumption is useful for identifying bad practices/operations which cause not needed energy consumptions, such as equipment remaining switched on when not necessary, or focusing on areas where potential for improvement exists.

If electricity consumptions are not monitored, the identification of anomalous consumptions can occur only by evidence, e.g.: in case of major malfunctions or damages to the equipment, or from the analysis of monthly electricity bills, which for complex sites might not allow the identification of the equipment responsible of the additional consumptions.

The key steps for a high-level design of monitoring system are:

- ✓ **identify the number and the position of the power meters** to be installed in the main electric switchboards of the supermarket;
- ✓ **check the network** for data acquisition;
- ✓ **install a software** for collection and analysis of the monitored data. The software shall provide curves of energy consumptions at the desired timescale (hourly, daily, weekly, monthly, etc.), to support the identification of load peaks, idles, oversized equipment, etc.; moreover, the breakdown of electricity consumption among different users will be known and this allows substituting assumptions with real measured data, thus increasing the reliability of the estimates of pay-back time of the energy related investments;
- ✓ **identify an energy manager** or responsible person to follow up the monitoring process.

The energy savings associated with this intervention strongly depend on the attention that the supermarket management pays to the monitored data: if consumptions are simply monitored and not analysed for energy efficiency purposes, the installation of the monitoring system is useless.

3.1.3 Blockchain Enabled Smart Meters

Blockchain enabled smart meters are an enabling technology. What blockchain does is to put a "stamp" on data which is secure, and which can be used as a true or trusted measurement between parties. In the energy landscape, such meters can become the backbone of energy communities and peer to peer remunerations schemes. Fiscally certified blockchain enabled smart meters can also put prosumers and consumers in charge of their own data with respect to ownership, accessibility, the timing on which that data is accessible and transparency.

The key steps for a high-level design of blockchain enabled smart meters are:

- ✓ **identify the number and the position of the smart meters** to be installed in the supermarket;
- ✓ **assess the potential of forming an energy community** around the supermarket. In the case of smaller individual supermarkets in a community, one can imagine the exchange of energy flows between nearby homes and buildings;
- ✓ **estimate the renewable energy potential** of the supermarket and/or of neighbouring buildings;

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- ✓ **identify the potential position of energy plants**. In the context of shopping centres, one can imagine energy might be exchanged between different vendors in the same complex (e.g.: rooftop solar being self-consumed by different vendors).

There is a strong economic benefit to self-consumption as up to 60% of energy bills are tax and system costs. There may also be incentives related to the formation of an energy community or collective self-consumption. Enabling and maximizing the use of local produced energy effectively lowers the price of energy within the energy community ecosystem and provides grid benefits. Electricity is one energy vector, but the same concepts are extending to other energy vectors (thermal), being coupled to energy storage technologies, and to technologies that allow crossing between energy vectors (power to gas).

3.1.4 Artificial Intelligence for Smart Electric Load Management

Any system that provides data is a candidate for AI-based control and/or continuous commissioning. Such systems target the identification of faults, incorrect set points, or the optimization of set points via access to operational data of a specific technology and/or the crossing with other data streams in a specific building/installation over time (climatic conditions, occupancy, efficiency, energy pricing, etc.). The more data that can be combined, the better the intelligence can become. Such AI can take the form of specific technologies connecting to the cloud for technology-provider based algorithms or "smart" systems that sit on top of aggregated systems or on top of the building as a whole may be deployed. What it does is to collect hundreds of thousands of real time data points such as outside temperature, sun/cloud positioning, fan speed, duct pressure, heater status, humidity levels, occupant density and others. It then catalogues a buildings specific operating behaviour and energy flows across time.

The key steps for a high-level design of AI-based control are:

- ✓ **identify the target energy systems** (for example HVAC);
- ✓ **identify the number and the position of the smart meters** to be coupled with AI;
- ✓ **train and implement the AI software** via direct control or integrated into a BMS

3.1.5 Microclimate Design and Simulation using Nature-Based Solutions

Urban heat islanding can be reduced via the use of vegetation for shading and as a tool to change wind vectors. Using vegetation in design can lower the demand on cooling systems, increase comfort, increase social acceptance of building spaces, lower carbon footprint and gain access to zoning approvals, volumetric bonuses or other incentives applied to sustainable architecture.

The key steps for a high-level design of microclimate design and simulation using nature-based solutions are:

- ✓ **analyse the building and local area characteristics**, i.e. orientations, heights, construction materials;
- ✓ with the support of tools (for example GREENPASS), **identify a methodology, a set of indicators, and a database on greenery options** that can be included in the design or retrofit decisions.

3.1.6 Building and Urban Area Dynamic Energy Simulation

Dynamic energy simulations are required within various building sustainability certification schemes and can be used to assess the performance of building systems and material components acting together

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across time. The energetic performance, daylighting and comfort of buildings can be simulated in various software environments.

The key steps for a high-level design of building and urban area dynamic energy simulation are:

- ✓ **analyse the building characteristics**, i.e. orientation, height, construction materials;
- ✓ **identify the software** to use for the energy simulation;
- ✓ **delineate the retrofit scenarios** to be modelled.

3.1.7 Asset Management Software

Supermarket chains with multiple locations are excellent candidates for asset management software that facilitates fleet-wide assessment and reporting and/or Environmental, Social and Governance (ESG) assessment and reporting.

The key steps for a high-level design of building and urban area dynamic energy simulation are:

- ✓ **select fleet management KPIs,** age, energy/m^2, equipment typologies, size, turnovers, …
- ✓ **analyse the asset building characteristics**, i.e. orientation, height, construction materials;
- ✓ **identify the software** to couple fleet management to fleet modelling. The software can pull approximate building geometries from GIS data as a start point and performance metrics for buildings of various construction/material/use scenarios are available as a starting point;
- ✓ **delineate the retrofit scenarios** to be modelled. One can manage existing portfolio performance (aggregated or site-specific) and simulate potential energy or carbon reduction measures (aggregated or site-specific).

3.1.8 Regular Maintenance of Energy Users

A regular maintenance of all equipment is fundamental to ensure the correct operation of the device and to maximize its level of energy efficiency, thus reducing energy consumptions. This is particularly important for some of the energy users in the supermarket, such as refrigeration systems, HVAC systems and, to a lesser extent, lighting systems.

The proposed solution is a simple good housekeeping practice that foresees the creation of a checklist with the main maintenance actions, the responsible person or department and the frequency of operation (daily/weekly/monthly, etc.). The checklist shall be developed considering the specific features of the supermarket, but should cover at least the following items:

- compressors and fans of centralized/local refrigeration system;
- refrigerated cabinets and cold storage rooms (with focus on doors seals and local temperature control systems);
- refrigeration coils;
- HVAC systems (with focus on air filters, fans, compressors);
- refill of working fluid in products’ refrigeration systems and heat pumps/chillers;
- boiler combustion efficiency and exhausts’ composition;
- air curtains with focus on set-point and electrical resistance;
- piping for hot/refrigerated water distribution;

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- compressed air distribution system, if present;
- lamps testing, cleaning and replacement when needed;
- windows' cleaning.

3.2 Energy Supply

The optimization of energy supply of a supermarket is related to actions for the increase of the level of sustainability and energy efficiency of the site, thanks to changes in the energy mix towards the increased penetration of renewable or more sustainable sources than the purchase of electricity and fuels from the local grids.

The main opportunities for improvement identified for this field are:

- rooftop photovoltaic plant;
- building-integrated photovoltaic modules;
- photovoltaic modules on parking lots;
- micro-wind power production systems;
- solar thermal for hot water production;
- cogeneration/trigeneration;
- reactive power compensation systems;
- waste-to-energy solutions.

3.2.1 Rooftop Photovoltaic Plant

Photovoltaic plants allow the direct conversion of solar radiation into electric power, with the aim of self-producing part of the electricity needed for the supermarket operation.

Photovoltaic modules can be installed on many different supports, but the most significant opportunity for supermarkets is constituted by the installation of modules on the rooftop. The best suitable rooftops are those having a slight inclination (10-30°) and oriented to the South, but also flat roofs are acceptable, provided that modules are mounted on a suitable support structure to ensure a minimum inclination and optimal orientation.

The key steps for a high-level design of a rooftop photovoltaic plant are:

- ✓ **estimate the electricity demand** using monitoring mechanisms or consulting the electricity bills in order to understand the supermarket power needs and design the PV plant accordingly;
- ✓ **check available rooftop area** to host PV panels (inclined or flat) considering that only a fraction (around 60%) can be used for PV systems due to several factors including: other uses of the roof and obstacles (e.g. air conditioning, chimneys), shading from construction elements or neighbouring buildings, un-favourable orientation/inclination of roof parts and the required walkways to access the PV system itself for maintenance[1].
- ✓ **estimate the solar energy potential** with the support of tools or local solar strategies/policies;
- ✓ **define the plant size and the number of modules** taking into account all the previous consideration on demand, available rooftop area and solar energy potential. It should be mentioned that modules typically lose 0.5% of their power per year of operation due to

[1] https://www.sciencedirect.com/science/article/pii/S1364032119305179

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degradation (assuming a system lifetime of 20 years meaning that the remaining power at the end of that period would be 90% of the nameplate one). Additional system losses occur in the inverter where PV output is transformed into AC current and in cables. According to the scientific literature[2], a uniform value of 14% for system losses and losses due to ageing over the EU.

3.2.2 Building-Integrated Photovoltaic Modules

BIPV modules are building elements that serve a structural purpose and which simultaneously generate energy from the sun. The most common BIPV applications are skylights using transparent solar glass, structural windows, façade cladding (also opaque), double facades, and photovoltaic walkways/patio elements. These structural elements have the benefit of a long-term return of investment (e.g. they pay for themselves over their lifespan as opposed to a non-energy producing construction material).

The key steps for a high-level design of BIPV modules are:

- ✓ **estimate the electricity demand** using monitoring mechanisms or consulting the electricity bills in order to understand the supermarket power needs and design the PV plant accordingly;
- ✓ **identify the BIPV typology more appropriate to the supermarket**, the BIPV can be opaque construction elements or solar glass areas (crystalline solar cells between glass layers in typical glass construction methods);
- ✓ **estimate the BIPV plant total area,** BIPV can be deployed in skylights, atriums, ventilated facades, structural glass, shading structures in parking areas, and PV flooring / walkable elements which are typically used on roof patio areas and outdoor walkways;
- ✓ **estimate the solar energy potential** with the support of tools or local solar strategies/policies;
- ✓ **define the plant size and the number of modules** taking into account all the previous consideration on demand, available area and solar energy potential.

3.2.3 Photovoltaic Modules on Parking Lots

Supermarkets can take advantage of the external parking lots large surfaces and apply photovoltaic modules on shelters. The photovoltaic modules can be installed on shelters that have the double purposes of shading vehicles and self-producing electricity for the nearby supermarket and EVs charging.

The key steps for a high-level design of photovoltaic modules on parking lots are:

- ✓ **estimate the electricity demand** using monitoring mechanisms or consulting the electricity bills in order to understand the supermarket power needs and design the PV plant accordingly;
- ✓ **check available shelters area** and number of modules;
- ✓ **estimate the solar energy potential** with the support of tools or local solar strategies/policies;
- ✓ **define the optimal modules, hence shelters, orientation;**
- ✓ **define the plant size and the number of modules;**
- ✓ **accommodate EVs charging points.** In case the parking is provided with electric vehicles charging points, the self-produced electricity could be directly fed to the cars under recharge, with excess power supplied to the energy users in the supermarket.

[2] https://www.sciencedirect.com/science/article/pii/S1364032119305179,

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3.2.4 Micro-Wind Power Production Systems

Micro-wind power production systems are typically based on a small vertical-axis turbine installed on the building rooftop in order to produce power from the wind kinetic energy.

The key steps for a high-level design of micro-wind power production systems are:

- ✓ **estimate the electricity demand** using monitoring mechanisms or consulting the electricity bills in order to understand the supermarket power needs and design the PV plant accordingly;
- ✓ **check available rooftop area** and the number of systems that can be applied;
- ✓ **estimate the wind potential** with the support of tools or local solar strategies/policies;
- ✓ **check eventual urban constraints** in local policies;
- ✓ **calculate the size of the plant,** typical sizes of vertical axis wind turbines range from 1 to 100 kW.

