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D2.1 - SUPER-HEERO RENOVATION MEASURE CATALOGUE FOR SUPERMARKETS

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SUPER HEERO
Human Energy Efficiency Retrofitting Optimisation

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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 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.

The present D2.1 of the SUPER-HEERO Project, building upon a high-level analysis of typical supermarkets' energy systems and equipment, creates a catalogue with the most relevant and easy to replicate energy efficiency measures to be promoted by SUPER-HEERO renovation approach.

Based on this catalogue of solutions, guidelines will be provided to promote the implementation of energy efficiency measures in supermarkets according to their size, estimated sales volume, staff amount, kind of products, etc., covering both technical and financial aspects. These guidelines will be included in SUPER-HEERO D2.2, available in Spring 2021.

In the present Deliverable, to define the catalogue of the most suitable energy efficiency actions for supermarkets, a high-level energy analysis of a typical supermarkets is needed and is carried out according to the following main steps:

- identification of supermarkets' typical energy balance;
- definition of typical energy consumption level (electricity/heat);
- analysis of typical breakdown of energy consumption;
- selection of key areas for energy efficiency improvement;
- elaboration of energy efficiency measures' catalogue.

Based on the analysis of typical supermarkets' energy balances, the key areas for energy efficiency are identified as the following six:

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

A number of 42 energy efficiency interventions are presented that belong to the above-mentioned six areas. It can be noticed that the last four areas are directly correlated with the categories of energy users that are identified as responsible for the largest part of energy consumptions in the previous section, whereas the first two are more general and may lead to a decrease of the overall energy consumptions of supermarkets.

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2. Introduction

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 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.

The approach relies on three main instruments: engineered Energy Performance Contracts (EPC), product-service models for technology providers engagement and community-based crowdfunding/cooperative initiatives.

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 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 will be leveraged;
- delivery of innovative financing schemes that are operational and ready to be implemented.

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

2.1 Purpose of the Document

The present deliverable, building upon a high-level analysis of typical supermarkets' energy systems and equipment, will create a catalogue with the most relevant and easy to replicate energy efficiency measures to be promoted by SUPER-HEERO renovation approach. The identified energy efficiency measures cover six main areas, i.e. overall energy management, energy supply, HVAC, lighting, products' refrigeration, other areas.

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Based on the catalogue of solutions, guidelines will be provided to promote the implementation of energy efficiency measures in supermarkets according to their size, estimated sales volume, staff amount, kind of products, etc., covering both technical and financial aspects. These guidelines will be included in D2.2, available in Spring 2021.

2.2Structure 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 methodological approach to the analysis;
- Chapter 4 illustrates an overview of supermarkets' energy systems;
- Chapter 5 is the core of the document, i.e. the catalogue of energy efficiency renovation measures for supermarkets;
- Chapter 6 focuses on ranking of the identified measures;
- Chapter 7 draws the conclusions of the study.

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3. Methodology

The aim of the present Deliverable is to define the catalogue of the most suitable energy efficiency actions for supermarkets. To achieve this aim, a high-level energy analysis of a typical supermarkets is needed and is carried out according to the following main steps (as also schematized in Figure 1):

- identification of supermarkets' typical energy balance;
- definition of typical energy consumption level (electricity/heat);
- analysis of typical breakdown of energy consumption;
- selection of key areas for energy efficiency improvement;
- elaboration of energy efficiency measures' catalogue.