3.2.5 Solar Thermal for Hot Water Production

Solar radiation might be used also to heat water for several purposes, i.e. for toilets for clients and toilets/showers for employees, as well as other domestic hot water uses in the supermarket (e.g. kitchen if present) and potentially also for space heating purposes. This opportunity is based on the installation on the rooftop or on a suitable location of solar thermal collectors and of a hot water storage, which need to be integrated with the existing sanitary hot water system in the supermarket.

The key steps for a high-level design of solar thermal for toilet's hot water production systems are:

- ✓ **estimate the hot water demand** using monitoring mechanisms or analysing number of the customers and employees using the toilets;
- ✓ **check available area** (rooftop, nearby garden or parking lot) and the number of systems that can be applied. For small and medium supermarkets, due to the limited thermal energy needs and the relatively low required water temperature (below 50-60°C), the most suitable solution is constituted by a limited number (max. 10) of forced circulation flat-plate collectors equipped with a relatively small (few m^3) water storage tank;
- ✓ **estimate the solar potential** with the support of tools or local solar strategies/policies;
- ✓ **check eventual urban constraints** in local policies;
- ✓ **calculate the size of the plant.** Solar collectors' efficiency varies since they may be of different types according to the technology (flat-plate, evacuated flat-plate, parabolic trough, parabolic dish, etc.), circulation (natural circulation, forced circulation), working fluid loop (open, closed), type of working fluid, with different types of collectors having a different efficiency, maximum temperature, etc.

3.2.6 Cogeneration/Trigeneration

Cogeneration, also called Combined Heat and Power (CHP) production is the simultaneous production of electric power and useful heat from a single source using a single device, located in proximity of the final users of electricity and heat. Heat produced from the cogeneration plant can be exploited for the heating needs of the supermarket (space heating and sanitary hot water production) but also exploited in absorption chillers for trigeneration purposes, i.e. to cover also cooling needs (space cooling and product refrigeration).

The key steps for a high-level design of cogeneration systems are:

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- ✓ **estimate the electricity and hot water demand** using monitoring mechanisms or checking the previous bills;
- ✓ **check available area** (cellar, nearby garden or parking lot);
- ✓ **decide the main energy carriers/burners**, cogeneration can be realized from fossil (e.g.: natural gas) and renewable (e.g. biomass) fuels, with environmental and economic benefits that vary depending on the energy mix of the electricity grid and on the technology adopted for heat production in the baseline situation;
- ✓ **define the plant technology**, the different technologies have a variable efficiency in terms of electricity and heat production, as well as different size (electric/thermal power), heat output by fluid (water, steam, air/gases), temperature, etc. Cogeneration can be based on many different technologies, including: internal combustion engines fuelled with natural gas, biogas or liquid biofuels; gas turbines fuelled with natural gas, biogas or liquid biofuels; steam systems (boilers + turbines) fuelled with solid biomass; fuel cells fed, emerging solution, based on natural gas;
- ✓ **check feed-in tariffs and incentives;** Both the power, the heat and the cold produced in the plant can sold to the grid (for heat/cold, this applies only in case a district heating/cooling network is locally available). The feasibility and the availability of incentives that may impact on the economic profitability of such solutions are different from Country to Country based on local legislations and grid regulations.

In the case of a small/medium-sized supermarket, the most suitable cogeneration technology is probably constituted by natural gas-fired engines, equipped with a system for heat recovery from exhausts and engine cylinders.

3.2.7 Reactive Power Compensation Systems

The power factor (cosϕ) is the ratio between the actual load and the apparent load absorbed by an electricity user and is a useful indicator measuring how efficiently the current is converted into work output. Since most electricity users (electric motors, lighting bodies, etc.) are characterized by a power factor lower than 1, power utilities allow their clients to absorb reactive power up to a certain amount, generally by imposing a minimum value of 0.9 to the power factor. When the measured power factor is lower than this minimum value, energy supply contracts foresee penalties for the clients.

The key steps for a high-level design of reactive power compensation systems are:

- ✓ **check the current power factor of the electricity system**, by analysing the electricity bills or the data from their power meter, and to act if this value is low, especially if lower than 0.9. The operation with low power factor does not only affect the electricity distribution grid outside the supermarket but also the electric system of the supermarket since it introduces additional losses that may reach considerable amounts depending on the size of the building and thus on the length of the cables;
- ✓ **investigate the need for installation of suitably sized switched capacitors** into the power distribution circuit, which have the characteristic to improve the power factor, whose value becomes closer to 1;
- ✓ **evaluate the specific location of the capacitors** based on monitoring or spot measurements of the reactive power absorption of the different energy users in the supermarket; if a specific user is identified as main responsible of the reactive power absorption, the most cost-effective option

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is to install the capacitors in parallel to its switchboards instead of installing a larger battery of capacitors at supermarket level.

3.2.8 Waste-to-Energy Solutions

Pyrolysis waste to energy solutions could be used to transform packaging and food waste into energy (saving energy costs, reducing waste disposal costs, and changing dramatically life-cycle carbon emissions).

The key steps for a high-level design of waste-to-energy systems are:

- ✓ **estimate the electricity and hot water demand** using monitoring mechanisms or checking the previous bills;
- ✓ **estimate the amount of packaging and food waste** of the supermarket;
- ✓ **check available area for the plant and the waste storage** (cellar, nearby garden or parking lot);
- ✓ **define the optimal technology for pyrolysis** according to waste typology and energy demand.

One solution targeting plastics is being demonstrated in the Waste4ME R&D project which builds and operates chemical recycling plants for plastic waste starting by 35,000 t/y. The goal is to increase the size of the waste plants in order to recycle 250.000 t/y. The first plant is planned to be built in Moerdijk, the Netherlands, in 2022.

A second solution is called the HERU, which is starting as a domestic-scale pyrolysis solution (for nearly all materials except gas and metal) and has also been deployed at a small farm and small restaurant setting. The units use pyrolysis to attain syngas and hot water. The inventors claim that units produce twice as much energy as they consume while eliminating waste.

3.3 Heating, Ventilation, Air Conditioning

This category includes systems adopted for the production, distribution and release into the supermarket indoor environment of the thermal energy needed to guarantee the comfort for applicants in all seasons of the year.

The devices covered by this category include boilers, heat pumps, chillers, air handling units for ventilation. Indeed, the typical configuration in a supermarket foresees that heat/cold are produced at centralized level and then distributed in the building with ventilation systems. However, small supermarkets may also be equipped with separate systems for heating and cooling, or standalone systems like split-type air conditioners.

The main opportunities for improvement identified for this field are:

- improvement of building envelope thermal insulation;
- high-efficiency reversible heat pumps;
- condensing gas-fired boilers for heat production;
- biomass boilers for heat production;
- heat recovery from products' refrigeration systems;
- air handling units with integrated heat recovery system;
- free cooling and evaporative cooling;
- high-efficiency motors and VFD control in ventilation systems;

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- high-efficiency pumping systems;
- smart control of HVAC systems;
- improvement of air-tightness;
- air curtain at building entrance;
- low-flow aerators on toilet water.

3.3.1 Improvement of Building Envelope Thermal Insulation

The first step in the optimization of the heating and cooling of a building is constituted by the improvement of the performance of the building envelope, i.e. walls, roof, windows and doors.

The key steps for a high-level design of building envelope thermal insulation are:

- ✓ **assess the building envelope transmittance U and losses** eventually with the support of building energy models BEM, doors and windows need to be as air-tight as possible to avoid infiltration of air from outside, which leads to an extra-consumption of electricity/fuels for heating/cooling purposes; moreover, the overall heat transfer coefficient of the doors and windows shall be as low as possible;
- ✓ **estimate the area of interventions in order to improve the envelope performance**, i.e. walls, roof, windows and doors;
- ✓ **define the retrofit measure**, for external vertical walls and roofs, the solution foresees the installation of additional layers of thermal insulation material (such as expanded/extruded polystyrene, glass wool, cork, etc.) on the external or internal surface of external walls, followed by a new finishing coating. Another potential solution for vertical walls only is constituted by a ventilated façade, which is constituted by two walls separated by a ventilated space partially provided with thermal insulation material, and a natural or mechanical ventilation system with top/bottom openings. On the other hand, on flat roofs a green roof could be realized, which implies an extension of the existing roof covered with vegetation, which acts as solar screen during summer and natural thermal insulation during winter. Old and inefficient windows, such as single-glazed ones and those with aluminium frame and no thermal break could be replaced with more efficient models (PVC frames, aluminium frames with thermal break, equipped with double-glazing and/or low emissivity/solar control glass);
- ✓ **check urban constraints**, supermarkets in historical buildings or similar cannot apport extensive interventions to the envelope;
- ✓ **check incentives**, local policies might provide support to the retrofit measures.

The benefits from the implementation of the measures described in this paragraph are variable depending on the characteristics of the building in the baseline situation, on its location and climate conditions, with savings up to 50% of the energy demand in case of joint implementation of actions on walls, roof and windows/doors.

3.3.2 High Efficiency Reversible Heat Pumps

The replacement of old equipment used for producing heat and cold for space heating and cooling purposes is an opportunity when the existing equipment is outdated (i.e.: more than ten years old) and with low efficiency compared to new models. It is estimated that an old heat pump may be operating with an average COP lower than 2, whereas recent models are much more efficient, reaching average COP values higher than 3, up to 5 depending on the type of heat source/sink that they exploit.

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The key steps for a high-level design of high efficiency reversible heat pumps are:

- ✓ **estimate the heating and cooling demand** using monitoring mechanisms or checking the previous bills in terms of consumption;
- ✓ **define the optimal heat pump technology** according to energy needs and market availability. Indeed, this measure refers to the replacement of existing heat pumps with new models that can exchange heat with three different mediums, according to the local availability:
  - air (aerothermal heat pump), which is the most common and less-efficient solution but is always applicable;
  - water (hydrothermal heat pump), which allows a higher efficiency but requires availability of a water body close to the heat pump installation site;
  - ground (geothermal heat pump), which reaches the maximum possible efficiency but requires availability of space and suitable soil characteristics for the installation (horizontal or vertical) of geothermal probes.

A potential alternative to the use of electric heat pumps using air, water or ground as heat source/sink is the adoption of absorption heat pumps for cooling purposes, fed with hot water produced from solar thermal panels. In this case, the concept is similar to the one outlined in section 3.2.6 with reference to trigeneration, but with the heat production system that is constituted by a solar thermal system like the ones mentioned in section 3.2.5. Clearly, in order to achieve a sufficient production of heat for the operation of the supermarkets' space cooling systems, the number of solar thermal modules should be significantly higher than in the case of domestic hot water production only. This solution could be of interest for supermarkets in Southern Europe, characterized by high cooling loads and contemporary high availability of solar radiation during summer.

On the other hand the measure on electric heat pumps is applicable to any supermarket of any size; the best results in terms of efficiency of the whole heating/cooling system are obtained when air handling units and fan-coils are used for space heating/cooling.

3.3.3 Condensing Gas-Fired Boilers for Heat Production

The replacement of an old boiler with a new condensing boiler leads to a fuel saving up to 20-30% compared to the baseline situation, with even higher economic savings in case fuel switching from diesel to natural gas is carried out.

Condensing boilers available on the market reach very high efficiency levels (up to 105% with reference to fuel input in terms of LHV) when used to produce water at low temperature (40-60°C); such high efficiency levels are reached thanks to the recovery of latent heat from water in the exhausts, which is used to further heat the produced water.

The key steps for a high-level design of condensing gas-fired boilers for heat production are:

- ✓ **estimate the heating demand** using monitoring mechanisms or checking the previous bills in terms of fuel consumption;
- ✓ **identify the optimal condensing boilers** available on the market;
- ✓ **check incentives**, local policies might provide support to changing old equipment with new machines.

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The main prerequisites for this intervention are, on the one hand, the availability at the site of a natural gas distribution network, which is relatively a common condition in urban areas in the EU and, on the other hand, the suitability of the space heating system to work at with lower-temperature water.

Types of space heating systems suitable for these low temperatures mainly include air handling units, fan-coils and radiant underfloor heating systems, thus most of the systems used in supermarkets.

3.3.4 Biomass Boilers for Heat Production

The main benefits associated with this solution are in the economic field (since the price of biomass per unit of energy input is much lower than that of diesel and lower also than for natural gas), whereas in the environmental field there are benefits and drawbacks: GHG emissions from biomass are conventionally considered as zero (since the amount of CO_2 emitted during combustion is the same sequestrated by the plant during its life) but local issues may arise due to the release of particle matter.

The key steps for a high-level design of biomass boilers for heat production are:

- ✓ **estimate the heating demand** using monitoring mechanisms or checking the previous bills in terms of fuel consumption;
- ✓ **estimate the type and amount of biomass** according to the local context (i.e., wood pellets, biomass chips or wood logs etc.);
- ✓ **identify the most suitable technology** available on the market considering that the technological features of biomass boilers depend on the type of material to be burnt; pellet-fuelled boilers are compact and fully-automated since they work with a pre-treated fuel with high heating value, low moisture and ash content; on the other hand, other types of boilers may require higher operation and maintenance efforts.
- ✓ **identify the area for the biomass boiler and auxiliary equipment;**
- ✓ **check incentives**, local policies might provide support to changing old equipment with new machines.

3.3.5 Heat Recovery from Products' Refrigeration Systems

Refrigeration systems work continuously and their condensers release to the surrounding environment a large amount of heat, in the form of air at 30-50°C. The recovery of part of this heat for reuse within the supermarket building is particularly of interest, since during winter, supermarkets are characterized by contemporary space heating needs and products' cooling needs, and the range of temperatures of the two heat streams is compatible.

The key steps for a high-level design of heat recovery from products' refrigeration systems are:

- ✓ **estimate the heating demand** of the supermarket using monitoring mechanisms or checking the previous bills in terms of fuel consumption;
- ✓ **estimate the type and amount of auxiliary condenser** to add to the existing ones in order to modify the space heating water circuit to be preheated or heated using waste heat from the refrigerators' condensers, or may exploit a suitable thermal energy storage solution, which may constitute an interesting solution also to match the time distribution of the resource with that of the demand;
- ✓ **check incentives**, local policies might provide support to retrofit measures.

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3.3.6 Air Handling Units with Heat Recovery Systems

Air Handling Units (AHUs) are devices where the temperature and humidity of the air is controlled and air is fed to the indoor environment. AHUs are constituted by different sections, dedicated to air heating, cooling, humidification, filtering, etc. and also include fans for extracting exhaust air from the building and supplying fresh air to the indoor environment. Air heating and cooling batteries are typically based on heat exchanging coils where hot and chilled water produced in boilers/heat pumps/chillers is circulated.

In both the heating and the cooling season, the extraction of air from the indoor environment and the supply of external air introduces a source of energy loss, since – with reference to the heating period (but the same applies to the cooling period) – hot air from inside is extracted and cold air from outside is supplied. The proposed solution foresees the addition of a section in the AHU, whose aim is to exchange heat between the extracted air and the supplied air: this allows saving energy in the heating period since the supplied air is preheated using exhaust air and in the cooling period since the supplied air is pre-cooled using exhaust air.

The key steps for a high-level design of air handling units with heat recovery systems are:

- ✓ **estimate the heating demand** of the supermarket using monitoring mechanisms or checking the previous bills in terms of fuel consumption;
- ✓ **evaluate the device technology for heat recovery** such as:
  - o recuperator heat exchanger, usually plate-type with cross-flow between hot and cold air;
  - o rotary heat exchanger, also named thermal wheel, which is based on a slowly-rotating wheel made of corrugated material that is heated by hot air and releases heat to the cold air, with higher efficiency compared to stationary recuperators;
  - o heat exchange coil or heat pipe, based on different physical principles but in any case, involving a heat exchange medium that is heated from the hot side and releases heat to the cold side, with or without the need for a circulation pump; the heat recovery efficiency is lower than the previous two solutions;
- ✓ **check incentives**, local policies that might provide support to retrofit measures.

3.3.7 Free Cooling and Evaporative Cooling

Free cooling means exploiting external air to cool the indoor environment without using the available cooling equipment; it is implemented by disabling the heating and cooling sections of the AHU, leaving only the extraction and supply fans on. This action is particularly recommended during the night and the early morning, when the outdoor temperature is lower and the supply of external air can significantly cool down the indoor environment, thus reducing the need to use the chiller for space cooling purposes during the other periods of the day.

Another possible opportunity is related to evaporative cooling, i.e. cooling supply air through direct or indirect water evaporation: the former solution is based on enhanced air humidification, whereas the latter avoids contact between the evaporating water and the supply air, thus being more suitable for supermarkets. In both cases, constraints related to indoor air quality and legionella should be carefully taken into account.

The key steps for a high-level design of free cooling systems are:

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- ✓ **check whether the existing ventilation systems are suitable for free cooling**, i.e. if the cooling sections can be disabled from the management system or manually;
- ✓ **estimate the cooling demand** of the supermarket at least at monthly level using monitoring systems, carrying out spot measurements or analysing electricity bills;
- ✓ **gather external ambient conditions** in terms of temperature and humidity, based on reliable weather data providers;
- ✓ **identify the period in which free cooling could be feasible**, by crossing demand data with external temperature data;
- ✓ **act on the ventilation system**, disabling the chiller-based cooling sections until the external air temperature is below a given threshold.

3.3.8 High Efficiency Motors and VFD Control in Ventilation Systems

All AHUs foresee at least two fans, one for the extraction of exhaust air from indoors and one for the supply of fresh air from outdoors. In the most outdated installations, these fans work at constant power and flow rate or, as only method for varying the ventilation rate, through dampers that reduce the air flow without reducing the power absorbed by the fans; more recent installations may be equipped with dual-speed fans that at least are allowed to operate at high- or low-speed, thus varying absorbed power and treated air flow rate between two different values.

The high efficiency motors and VFD control in ventilation systems allow a flexible operation to the fans through the whole range of ventilation rates and with proportional variation of the absorbed power. The control system for fans is based on inverters (or VFD – Variable Frequency Drives); the inverter varies the frequency of the power supply to the fan according to the real ventilation needs (based on temperature and/or humidity measurements), thus reducing power consumption accordingly. The reduction of electricity consumption at annual level may be in the range between 10-30%.

In addition to the improvement related to the control of electric motors with inverters, also the replacement of old electric motors with new models can lead to significant electricity savings. Indeed, according to the EU EcoDesign regulation, motors with power between 0.75 kW and 375 kW commercialized in Europe since 2017 need to be at least IE3 class, which means e.g. for a 10 kW motor that its efficiency shall be at least 92%, compared to the minimum 86% of older motors. Benefits from this action are even higher for smaller motors, thus considering the typical size and power of fans in ventilation systems, an average saving of 5-10% of the electricity consumed by the motor can be estimated.

The key steps for a high-level design of high efficiency motors and VFD control in ventilation systems are:

- ✓ **analyse the status of AHUs** in the supermarket;
- ✓ **evaluate number and power of fans** without inverters and/or with inefficient electric motors;
- ✓ **check the inverters for VFD control and the more efficient electric motors available** in the market;
- ✓ **check the availability of sensors** (e.g.: temperature, humidity, CO concentration, etc.) that could provide inputs to the VFD;
- ✓ **replace the motor/install the VFD** and define suitable control logics.

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3.3.9 High-Efficiency Pumping Systems

Significant electricity savings can be obtained through the replacement of the electric motors and the control of the water pumping through VFD in the pumps used to distribute the hot/refrigerated water in the supermarket. In this case, the benefits are in the range of 10-30% for VFD control and 5-10% for electric motors replacement.

The key steps for a high-level design of high efficiency pumping systems are:

- ✓ **analyse the status of pumps** in the supermarket;
- ✓ **evaluate number and power of pumps** without inverters and/or with inefficient electric motors;
- ✓ **check the inverters for VFD control and the more efficient electric motors available** in the market;
- ✓ **check the availability of sensors** (e.g.: temperature, flow rate, etc.) that could provide inputs to the VFD;
- ✓ **replace the motor/install the VFD** and define suitable control logics.

3.3.10 Smart Control of HVAC Systems

The installation of sensors for monitoring temperature, humidity and other (e.g.: carbon monoxide concentration) throughout the whole supermarket building, feeding the monitored data to a smart HVAC control system or to a Building Management System (BMS) can provide significant benefits in terms of energy consumptions.

The key steps for a high-level design of smart control of HVAC systems are:

- ✓ **analyse the current status of the supermarket** in terms of BMS and sensors;
- ✓ **identify locations for additional sensors**;
- ✓ **check the sensors and BMS software available** in the market;
- ✓ **evaluate the infrastructure needed** for data transmission (cabled/wireless) and define its layout.

The availability of monitored data related to indoor air quality and the implementation of suitable control logics that take into account the structure of the HVAC system in the supermarket can be used to provide inputs to the inverters controlling the fans in ventilation systems, the pumps for distribution of hot/refrigerated water, the compressors of the heat pumps/chillers.

3.3.11 Improvement of Air-Tightness

In order to minimize the energy losses related to the frequent opening of doors due to the entrance and exit of customers, the present measure suggests, where possible, the replacement of entrances with single doors with a vestibule entrance located between two doors. The creation of this space between the two doors reduces the direct air exchange with outdoors, thus increasing thermal comfort and reducing energy consumption for heating and cooling.

The key steps for a high-level design of air-tightness improvements are:

- ✓ **identify the entrances with single doors** that can be replaced with a vestibule entrance located between two doors;
- ✓ **check the availability of spaces** for the installation of the vestibule entrance.

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The feasibility of this measure mainly depends on the availability of space, but the benefits are considerable and may reach 5% of the energy consumption for heating and cooling purposes, depending on the supermarket location and climate conditions.

3.3.12 Air Curtain at Building Entrance

Another possibility to reduce the air exchange between the indoor and the outdoor environment is the installation of an air curtain (or air barrier, or air door) at the supermarket entrance. This can be performed by installing an air blower facing downwards on the entrance (between the two doors if the previous measure is implemented).

The key steps for a high-level design of air-curtains at the building entrance are:

- ✓ **identify the entrances with single doors** where air blowers can be installed;
- ✓ **check the air curtains available** in the market and their characteristics in terms of size, power, air flow rate and temperature, etc.;
- ✓ **identify the most suitable air curtain** based on specific needs.

This measure reduces the air exchange between the two sides by 60-80% and further reduces by around 5% the energy consumption for heating and cooling purposes, depending on the supermarket location and climate conditions.

3.3.13 Low-Flow Aerators on Toilet Water

Although it is typically considered a water saving measure rather than an energy saving measure, the installation of low-flow aerators on the toilets of the supermarket, both for clients and for staff, is also an energy saving option. Indeed, since it is applied both to cold and hot water taps, it allows a reduction of energy consumption for sanitary hot water production, typically carried out through electric or natural gas-fired boilers.

The key steps for a high-level design of low-flow aerators on the toilets are:

- ✓ **identify the toilets taps** where the low-flow aerators can be installed;
- ✓ **check the low-flow aerators available** in the market;
- ✓ **identify the most suitable aerator** based on specific needs.

3.4 Lighting

Lighting is responsible for a relevant share of the energy consumptions of the supermarket, especially if carried out with other technologies than LEDs. Lamps in supermarkets are typically used for the whole opening period in order to ensure the desired visibility of products, whereas in external areas they are always used during the night, also for security reasons.

The main opportunities for improvement identified for this field are:

- LED lighting of indoor/outdoor spaces;
- solar-powered lighting poles in outdoor areas;
- natural lighting sensors in highly-fenestrated areas;
- timers on indoor lighting systems;
- movement sensors;

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- smart control of lighting systems in indoor/outdoor areas.

3.4.1 LED Lighting in Indoor/Outdoor Spaces

LED lamps are a consolidated and widespread technology for high-efficiency lighting of indoor and outdoor areas and are implemented in the vast majority of supermarkets. Where this measure has not been implemented yet, the recommendation is to implement it as soon as possible in order to reduce power absorption for lighting while improving visual comfort in the supermarket.