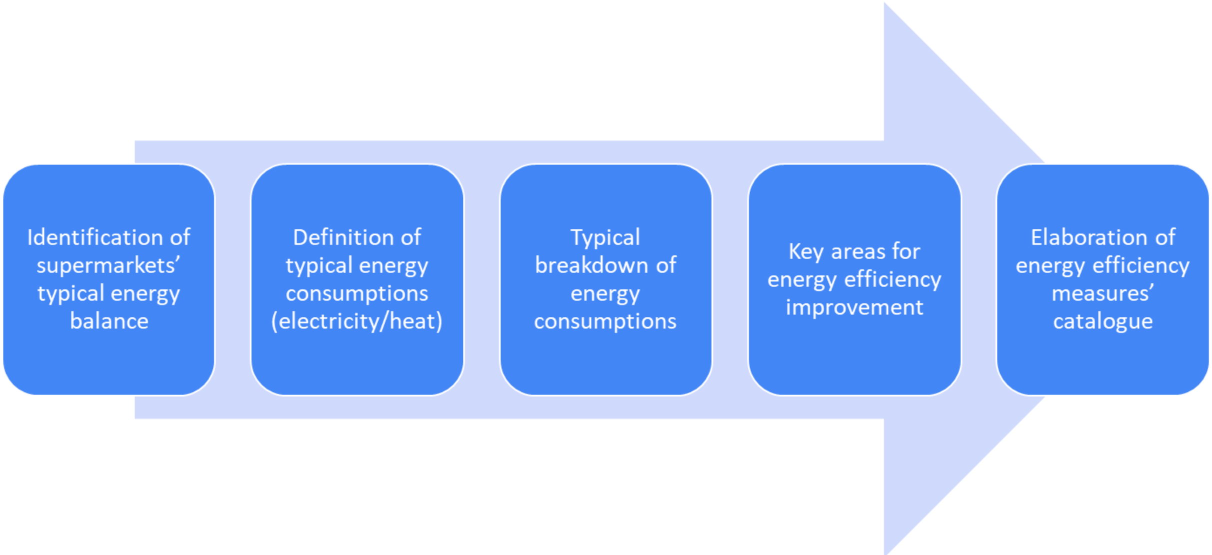

Figure 1: Methodological Approach for Elaboration of Energy Efficiency Measures' Catalogue

The analysis is based on a review of publications on scientific literature, outcomes of research projects on supermarkets' energy efficiency, guidelines for energy auditing in the retail sector and reports published by trade associations.

The analysis is focused on commercially available solutions, with the mention of potential emerging technologies that can be of interest, provided that they have at least a TRL 7. As a general rule, the name of the technology providers is not mentioned directly but focus is given to the description of the technical features and the benefits that technologies can have on supermarkets' energy balance.

After the presentation of the selected technologies, a potential ranking is presented according to the following criteria: maturity of solution, prerequisites for implementation, impact on energy balance, investment cost and profitability.

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4. Overview of Supermarkets' Energy Systems

Supermarkets are one of the retail sectors with the highest energy consumption mainly due to refrigeration equipment, space heating/cooling and lighting (SuperSmart Project, 2016).

The present chapter focuses on the typical energy balances and consumptions of supermarkets and on the identification of main energy consuming areas, on which higher margins for improvement exist.

4.1 Supermarkets' Energy Consumptions and Balances

Several studies have been carried out at European and national level on energy-related aspects in supermarkets; these studies, which include publications on international scientific literature, presentations at international conferences and events and deliverables of research projects on the topic, have focused on the typical energy consumption of retail centres, on the breakdown of these consumptions by fuel, final energy use, equipment and on the opportunities for the improvement of the energy efficiency level.

Depending on the specific location, supermarkets were found to have an average final energy consumption in the range between 320 and 800 kWh/m^2/y; data taken from different sources (Lindberg 2018, Kolokotroni 2019, SME EnergyCheckUp, Supersmart projects) show – for example – that in Spain the average consumption was of 327 kWh/m^2/y, in Sweden of 420 kWh/m^2/y, in France of 570 kWh/m^2/y, in Italy of 598 kWh/m^2/y, in Poland of 800 kWh/m^2/y, in the United Kingdom it varied between 400 and 740 kWh/m^2/y, in Norway 500 kWh/m^2/y, whereas in the USA it was of 600 kWh/m^2/y.

These final energy inputs are generally almost entirely attributable to electricity, which typically covers all energy uses in the supermarket, except for the cases where natural gas (or diesel) fired boilers are used for heating and sanitary hot water production purposes.

The main energy flows in supermarkets are well schematized in the diagram presented in Figure 2, taken from Lindberg (2018); it can be noticed that out of the net energy inputs related to the externally purchased electricity, fuels or heat/cold or self-produced through non-fuel based renewables, the energy flows to space heating, space cooling and products refrigeration, lighting, ventilation, sanitary hot water production and appliance. In addition, heat is exchanged with the external environment, both through the building envelope and through the systems used for HVAC and refrigeration.

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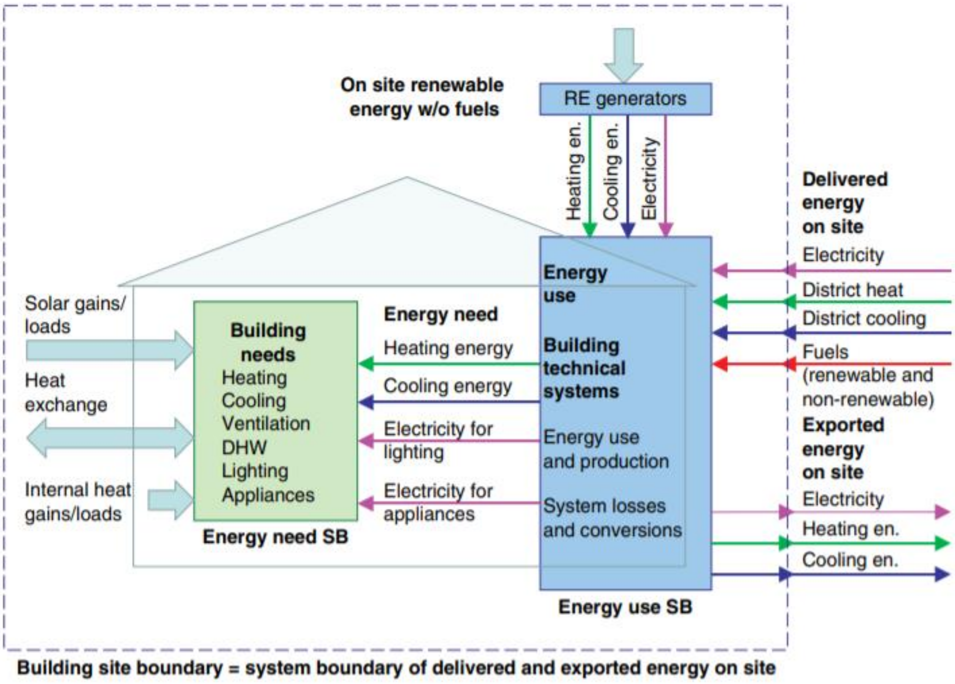