They have instant start-up, most of them are dimmable and do not suffer from flicker and their lifetime is not impacted by many on-off cycles, which makes them ideal for control through natural lighting and movement sensors.

The key steps for a high-level design of LED lighting in indoor/outdoor spaces are:

- ✓ **identify the lamps** in the supermarket that need to be replaced, creating a list with luminous flux, size and power in the baseline situation;
- ✓ **identify on the market suitable lamps** to carry out 1:1 replacement (in terms of luminous flux and size) of old lamps;
- ✓ **carry out a dedicated lighting study** if needed, to evaluate the correct distribution of light with reference to the specific needs of the supermarket.

3.4.2 Solar-Powered Lighting Poles in Outdoor Areas

Another opportunity for lighting outdoor of supermarkets is the adoption of solar-powered lighting poles equipped with an integrated photovoltaic module and battery to self-produce and store the electricity required for the lighting pole. The PV module and the battery are designed to allow 3-5 days of power supply to the lamp even under low-solar radiation and bad weather conditions; the battery is generally guaranteed for replacement every 8-12 years, which corresponds approximately to the lifetime of the installed LED lamps if working on average for 12 h/d.

The key steps for a high-level design of solar-powered lighting poles in outdoor areas are:

- ✓ **identify the outdoor lights** that can be replaced by solar powered lighting poles;
- ✓ **estimate the solar energy potential** with the support of tools or local documents;
- ✓ **identify on the market suitable solar lamps** to carry out 1:1 replacement (in terms of luminous flux and size) of old lamps.

This allows reducing the installed power for external lighting compared to the baseline and, furthermore, self-producing the electricity needed from these users; the overall impact is therefore the reduction to zero of the purchase of electricity from the grid for external lighting and of the associated emissions.

3.4.3 Natural Lighting Sensors in Highly Fenestrated Areas

The maximization of the use of daylight as an alternative to electric lighting is an interesting opportunity for areas provided with large windows in the supermarket. This can be obtained by installing on the lamps closer to the windows a natural lighting sensor that reduces the luminous flux provided by the lamps according to the amount of available natural lighting. Thanks to the properties of LED lamps, this is feasible, does not impact on the lamps' lifetime and reduces the power absorption proportionally to the provided luminous flux.

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The key steps for a high-level design of natural lighting sensors in highly fenestrated areas are:

- ✓ **identify the lamps** in areas provided with large windows in the supermarket that can be coupled with natural lighting sensors;
- ✓ **analyse the power supply** of the selected lamps to evaluate the number of sensors needed to control the selected lamps;
- ✓ **analyse the layout** and use of the area to identify the most suitable location of the sensors.

3.4.4 Timers on Indoor Lighting Systems

There are many areas of the supermarket where lamps remain switched on constantly, even out of the opening hours and in hours with no human presence. To avoid this, it is recommended to install timers on all lighting systems except for those needed for safety and security reasons, in order to switch off (or reduce the luminous flux of) all non-required lighting systems and avoid the corresponding power absorption.

The key steps for a high-level design of timers on indoor lighting systems are:

- ✓ **identify the areas** where timers can be applied to switch off the lamps, this measure can be applied also to lamps installed within refrigerated cabinets, that typically remain constantly switched on;
- ✓ **analyse the power supply** of the selected lamps to evaluate the number of timers needed to control the selected lamps;
- ✓ **analyse the layout** and use of the area to identify the most suitable set-up for timers.

3.4.5 Movement Sensors

In areas like warehouses, changing rooms, toilets, in order to avoid lamps remaining switched on when nobody is in the room, the installation of movement sensors/presence detectors is suggested. With these sensors, on/off control of lighting systems is carried out automatically based on the presence of persons in the area.

The key steps for a high-level design of movement sensors are:

- ✓ **identify the areas** where sensors can be applied to switch off the lamps;
- ✓ **analyse the power supply** of the selected lamps to evaluate the number of sensors needed to control the selected lamps;
- ✓ **analyse the layout** and use of the area (specifically to guarantee the safety of the personnel working in the area) and identify the most suitable location of the sensors and timing of the on/off cycles.

3.4.6 Smart Control of Lighting Systems in Indoor/Outdoor Areas

An integrated approach to lighting could be implemented into a dedicated software, which could receive inputs from the different sensors located across the building (natural lighting, presence, etc.) and consequently optimize the lighting level in the different areas of the supermarket.

The key steps for a high-level design of smart control of lighting systems in indoor/outdoor areas are:

- ✓ **identify suitable software** (Lighting Management Systems or into a more general Building Energy Management System, covering also other utilities);

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- ✓ **evaluate the sensors available** and the potential need for new sensors in line with the previous paragraphs;
- ✓ **elaborate an optimized lighting scheme** that will be implemented by the software.

3.5 Products' Refrigeration

The refrigeration of the food products, both in cabinets and freezers in the sale area and in the refrigerated storage areas in warehouses are responsible for the largest share of energy consumptions in the supermarket. This is strongly related with the need to maintain the quality of products in line with the applicable laws.

Devices in this category include on the demand side the cabinets, freezers and cold storage rooms and on the supply side the refrigerators systems, composed of compressors, evaporators and condensers in line with the needs of the thermodynamic cycle applied for cooling. Refrigeration systems may be centralized (i.e. adopting a remote unit for compressors and condensers and local units for evaporators) or standalone (i.e. like in domestic fridges and freezers, all cooling equipment is concentrated at the cabinet).

The main opportunities for improvement identified for this field are:

- advanced design of refrigerated cabinets;
- high-efficiency refrigeration systems;
- use of centralized instead of standalone refrigerating equipment;
- advanced maintenance of products refrigeration systems.

3.5.1 Advanced Design of Refrigerated Cabinets

The reduction of the energy demand of the refrigerated cabinets can be done through different solutions that are presented in the present paragraph, which mainly deal with the minimization of energy losses from doors.

The key steps for a high-level design for reduction of the energy demand of the refrigerated cabinets are:

- ✓ **identify the optimal measures:**
  - the installation of **doors** on open cabinets is a simple and low-cost option to reduce energy losses thanks to the separation of the indoor refrigerated space from the outdoor environment; this measure is also expected to avoid overcooling of the aisle where refrigerated cabinets are located, thus increasing thermal comfort for clients;
  - the installation of single or multiple air **curtains**, of strip curtains (made of transparent and flexible material) or of night blinds (to be closed during supermarket closing hours);
  - **anti-sweat electric heaters** are typically used to avoid condensation on the glass of the refrigerated cabinets' doors; the improvement of their control system to reduce power absorption, or better the adoption of an anti-fogging glass;
  - the adoption of **control systems for defrost** can reduce the electricity consumption of frozen food cabinets with the scope of contrasting freezing on the evaporator tubes;
  - benefits can be achieved by **switching off or reducing the luminous flux** of lamps in cabinets during closing hours (or when no clients are present, thanks to movement/presence sensors), and also by **installing cabinets' lighting systems out of the**

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refrigerated area, in order to minimize their heating load and the consequent consumption for cooling.

- ✓ **identify the most suitable models** of the devices to be installed based on the size and power of the existing systems, in order to ensure the feasibility of the retrofitting option.

3.5.2 High Efficiency Refrigeration Systems

The energy consumption of the refrigerated cabinets can be reduced thanks to different types of solutions, mainly related to the compressors of the cooling systems, the type of refrigerant fluid used and the distribution of the working fluid along the cooling circuit.

The key steps for a high-level design for reduction of the energy consumption of the refrigerated cabinets are:

- ✓ **identify the areas of interventions:**
  - the **cooling circuit** is characterized by a cold side, i.e. that of the refrigerated cabinet/storage, whose temperature is fixed, and by a hot side, i.e. the outdoor environment, whose temperature is variable during the day and the year. The head pressure of the thermodynamic cycle is therefore variable with the external temperature and therefore benefits can be achieved if the compressor of the cooling system is able to vary its load with the cooling needs. This can be achieved by providing it with a control system based on VFD, which can therefore reduce the electricity consumption of the compressors by an extent variable in the range 15-30%.
  - the **working fluid** of the cooling circuit, the most relevant opportunity is related to the adoption of cooling systems based on ammonia (R717) or carbon dioxide (R744) as cooling medium; however, the retrofitting of existing cooling systems to work with these fluids is difficult, thus the replacement of the devices is the best option.
    For retrofitting purposes, the best option is the replacement of organic working fluids characterized by high ozone depletion potential and global warming potential like CFCs and HCFCs with more eco-friendly substances like HFCs. The fluids with the highest environmental impact have already been banned in the EU and other will be banned in the upcoming years, but at the moment the most recommended replacements are:
    - R407A for R404A, with a reduction of the fluid GWP and energy efficiency benefits due to a reduction of the operational pressure;
    - R407C for R507A, allowing a reduction of GWP;
    - R1234yf for 134A, leading to a reduction of GWP, but not feasible in low-temperature systems.
  - **piping**, changes in the layout and path of the refrigeration circuit pipes can be done in order to minimize the pressure drops, thus reducing power absorption of compressors; since refrigeration circuits have a considerable length, also the thermal insulation of the pipes is very important, with energy savings that may reach 5% of the electricity use of the compressors.

3.5.3 Use of Centralized instead of Standalone Refrigerating Equipment

Centralized refrigeration systems are characterized by a single remote outdoor unit (that includes the air-cooled condenser and the compressors of the refrigerating cycle) and many indoor units (that include the

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evaporators, located in the refrigerated spaces), connected through insulated pipes, where refrigerant fluid flows. Centralized systems are more efficient than standalone refrigerators and avoid the release of the waste heat generated into the supermarket.

The key steps for a high-level design of centralized refrigerating equipment are:

- ✓ **identify the refrigeration systems** to be replaced by a centralized one;
- ✓ **estimate the size of the centralized unit** based on the refrigeration demand;
- ✓ **identify the optimal technology** available in the market.

3.5.4 Advanced Maintenance of Products Refrigeration Systems

A regular maintenance on refrigeration systems allows to keep the best operating conditions in terms of efficiency and minimization of power absorption.

The key steps for a high-level design of advanced maintenance of products refrigeration systems are:

- ✓ **identify the refrigerant leakages**, which lead to a reduction of refrigeration efficiency (as an effect of the increased compressors' load and working time) as well as to direct emissions characterized by GWP impact;
- ✓ **implement cleaning schedules** for the main devices (condensers/evaporators), since dust and dirt in general worsen the heat exchange capacity, thus implying an increase of the temperature and a higher power absorption for cooling;
- ✓ **check local temperature set-points**, in order to keep the highest temperature that ensures the correct conservation of the products but minimizes energy consumption for cooling;
- ✓ **check the correct loading of cabinets**, since overloading increases energy consumption for cooling, contemporarily worsening product conservation due to the more difficult distribution of cold inside the cabinet.

3.6 The Opportunity of Energy Communities

Energy communities incentivize the production, storage and use of renewable and more sustainable energy at the local level between members of the community. Energy communities are defined in two separate laws of the Clean Energy Package, the revised Renewable Energy Directive (EU) 2018/2001 which sets the framework for 'renewable energy communities' covering renewable energy and the revised Internal Electricity Market Directive (EU) 2019/944 which introduces new roles and responsibilities for 'citizen energy communities' in the energy system covering all types of electricity. Such communities are a relatively new development that is interesting within the context of Super Heero for several reasons. First, they provide a new way to connect supermarkets, their clientele, and local area residents/businesses. Second and increasingly, there are incentives surrounding the formation and implementation of energy communities which can improve the return of investment of renovation measures. Third, there is a niche of supermarkets that are nested directly within housing development projects/areas often under a common developer / managing agency. These, in particular, are easy to conceptualize as first movers into energy community implementations.

Italy, one focus country for Super Heero, has recently published interesting incentives for Energy Communities. There are two types: jointly acting renewable self-consumers AND renewable energy

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communities. Jointly acting renewable self-consumers are final energy users that are located in the same building or apartment block (e.g. condominium) where shared walls are present. Renewable energy communities are instead a legal entity whose members are located in the same piece of the distribution grid (below the same MV/LV substation) and whose primary business is not the production of energy.