Figure 2: Overview of Main Energy Flows in Supermarkets, from Lindberg (2018)

After these qualitative evaluations, the mentioned sources report a qualitative analysis on the breakdown of energy uses among different users and/or devices. A selection of the pie charts available in literature on this topic are presented below:

- in Figure 3, taken from Kolokotroni (2019), products refrigeration is responsible of the largest share of consumptions (29%), followed by lighting (23%), HVAC (9%), bakery and food preparation (12%) and other energy users (offices 4%, further uses 9%);
- in Figure 4, taken from SME EnergyCheckUp project, products refrigeration is again responsible of the highest consumptions (47%), followed by lighting (27%), HVAC (13%) and other areas (kitchen 5%, external areas 3%, further users 5%);
- in Figure 5, taken from the SuperSmart project, refrigeration has the highest share of total consumptions (48%), followed by lighting (26%) and other users (26%).

Clearly, the above listed charts are only a selection of those available in literature and the values they present are determined in different types of studies, referring to different supermarkets with variable size, location and climate conditions. Therefore, no quantitative result is hereby drawn relying on the figures above, which are on the other hand used only to conclude the identification of the areas responsible for the largest share of energy consumption in supermarkets as: heating, ventilation, air conditioning, lighting, product refrigeration.

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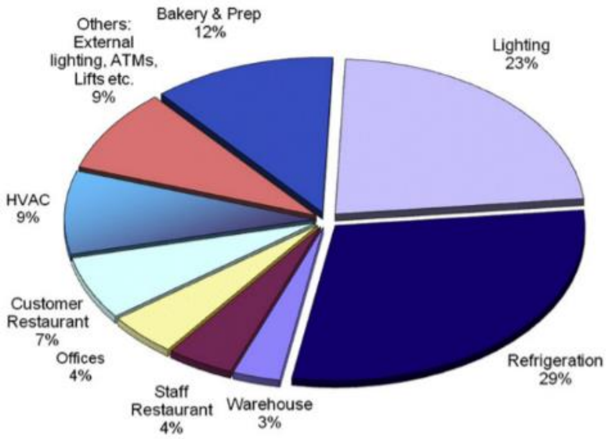

Figure 3: Breakdown of Energy Consumption from Kolokotroni (2019)

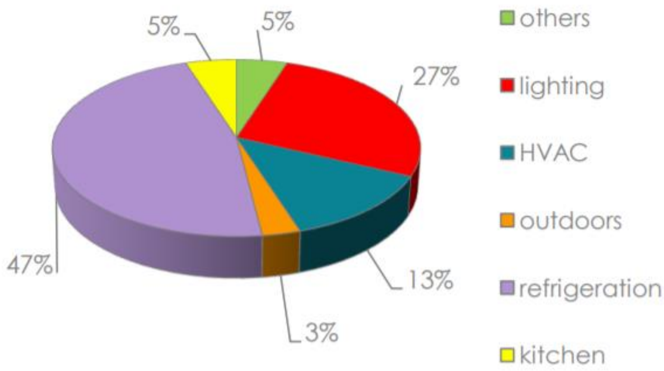

Figure 4: Breakdown of Energy Consumption from SME EnergyCheckUp project

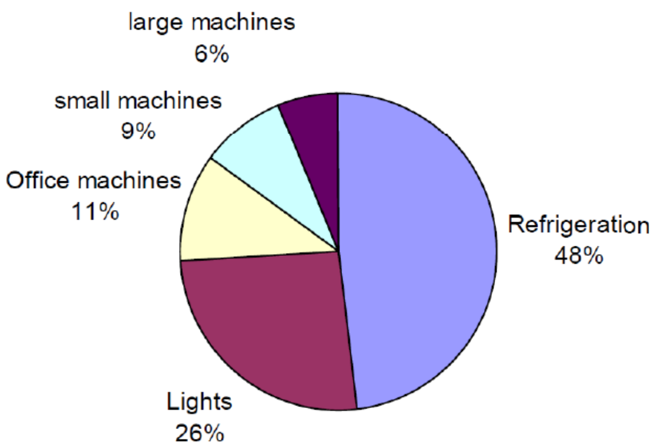

Figure 5: Breakdown of Energy Consumption from SuperSmart project

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4.2Key Areas for Energy Efficiency