For such scenarios, a Ministerial Decree dated 16 September 2020 introduced an incentive of 100 euro/MWh for the electricity that jointly acting renewable self-consumers jointly self-consume and an incentive of 110 euro/MWh for the electricity that members of a renewable energy community share. This incentive is granted for 20 years. Jointly self-consumed or shared electricity is, for each hour of the day, the minimum BETWEEN the sum of all the energy withdrawn by all community members AND the sum of all the energy injected by all community members.

In Spain, a second focus country for Super Heero implementation has not yet implemented national policy on Energy Communities but collective self-consumption is possible.

3.7 Other Areas

This category includes all types of energy users not included in the previous categories, such as offices, warehouses' logistic equipment, lifts, etc.

The main opportunities for improvement identified for this field are:

- retrofitting of lifts;
- retrofitting of internal logistic equipment;
- retrofitting of office equipment.

3.7.1 Retrofitting of Lifts

Elevators present several opportunities for the reduction of energy consumption.

The key steps for a high-level design of lift's retrofitting are:

- ✓ **install VFD on electric motors**, provided with auto-standby device, to allow a controlled start and operation of motors, car movement and comfort for passengers, but also a reduction of power absorption at partial load and during standby;
- ✓ **install regenerative drives** that accumulate energy during the braking phase to be used in the next operational cycle instead of dissipating it through braking resistors;
- ✓ **optimize the counter-balance system**, which reduces the load of the drive system, thus allowing a reduction of motors' size and of electricity consumption;
- ✓ **switch the cabin lighting to LED lamps**, and couple them with use of sensors to switch lighting off when the elevator is not in use;
- ✓ **minimize the ventilation rate** (if available) when the lift is not in use.

3.7.2 Retrofitting of Internal Logistic Equipment

In supermarkets' warehouses, typically different types of forklifts are used for internal logistic purposes, covering the whole cycle from the discharge of goods from trucks to the storage and subsequent positioning on the supermarkets' shelves.

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The key steps for a high-level design of the retrofitting of the fleet of forklifts are:

- ✓ **lower electricity consumption** per hour and unit of payload/distance;
- ✓ **install high-efficiency batteries** over the whole charge/discharge cycle;
- ✓ **introduce regenerative drives** that accumulate energy during the braking phase instead of dissipating it;
- ✓ **install smart chargers** optimizing load management and avoiding idle power absorption when forklifts are not plugged or are plugged but charging is completed.

3.7.3 Retrofitting of Office Equipment

Although having a limited impact on the energy balance of the supermarket, offices also present a certain potential for the improvement of energy efficiency.

The key steps for a high-level design of the retrofitting of office equipment are:

- ✓ **switch to LED lamps** as suggested for other areas of the supermarket;
- ✓ **use high efficiency heating and cooling systems** as suggested for other areas of the supermarket;
- ✓ **use computers, monitors and printers with low energy consumption**; use shared printers and limit as much as possible printing;
- ✓ **elaborate guidelines for employees** aimed at the correct management of office devices during and at the end of the work activities (e.g.: switching off lighting and HVAC systems, computers, devices chargers, etc.);
- ✓ **adopt good "green procurement"** practices, i.e. minimizing the total cost over the devices' lifetime (purchase plus energy consumption and maintenance during operation) rather than purchasing the model that ensures the lowest initial cost.

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4. Potential Pathways to Energy Efficiency

This chapter focuses on the identification of the potential pathways to energy efficiency for supermarkets, depending on the baseline situation and on a number of boundary conditions.

Based on the baseline conditions of the supermarkets (old, medium, new) and on the geographical location (Northern or Southern Europe), a number of different starting points have been identified, and then energy efficiency renovation packages have been created characterized by a different depth and consequently by a different investment.

The renovation packages have been created by selecting from the catalogue of potential energy efficiency actions defined in Chapter 3 the most suitable ones for the specific category of supermarkets in terms of level of energy efficiency, location/climate and depth of renovation needed. For instance, a basic renovation package for an old supermarket consists of the easy-to-implement and cheap interventions that can significantly improve the level of energy efficiency of the supermarket without requiring a too large investment for the company. On the other hand, for medium and newer supermarkets, the selected actions are those allowing a further energy efficiency improvement beyond the level already achieved thanks to the implemented actions.

As concerns the structure of the chapter: based on clusters created to cover the analysis of these conditions (described in paragraph 4.1), 18 renovation packages are created (paragraph 4.2) and their technical and financial performance is evaluated (paragraph 4.3) in terms of achievable energy savings, investment needed, payback time. Further considerations based on additional features of the supermarkets not covered in the 18 packages are then given (paragraph 4.4).

4.1 Definition of Supermarkets' and Measures' Clusters

The clusters of supermarkets and measures on which the present analysis is carried out are defined based on the following main features:

- supermarket baseline conditions;
- reference climate conditions;
- depth of energy efficiency renovation;
- further supermarket features.

The following paragraphs present the categories identified within each of the above-mentioned areas.

4.1.1 Supermarket Baseline Conditions

For the present assessment, European supermarkets are clustered into three main groups (summarized in Table 1) based on their baseline conditions under an energy efficiency perspective:

- old supermarket with low-efficiency devices – energy use per unit of area higher than 700 $kWh/m^2/y$;
- supermarket in average conditions – energy use per unit of area between 400 and 700 $kWh/m^2/y$;

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- recent supermarket with state-of-the-art technologies – energy use per unit of area below 400 kWh/m^2/y

The values presented above are based on the typical energy consumptions of supermarkets, as described in SUPER HEERO D2.1 based on a review of literature studies on the topic.

In addition to the above-mentioned qualitative indicator, calculated as final energy consumption per unit of area, a supermarket can be assigned to one or another category also depending on qualitative considerations related to the status of the building and of the devices/systems installed.

Table 1: Supermarket Baseline Conditions

	Old Supermarket with Low-Efficiency Devices	**Supermarket in Average Conditions**	**Recent Supermarket with State-of-the-Art Technologies**
Energy use per unit of area kWh/m^2/y	> 700	400 – 700	< 400

4.1.2 Reference Climate Conditions

Supermarkets are characterized by different features and energy uses depending on their geographical location and on the consequent climate conditions, which directly influence the energy demand for space heating and cooling, product refrigeration and lighting. For the purpose of the present assessment, Europe is divided into two macro-areas (summarized in Table 2) for climate-related considerations:

- Northern Europe, including the Countries and territories having a latitude of 47° or higher, including all Central Europe and Scandinavian Countries; this area is characterized by cool to warm summers and cool winters with frequent overcast skies;
- Southern Europe, including the Countries and territories having a latitude lower than 47°, mostly on the Mediterranean Sea; this area is characterized by warm to hot, dry summers and cool to mild winters and frequent sunny skies.

Table 2: Supermarket Geographical Location / Climate Conditions

	Northern Europe	**Southern Europe**
Latitude	> 47°	< 47°

4.1.3 Depth of Energy Efficiency Renovation

The energy efficiency improvements that can be achieved by a supermarket thanks to renovation actions strongly depend on the investment that the supermarket is able to mobilize. In order to analyse the

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investment needs, the proposed renovation packages have been clustered into three main categories, (summarized in Table 3) based on the investment needed for their implementation:

- deep renovation – having an investment need higher than 500 €/m^2;
- partial renovation – having an investment need between 200 and 500 €/m^2;
- basic renovation – having an investment need below 200 €/m^2.

Table 3: Depth of Energy Efficiency Renovation

	Deep Renovation €€€	**Partial Renovation €€**	**Basic Renovation €**
Investment needed	> 500 €/m^2	200 – 500 €/m^2	< 200 €/m^2

4.1.4 Further Supermarket Features

In addition to the aspects covered in the previous sections concerning baseline conditions, geographical location and renovation depth, other factors influencing the applicable measures and the achievable energy efficiency improvements include the following items:

- supermarket ownership model (independent supermarket, franchising, supermarket directly-operated by the chain, etc.);
- building typology (standalone building, supermarket at the ground floor of a multi-storey building, presence of external parking, etc.);
- "size" in terms of annual operating hours and/or sales volumes.

It is highlighted that the size of the supermarkets in terms of retail area is a less important factor – although not negligible – to be considered; in the present analysis, all the quantitative evaluations done are referred to the unit of area and the potential indirect impact of the area on the specific consumptions is assumed to be covered by the uncertainty correlated to the high-level of this analysis compared to a site-specific one (e.g.: energy audit).

Due to the more limited impact of these additional supermarket features compared to the three main ones discussed in the previous paragraphs, they will not be subject of dedicated renovation packages but will only be considered qualitatively in the comments to the main packages, as well as included in all site-specific activities like energy audits and like the case study presented in Chapter 5.

4.2 Definition of Supermarkets' Renovation Packages

Based on the clusters defined in the previous paragraph, the renovation packages are created.

To start, two main criteria are considered for the creation of the packages, which are the baseline conditions of the supermarkets (old/average/recent) and the renovation depth (deep/partial/basic). Then, for each of these nine cases, two packages are identified, corresponding to the geographical

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location/climate conditions, in Northern or Southern Europe. Based on this approach, summarized in Table 4, the 18 renovation packages are therefore created.

It is highlighted that the additional features of the supermarkets introduced in paragraph 4.1.4 and related to ownership model, building typology, sales volumes, etc. are not considered in the definition of the renovation packages, but additional considerations to cover also these supermarkets' features are outlined in paragraph 4.4.

Table 4: Supermarkets' Energy Efficiency Renovation Packages

		Renovation Depth		
		Deep Renovation €€€	**Partial Renovation €€**	**Basic Renovation €**
Baseline Conditions	**Old Supermarket with Low-Efficiency Devices**	Package 1a (Northern Europe) Package 1b (Southern Europe)	Package 2a (Northern Europe) Package 3b (Southern Europe)	Package 3a (Northern Europe) Package 3b (Southern Europe)
	Supermarket in Average Conditions	Package 4a (Northern Europe) Package 4b (Southern Europe)	Package 5a (Northern Europe) Package 5b (Southern Europe)	Package 6a (Northern Europe) Package 6b (Southern Europe)
	Recent Supermarket with State-of-the-Art Technologies	Package 7a (Northern Europe) Package 7b (Southern Europe)	Package 8a (Northern Europe) Package 8b (Southern Europe)	Package 9a (Northern Europe) Package 9b (Southern Europe)

4.3 Technical and Financial Features of Renovation Packages

For each of the renovation packages framed in the previous paragraph, a set of up to seven among the most applicable energy efficiency measures were selected.

Due to the high level of the present analysis, which is a guideline for supermarkets in their path to energy efficiency, the measures are selected based on the features of a typical supermarket and are not tailored on a specific site; for this reason, one or more measures could be not applicable to all sites and a detailed analysis is always needed before defining a tailored energy efficiency action plans for a supermarket.

Under this main assumption, the most common energy efficiency interventions that were considered in the creation of the renovation packages are:

- LED lighting, applicable to all supermarkets where this measure has not been implemented yet, i.e. under the assumptions of this study, the "old" and "average" ones;
- installation of doors on refrigerated cabinets, which is recommended especially to "old" supermarkets where they typically were not present;

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- fine-tuning of HVAC systems through the improved control of ventilation, hot/chilled water circulation and temperature/humidity control through VFD installation on electric motors, recommended to "old" and "average" supermarkets;
- use of high-efficiency heat pumps for space heating and cooling, fed with electricity from renewable sources, which is recommended especially to "old" and "average" supermarkets in Southern Europe willing to undergo a "deep" or "partial" renovation;
- the improvement of refrigeration systems' efficiency, applicable to "old" and "average" supermarkets willing to implement a "deep" or "partial" renovation;
- improvement of the energy performance of the building envelope, applicable only in case of "deep" renovations to "old" and "average" supermarkets;
- cogeneration of heat and power, especially applicable in Northern Europe for "old" and "medium" supermarkets;
- self-production of hot water through solar thermal panels, applicable in Southern Europe to "new" supermarkets or to "average" supermarkets willing to implement a "deep" renovation;
- heat recovery from refrigeration systems for self-consumption or sale of heat to the local district heating network (if present), typically applicable in Northern Europe and mainly to "new" supermarkets;
- smart control of lighting systems and other electric loads, recommended in particular to "new" supermarkets where most of the basic energy efficiency actions have already been implemented.

The main parameters of the selected energy efficiency interventions were then estimated, which include:

- the achievable energy savings, calculated based on the typical breakdown of energy consumptions in the reference supermarkets and on the typical performance/efficiency of the proposed devices/solutions;
- the investment needed, evaluated based on typical costs of the selected devices gathered by RINA within its energy auditing experience;
- the achievable cost savings, calculated based on the evaluated energy savings and on an energy supply cost of 150 €/MWh for electricity and 30 €/MWh for natural gas (i.e. those typical of the Italian market);
- the pay-back of the investment, calculated as the ratio between the investment needed and the annual economic savings, without any discount of cash flows.

These values were calculated making reference to a **400 m^2 supermarket** (medium-small, which is representative of many of the supermarkets targeted by the SUPER HEERO project) and then transposed into specific indicators per unit of area by dividing the values calculated for the reference supermarket by its floor area. The values obtained following this approach are presented in Table 5.

It is worth highlighting that the values presented in the Table – when extrapolated to different supermarkets in different locations – may be affected by an uncertainty that is estimated at approximately ±50%, due to several reasons:

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- the investment needs that are not tailored on the specific site features and, in addition, might be not linear with the size of the supermarket;
- the assumption on the investment costs of the different technologies, which are assumed not to vary significantly with the location of the supermarket, e.g. due to different labour costs;
- the assumption on the baseline energy uses of the supermarket;
- the assumption on energy prices (based on Eurostat data, electricity prices in the EU in 2020 ranged between the 100 €/MWh for Bulgaria and the 300 €/MWh for Germany).

Nevertheless, the presented values can constitute an interesting source of data for supermarkets willing to roughly estimate the costs and benefits that they could achieve thanks to the implementation of the proposed renovation packages.

Based on the analysis of the values presented in Table 5, it can be noticed that several opportunities for renovation measures exist, characterized by an investment below or around 200,000 € (for a 400 m^2 supermarket) and a payback below 5-6 years.

Looking at the different rows, it can be highlighted as expected that basic renovation measures on old supermarkets are those characterized by the best cost-benefit ratio, since they aim at taking “low-hanging fruits”; on the other hand, the actions on medium-level and new supermarkets are generally slightly less profitable, being focused on a site having already adopted the basic best practices. However, in the latter case, energy efficiency actions could be implemented for corporate social responsibility purposes or to meet company sustainability targets, thus the company might accept a slightly lower return of investment in order to reach other important objectives.

To conclude, it is highlighted that although characterized by very good technical performances and an acceptable financial return, these interventions could be sometimes difficult to finance – especially by small-medium supermarkets – through conventional financing approaches. For this reason, the innovative financing measures developed in the SUPER HEERO project are particularly of interest.

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Table 5: Supermarkets' Energy Efficiency Renovation Packages – Technical and Financial Features

	Categories	Measures Included	Energy Savings kWh/m²/y	Budget Needed €/m²	Economic Savings €/m²/y	Pay-Back Time y
Package 1a	Old supermarket, Northern Europe, deep renovation	LED lighting, Cabinets doors, HVAC fine-tuning, Cogeneration, High-eff. refrigeration, Envelope insulation	290.8	521.3	109.3	4.8
Package 1b	Old supermarket, Southern Europe, deep renovation	LED lighting, Cabinets doors, HVAC fine-tuning, Photovoltaic, High-eff. refrigeration, Envelope insulation, High-eff. heat pump	374.2	521.3	75.6	6.9
Package 2a	Old supermarket, Northern Europe, partial renovation	LED lighting, Cabinets doors, HVAC fine-tuning, Cogeneration, High-eff. refrigeration	190.8	421.3	94.3	4.5
Package 2b	Old supermarket, Southern Europe, partial renovation	LED lighting, Cabinets doors, HVAC fine-tuning, Photovoltaic, High-eff. refrigeration, High-eff. heat pump	307.5	421.3	65.6	6.4

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	Categories	Measures Included	Energy Savings kWh/m²/y	Budget Needed €/m²	Economic Savings €/m²/y	Pay-Back Time y
Package 3a	Old supermarket, Northern Europe, basic renovation	LED lighting, Cabinets doors, HVAC fine-tuning	107.5	46.3	16.1	2.9
Package 3b	Old supermarket, Southern Europe, basic renovation	LED lighting, Cabinets doors, HVAC fine-tuning	107.5	46.3	16.1	2.9
Package 4a	Average supermarket, Northern Europe, deep renovation	LED lighting, HVAC fine-tuning, Cogeneration, High-eff. refrigeration, Envelope insulation	249.2	506.3	103.0	4.9
Package 4b	Average supermarket, Southern Europe, deep renovation	LED lighting, HVAC fine-tuning, Photovoltaic, High-eff. refrigeration, Envelope insulation	279.2	493.8	61.4	8.0
Package 5a	Average supermarket, Northern Europe, partial renovation	LED lighting, HVAC fine-tuning, Cogeneration, High-eff. refrigeration	149.2	406.3	88.0	4.6
Package 5b	Average supermarket, Southern Europe, partial renovation	LED lighting, HVAC fine-tuning, Photovoltaic, High-eff. refrigeration	245.8	418.8	56.4	7.4

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programme under grant agreement No 894404

	Categories	Measures Included	Energy Savings kWh/m²/y	Budget Needed €/m²	Economic Savings €/m²/y	Pay-Back Time y
Package 6a	Average supermarket, Northern Europe, basic renovation	LED lighting, HVAC fine-tuning, Cogeneration	82.5	281.3	78.0	3.6
Package 6b	Average supermarket, Southern Europe, basic renovation	LED lighting, HVAC fine-tuning, Photovoltaic	82.5	131.3	31.9	4.1
Package 7a	New supermarket, Northern Europe, deep renovation	LED lighting, Heat recovery from refr., Smart load manag.	112.5	78.8	16.9	4.7
Package 7b	New supermarket, Southern Europe, deep renovation	LED lighting, Solar thermal, Smart load manag.	59.2	41.3	8.9	4.6
Package 8a	New supermarket, Northern Europe, partial renovation	LED lighting, Heat recovery from refr., Smart load manag.	112.5	78.8	16.9	4.7
Package 8b	New supermarket, Southern Europe, partial renovation	LED lighting, Solar thermal, Smart load manag.	59.2	41.3	8.9	4.6

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	Categories	Measures Included	Energy Savings kWh/m²/y	Budget Needed €/m²	Economic Savings €/m²/y	Pay-Back Time y
Package 9a	**New supermarket, Northern Europe, basic renovation**	**LED lighting, Smart load manag.**	**45.8**	**28.8**	**6.9**	**4.2**
Package 9b	New supermarket, Southern Europe, basic renovation	LED lighting, Smart load manag.	45.8	28.8	6.9	4.2

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4.4 Considerations based on Further Supermarket Features

As mentioned in the description of the general approach to energy efficiency renovation packages, there are many factors influencing the applicability, technical feasibility and economic profitability of energy efficiency actions, in addition to those considered in the creation of the renovation packages (baseline situation, climate conditions, depth of renovation).

The aim of this paragraph is to provide additional qualitative considerations on these topics, which are summarized under three main categories:

- supermarket ownership model (independent supermarket, franchising, supermarket directly-operated by the chain, etc.);
- building typology (standalone building, supermarket at the ground floor of a multi-storey building, presence of external parking, etc.);
- “size” in terms of annual operating hours and/or sales volumes.

As concerns the ownership models:

- no significant impact is expected on the applicability of the technologies proposed;
- some differences may exist regarding the decision-making and the financing aspects for the energy efficiency actions; indeed, on one hand an independent supermarket or a franchisee may have more room for defining its own budget to be allocated to energy efficiency actions compared to a supermarket belonging to a large chain where the budget is annually defined at corporate level; on the other hand, a large company managing many supermarkets can more easily allocate the budget needed for energy efficiency actions with own funds or recurring to corporate loans and credit lines for gathering the funds needed; similarly, a large company is expected to be potentially more willing to invest in a pilot project or an innovative solution compared to an independent supermarket that, on the other hand, would probably prefer to invest in consolidated energy efficiency technologies;
- regarding the financial schemes subject of analysis within SUPER HEERO, an independent supermarket is expected to be more interested in PAAS schemes, which minimize the need of personnel for operation and maintenance of energy systems; on the contrary, large supermarket chains have typically an internal energy management and /or facility management/maintenance department, which can optimize the efforts for the management of energy devices.

Regarding the building typology, it is clear that some differences exist in the applicability of the identified technologies, e.g.:

- for standalone buildings almost all the technologies proposed are applicable;
- for other types of buildings, some of the measures are not applicable; e.g. for supermarkets located at the ground floor of a multi-storey building the installation of a rooftop photovoltaic plant or of other devices to be installed in common spaces of the building will be difficult; supermarkets not provided with a parking will not be interested in the replacement of external lamps; supermarkets located within a shopping mall could have additional barriers to the

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implementation of some technologies because some services might be provided at centralized level by the shopping mall, but on the other hand may offer interesting opportunities for heat recovery and local reuse, and for cogeneration or self-production of electricity from renewables, etc.

Regarding the "size" of the supermarket, it is worth highlighting that:

- the savings associated with some of the proposed measures, like the interventions on the refrigeration systems, do not depend on the annual working hours of the supermarket because the operation of the related devices is independent from the supermarket opening hours;
- on the other hand, for energy uses strongly correlated with the opening hours, like lighting or HVAC of retail areas, the level of energy savings and consequently the economic savings and the payback time are strongly variable;
- the sales volumes of the supermarket are not significantly correlated with the feasibility and profitability of the proposed energy efficiency actions, but of course influence the capacity of the company of generating revenues to be reinvested (among others) into energy efficiency actions, or of receiving support from a bank or fund for the realization of these investments.

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5. Case Study: High-Level Design

The present chapter presents a case study of implementation of the renovation packages introduced in the previous chapter 4 on a real supermarket. The supermarket is located in Italy, has a total floor area of 400 m^2 and is a standalone building, and can be considered a "supermarket in average conditions" according to the classification presented in chapter 4, although the technical and financial evaluations carried out here, being customized on a specific supermarket and not generic, are not fully aligned with the packages and scenarios presented in the previous chapter.

In the following sections, the baseline energy consumptions of the supermarket are presented and analysed in terms of monthly trend, breakdown of demand among different users and energy performance indicators per unit of supermarket area.

Then, the potential for application of six measures out of those presented in Chapter 3 is analysed and a high-level design is carried out to determine the size of the required systems, the achievable energy savings and the needed costs, in order to evaluate also the financial feasibility.

To conclude, the overall features of the proposed renovation package are summarized in terms of investment, economic and energy/environmental benefits, impacts on the energy balance and energy performance indicators of the supermarket.

5.1 Analysis of Baseline Energy Consumption

The supermarket taken as a reference for the present case study is characterized, in the baseline situation, by the energy consumptions and GHG emissions presented in Table 6.

Table 6: Supermarket Baseline Energy Consumptions and GHG Emissions

	Value	Unit
Electricity	187,100	kWhe/y
Natural Gas	3,600	Sm^3/y
Final Energy	221,900	kWh/y
Primary Energy	441,700	kWhp/y
GHG Emissions	55.4	tCO_2e/y

The monthly trend of electricity and natural gas consumptions (both presented in terms of final energy) is also presented, in Figure 5.1. Looking at the Figure, it can be noticed that natural gas consumptions are concentrated during winter months, being this fuel used only for space heating purposes; on the other

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hand, electricity consumptions are relatively constant during the year, with higher values during summer due to the higher space cooling and product refrigeration needs.

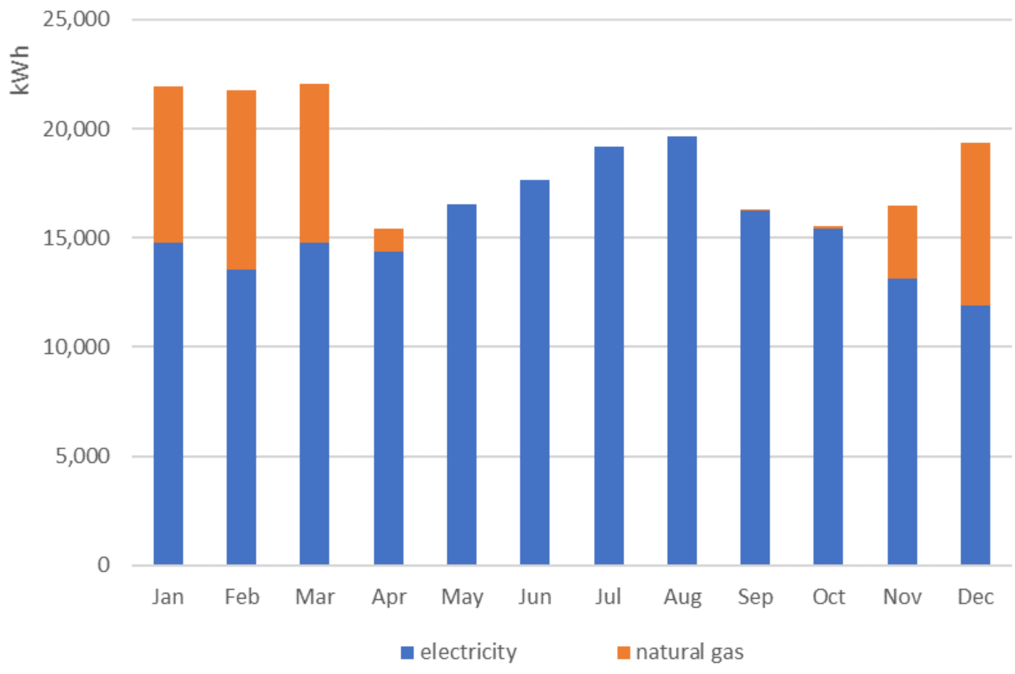

Figure 5.1: Supermarket Monthly Energy Consumptions

Based on the installed power and the typical use and load factor of the devices installed at the supermarket (that are available but not presented in the present report for confidentiality issues), the breakdown of electricity consumptions among the main users/areas of the supermarket has been determined and is presented in Figure 5.2.

Looking at the pie chart, it can be noticed that the refrigeration of products (both those in freezers and those in fridges – partly connected to centralized refrigeration units and partly based on standalone refrigerated cabinets) is responsible of the largest share of electricity uses, 40.0%, followed by lighting (carried out through neon fluorescent lamps) with 19.8%, by ventilation and space cooling (an air-water chiller and an Air Handling Unit) with 9.2% and by offices and logistics with 9.0%. The other areas/devices are not further analysed, due to their limited interest as case study for the present deliverable, being significantly related to the peculiarities of the specific site rather than to supermarkets in general.

The breakdown of natural gas consumptions is not presented graphically, being 100% of this fuel used in the boilers for space heating purposes.

Combining the breakdown of electricity consumptions and that of natural gas use, the overall breakdown of final energy demand of the supermarket presented in Figure 5.3 is determined. Looking at the pie chart it can be noticed that - compared to the breakdown of electricity uses only - the relative weight of HVAC increases up to 23.4%, with a subsequent reduction of other relative contributions to the total.

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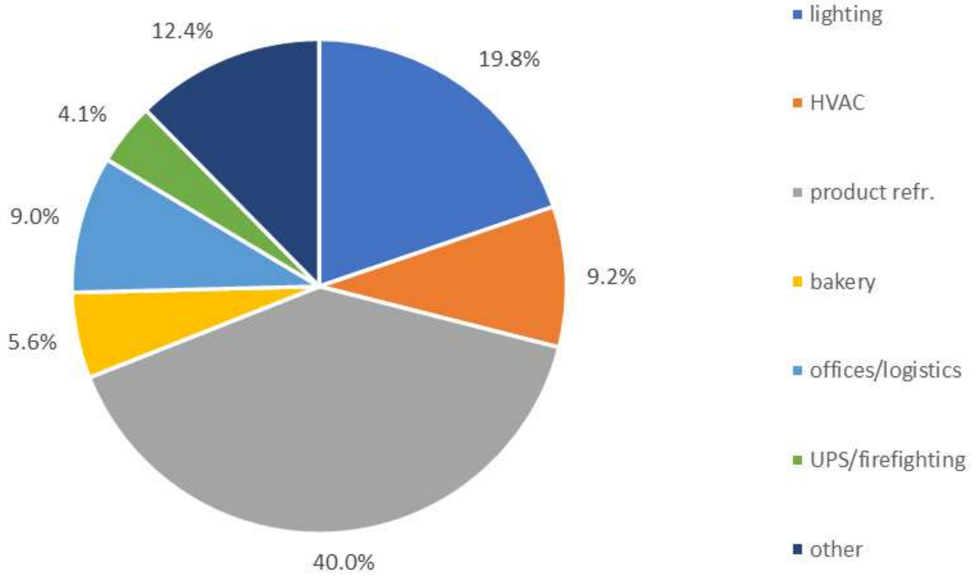

Figure 5.2: *Breakdown of Supermarket Electricity Consumption*

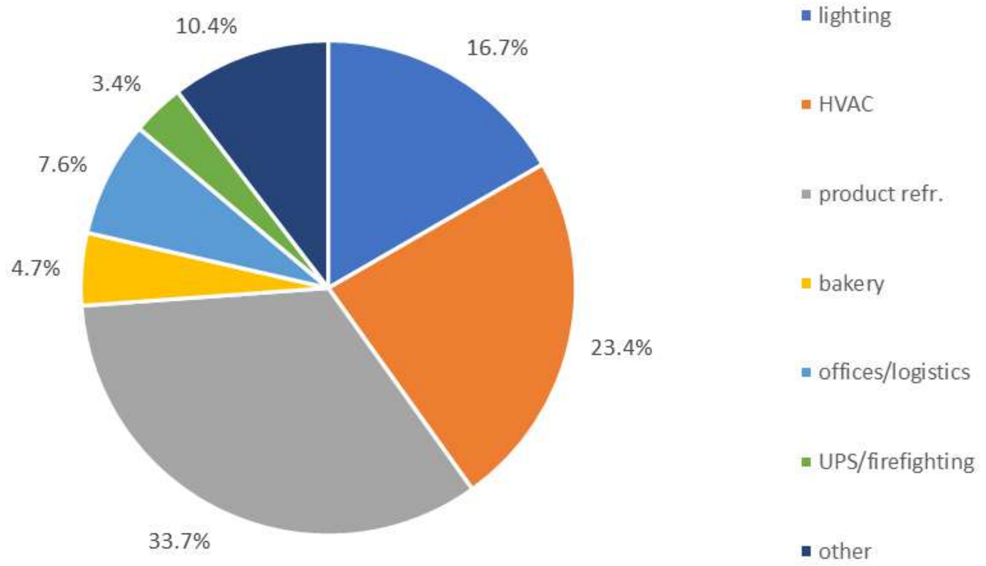

Figure 5.3: *Breakdown of Supermarket Final Energy Demand*

Based on the energy consumption data and on their breakdown among different users and areas presented above, a set of energy performance indicators referred to the unit of area (400 m^2) are calculated and presented in Table 7. It is worth highlighting that the overall final energy indicator is of 554.9 kWh/m^2/y, perfectly in line with the category "supermarket in average conditions" as defined in chapter 4, which for Southern Europe has a reference value of 500 kWh/m^2/y.

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Table 7: Baseline Energy Indicators

	Value	Unit
Total Final Energy	554.9	kWh/m^2/y
Total Electricity	467.8	kWh/m^2/y
Total Natural Gas	87.1	kWh/m^2/y
Electricity for Lighting	92.5	kWh/m^2/y
Electricity for Product Refrigeration	187.3	kWh/m^2/y
Electricity for HVAC	43.0	kWh/m^2/y
Natural Gas for Heating	87.1	kWh/m^2/y
Total Final Energy for HVAC	130.1	kWh/m^2/y

5.2 High-Level Design of Energy Efficiency Interventions

Based on the analysis of the baseline energy consumptions of the supermarket presented in the previous paragraph and on the assessment of the current level of energy efficiency of the supermarket itself, a set of improvement measures have been identified and their high-level design is the main subject of the present section.

The main weaknesses of the supermarket under the energy efficiency perspective are identified as the absence an electricity monitoring system, the use of fluorescent tubes for lighting, the low efficiency of the overall HVAC system (gas-fired boiler, electric chiller, water circulation pumps and ventilation fans), as well as of the products refrigeration systems. Moreover, the supermarket is characterized by a good potential for the self-production of electricity through the installation of a photovoltaic plant on the roof.

5.2.1 Energy Monitoring System

The supermarket is currently not monitoring its energy consumptions; the bills issued by suppliers of electricity and natural gas are the only sources of data on energy consumptions and are archived but only for accounting and not for energy management purposes. This means that in the present situation, anomalies in energy consumptions can be spotted only by evidence, e.g. in case of malfunctioning of equipment or significant variations in the energy bills.

The monitoring of energy consumptions is mainly useful for determining bad practices/issues that cause additional consumptions. For example, it helps detecting equipment remaining switched on when not needed or identify areas where additional low-cost investments are possible. Such a system provides daily

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curves of energy consumptions, supporting the identification of load peaks, idles, oversized equipment, etc. In case of anomalies/leakages, the measures will allow the identification of the lines to be further assessed, and/or the specific user responsible for anomalous consumptions.

It is therefore recommended to install an energy monitoring and management system, constituted by an energy software and a set of electricity meters covering at least the overall consumption of the site and the main 10-15 electricity users, i.e.: outdoor unit of the refrigeration systems, chiller for space cooling, air handling unit, lighting lines within the retail area and the warehouses, bakery, etc.

The savings from such a system can be estimated as 5% of the baseline electricity consumptions of the supermarket; this estimate is conservative, to account for the fact that the actual results will strongly depend on the effectiveness of the whole energy management system and of the actions taken based on the hints from the system.

5.2.2 LED Lighting

In the current situation, lighting of the supermarket is carried out with neon fluorescent lamps both in the areas for retail and in those not open to the public (warehouses and offices). Most of the lamps are 150 cm neon tubes, having an installed power of 56 W and a typical lifetime of 15,000 h.

The gradual replacement of neon fluorescent lamps with LED lamps would lead to a significant reduction of the installed power for lighting and consequently to a lower electricity consumption. The above-mentioned 56 W neon tubes could be replaced with 24-26 W LED tubes, keeping the same luminous flux and increasing the lamp lifetime to at least 30,000 h. This means that electricity savings higher than 50% could be achieved, together with operation and maintenance benefits, since LED lamps will need to be replaced every 7 years instead of the 3.5 years of the neon ones.

Moreover, a further opportunity would be the installation of sensors (natural lighting or presence, depending on the areas of the supermarket) for the reduction of the lamps working hours; these sensors are particularly applicable to LEDs, since these lamps are suitable for dimming and frequent on/off cycles without significant impact on their duration, whereas neon lamps are not suitable for varying luminous flux and for on/off cycles.

5.2.3 High Efficiency Heat Pump

Currently, the supermarket is provided with separate systems to produce hot water for space heating and of chilled water for space cooling. The former is constituted by a natural gas-fired, non-condensing boiler, installed 25 years ago and working with an estimated seasonal efficiency below 80%, whereas the latter is constituted by an electric air-water chiller, installed 15 years ago and working with an actual EER of approximately 2.2-2.5.

Both the above-mentioned systems supply water to an air handling unit, provided with heating and cooling batteries in addition to the filtering and humidification ones. The issues of the air handling unit are subject of a separate proposal for improvement.

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A significant improvement of the energy efficiency of the HVAC system at the supermarket could be achieved by installing a new, high-efficiency reversible heat pump for the production of both hot and chilled water for space heating in winter and space cooling in summer.

The new heat pump could be characterized by an average seasonal efficiency (COP for heating, EER for cooling) in the range 3.5-4.0 and therefore would allow the reduction to zero of the natural gas consumptions of the supermarket and – thanks to the high efficiency – only a limited increase of the electricity consumption of the site.

5.2.4 Retrofitting of HVAC Systems

As mentioned in the previous section, ventilation of the supermarket is carried out by a 25-year old air handling unit, whose two 3 kW fans are provided with low-efficiency electric motors and work on-off, without the possibility to control the air flow depending on the real ventilation needs of the building.

An increase of the energy efficiency of the ventilation process could be achieved by replacing the old electric motors with new IE3 motors, and installing variable frequency drives allowing the partialisation of the air flow rate depending on ventilation needs. The inverters shall be controlled based on inputs given by temperature, humidity and CO concentration sensors to be installed in the air return line.

The savings from the implementation of this measure can be estimated as a total of 20% of the baseline electricity consumption of the fans, of which 5-8% thanks to the higher efficiency of the electric motors and 12-15% thanks to their improved control through VFD.

5.2.5 High Efficiency Product Refrigeration

In the baseline situation, the supermarket is equipped with a 10-m long refrigerated cabinet, installed around 20 years ago, working at a temperature of 4-6°C, provided with doors and apparently not presenting significant energy efficiency or maintenance issues. On the other hand, the condensing unit is located outside, behind the supermarket, and appears in a relatively poor status of maintenance; during the survey it was not possible to check the whole path of the refrigerant fluid circulation pipes, but not negligible refrigerant fluid losses can be estimated based on the information provided by the maintenance personnel of the supermarket.

Based on the analysis of the baseline situation, it can be concluded that the whole refrigeration system would benefit from a complete renovation to reduce the energy demand for cooling and increase the chill production efficiency; however, based on the discussions held with the management, this is not a feasible option at the moment due to budget constraints.

Therefore, the present proposal for improvement is only focused on the renovation of part of the refrigeration system, including the replacement of the outdoor condensing unit and the reconstruction of the refrigerant fluid piping, aimed at reducing losses and increasing the overall energy efficiency of the refrigeration process.

The savings from the implementation of this measure are conservatively estimated as 30% of the current consumptions of the 10-m refrigerated cabinet and the associated external condensing unit.

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5.2.6 Photovoltaic Plant

As mentioned in the general description, the supermarket is a standalone building with a floor area of approximately 400 m^2. Its roof is flat and – based on the preliminary analyses done – suitable and almost fully available for the installation of a photovoltaic plant.

Based on the available spaces and on the electricity demand of the supermarket, it is assumed that a 30 kWp photovoltaic plant could be installed, which would require approximately 300 m^2 and based on the solar radiation data for the specific location could produce 39,000 kWh/y.

The electricity production on the photovoltaic plant (corresponding to approximately 20% of the baseline electricity needs) could be easily self-consumed within the supermarket, minimizing the exchanges with the national grid. In any case, thanks to the net metering currently allowed for photovoltaic plants below 200 kWp, the electricity possibly produced in excess to the supermarket needs could be fed to the grid and consumed in a different period, with no cost for the supermarket.

5.3 Expected Costs and Benefits

This section focuses on the presentation of the expected costs and benefits from the implementation of the proposed actions.

Specifically, a summary of the technical and financial features of the proposed actions is presented in Table 8, whereas Figure 5.4 shows a comparison and Figure 5.5 the relative variation between the baseline and future situation (for electricity, natural gas, primary and final energy, GHG emissions).

It can be noticed that the overall package of energy efficiency actions has an overall investment need of 172,500 € and a payback of 7.1 years; the implementation of the proposed actions would reduce:

- electricity purchases from the national grid by 22.7%;
- natural gas consumption by 100%, thanks to the switch from boiler to heat pump for heating;
- final energy consumptions by 17.3% and primary energy needs by 20.0%;
- GHG emissions by 32.6% thanks to the reduction of energy consumptions and the self-production of electricity from a renewable source.

Looking at the values in the Table, it can be noticed that some of the identified measures, like LED lighting and installation of a photovoltaic plant, seem easier to implement, since they have the shortest payback time and may be fully delegated to an external supplier. Other actions are characterized by a longer payback (e.g.: refrigeration system, heat pump, retrofitting of HVAC systems) but could significantly contribute to the improvement of the energy efficiency of the site and of the comfort or service quality for end-users. To conclude, energy monitoring is a low-cost action that potentially enables the identification of many further improvement actions, and is worth being implemented especially by a supermarket willing to adopt a continuous improvement approach for sustainability purposes.

Table 8: Main Facts of the Proposed Actions

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	Investment €	Savings €/y	PBT y	Electricity Savings kWh/y	Gas Savings Sm^3/y	Final Energy Savings kWh/y	GHG Emissions Avoided tCO_2e/y
Energy Monitoring System	10,000	1,600	6.3	9,400	-	9,400	2.4
LED Lighting	15,000	3,100	4.8	18,500		18,500	4.8
High-Efficiency Heat Pump	70,000	9,000	7.8	-8,700	34,800	26,100	4.8
Retrofitting of HVAC Systems	1,500	200	7.5	1,000		1,000	0.2
High-Efficiency Product Refrigeration	40,000	3,800	10.5	22,400		22,400	5.8
Photovoltaic Plant	36,000	6,600	5.4	39,000		39,000	10.1
TOTAL	**172,500**	**24,300**	**7.1**	**81,600**	**34,800**	**116,400**	**2.4**

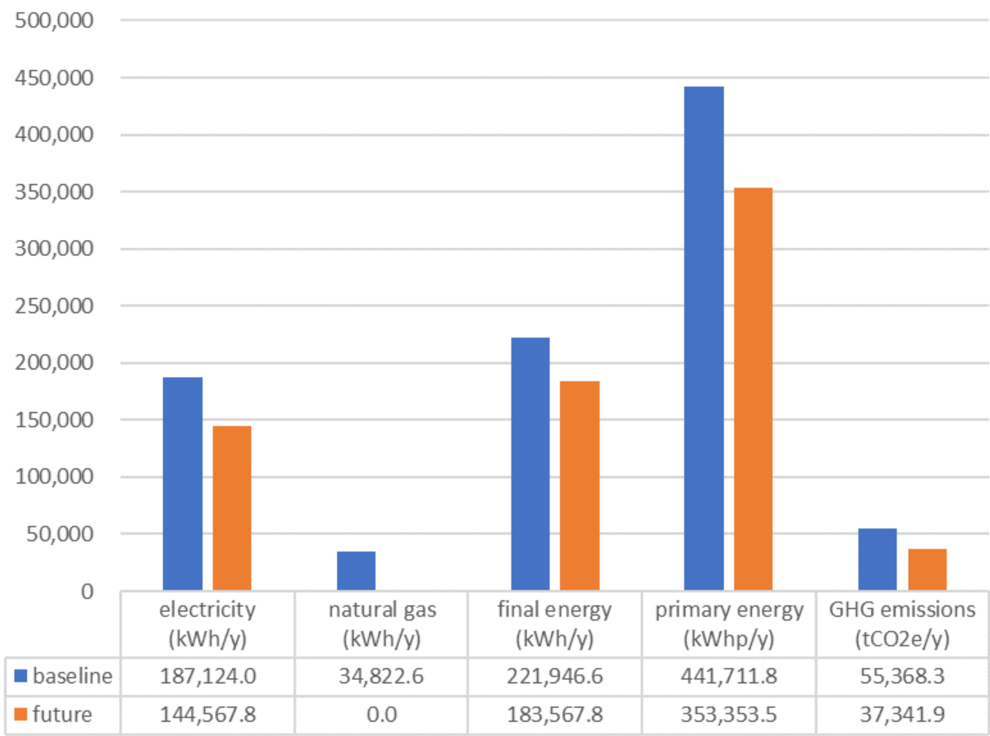

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Figure 5.4: Comparison Baseline – Future Situation

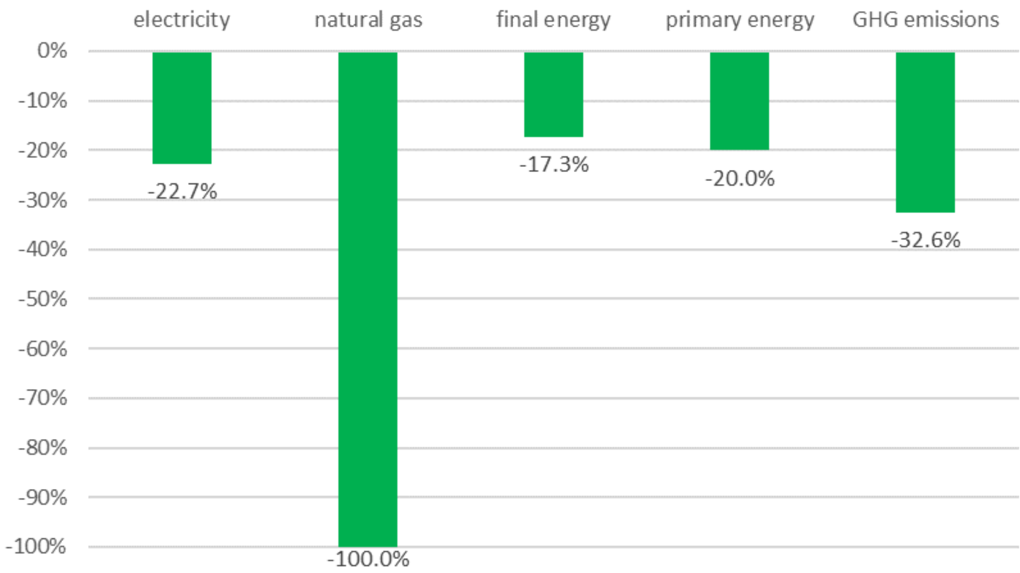

Figure 5.5: Variations Against Baseline Situation

As a result of the savings presented in the previous tables and charts, the variation of the energy performance indicators per unit of supermarket area is presented in Table 9.

Table 9: Comparison Future-Baseline Energy Indicators

	Baseline	Future	Unit	Variation
Total Final Energy	554.9	361.4	kWh/m²/y	- 34.9%
Total Electricity	467.8	361.4	kWh/m²/y	- 22.7%
Total Natural Gas	87.1	-	kWh/m²/y	- 100.0%
Electricity for Lighting	92.5	46.3	kWh/m²/y	- 50.0%
Electricity for Product Refrigeration	187.3	131.1	kWh/m²/y	- 30.0%
Electricity for HVAC	43.0	62.4	kWh/m²/y	- 45.1%
Natural Gas for Heating	87.1	-	kWh/m²/y	- 100.0%
Total Final Energy for HVAC	130.1	62.4	kWh/m²/y	- 52.0%

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6. Conclusions

Following the creation of a catalogue of energy efficiency actions for supermarkets carried out in D2.1 of the SUPER HEERO Project, the present document aimed at drafting guidelines for the high-level design of all the 42 energy efficiency measures included in the catalogue.

The high-level design guidelines refer to actions belonging to the following categories: overall energy management of the supermarket, energy supply, as well as main areas of energy use in the supermarket, i.e. HVAC (Heating, Ventilation, Air Conditioning) systems, lighting, products refrigeration and other areas.

Based on the analysis of the baseline energy uses in supermarkets and of the applicability of the proposed actions, practical suggestions for supermarkets' energy efficiency renovation are presented. Specifically, energy efficiency renovation packages have been created by selecting from the catalogue the most applicable energy efficiency actions based on their baseline conditions (old, medium, new) and geographical location (Northern or Southern Europe). Moreover, energy efficiency renovation packages with different renovation depths and consequently different investment needed were created.

The overall number of renovation packages created is of 18, which were created and subsequently analysed to evaluate technical and financial parameters including investment needed, achievable energy and economic savings and pay-back time. All the values are presented per unit of area of the supermarket, in order to ease extrapolation for supermarkets of different sizes. To conclude, also a case study based on data from a real supermarket has also been carried out.

The analysis allowed confirming that energy efficiency actions in supermarkets are feasible and sufficiently profitable. Indeed, the study highlighted that several opportunities for renovation exist, with overall investment below or around 200,000 € (for a 400 m^2 supermarket) and a payback below 5-6 years. Renovation packages of different depths are characterized by different technical and financial parameters, with the best cost-benefit ratio for the basic renovation of old supermarkets but interesting technical and financial results also for medium-high performing supermarkets having often a higher interest in implementing these solutions to meet corporate sustainability targets. To this aim, the development of innovative financing measures being carried out in the SUPER HEERO project is particularly of interest, to unlock investments and sustainability actions in this field.

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