Based on the analysis of typical supermarkets' energy balances presented in the previous paragraph, this section focuses on the key areas for energy efficiency, which are identified as the following six:

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

It may be noticed that the last four areas are directly correlated with the categories of energy users that are identified as responsible for the largest part of energy consumptions in the previous section, whereas the first two are more general and may lead to a decrease of the overall energy consumptions of supermarkets.

4.2.1 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 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.

4.2.2 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;

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- solar thermal for toilets' hot water production;
- cogeneration/trigeneration;
- reactive power compensation systems;
- waste-to-energy solutions.

4.2.3 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;
- high-efficiency pumping systems;
- smart control of HVAC systems;
- improvement of air-tightness;
- air curtain at building entrance;
- low-flow aerators on toilet water.

4.2.4 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;
- smart control of lighting systems in indoor/outdoor areas.

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4.2.5 Product 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.

4.2.6 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.

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5. Catalogue of Renovation Measures

This section aims at providing a description of the identified energy efficiency actions for supermarkets' renovation; the measures are articulated into the following six sections:

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

5.1 Overall Energy Management

In this section, the more general actions for energy efficiency in supermarkets are presented, which are those related to the overall energy management.

5.1.1 Energy Audit and Implementation of Energy Management System

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Energy audit and implementation of an Energy Management System	None	High	None	Depending on identified and adopted actions	Low

The present document presents a list of the most widely applicable energy efficiency interventions for supermarkets, but the real suitability of a measure for a specific supermarket needs to be carefully evaluated with a dedicated analysis carried out by a person who knows the characteristics of the site.

This is strongly connected with one of the easiest/cheapest solutions that can be implemented at supermarket level, i.e. the execution of an energy audit and the implementation of an energy management system (which includes the appointment of an energy manager, too).

An energy audit is a structured activity that aims at analyzing 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.

In any case, the activity – which can be carried out by an internal professional (e.g.: energy manager) or by external consultants – foresees the collection of energy bills data, monitored consumptions if available, technical characteristics of the installed energy systems (refrigeration, HVAC, lighting, logistics, etc.) and of the building envelope (walls, windows, doors, etc.), the execution of one or more surveys on site, the calculation of energy performance indicators and their comparison with available

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benchmarks, the gap analysis versus energy efficiency best practices of the sector and the pre-feasibility study of a number of energy efficiency actions including technical and economic evaluation.

Such an analysis, in addition to spotting potential investments for the improvement of the energy efficiency level in the supermarket, may represent the 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 execution of an energy audit typically leads to the identification of actions to improve the energy efficiency of the site by an extent that – depending on the baseline conditions – may vary between a minimum of 10% and a maximum of 50%, typically reachable thanks to investments with payback shorter than 3-4 years. 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 as high as possible, thus achieving further improvements compared to the execution of an energy audit alone.

5.1.2 Monitoring of Electricity Consumption at Main Switchboards

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Monitoring of electricity consumption at main switchboards	Electricity meters, EMS software	High	None	Medium High, depending on attention paid to monitored data	Low

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 proposed monitoring system is composed of three main parts, i.e., a number of power meters to be installed in the main electric switchboards of the supermarket, the network for data acquisition and a software for collection and analysis of the monitored data. The software shall be set to 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.

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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 analyzed for energy efficiency purposes, the installation of the monitoring system is useless. However, assuming an average level of attention to the monitored data, an electricity saving corresponding to 5% of the baseline energy consumption can be conservatively estimated.

5.1.3 Blockchain Enabled Smart Meters

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Blockchain Enabled Smart Meters	Smart meters, EMS software	Medium-High	None	Medium-High, depending on attention paid to monitored data	Low

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 become the backbone of energy communities and peer to peer remunerations schemes. In the context of shopping centers, one can imagine energy might be exchanged between different vendors in the same complex (e.g.: rooftop solar being self-consumed by different vendors). In the case of smaller individual supermarkets in a community, one can imagine the exchange of energy flows between nearby homes and buildings. There is a strong economic benefit to self-consumption as up to 60% of energy bills are tax and system costs. As such, enabling and maximizing the use of local produced energy effectively lowers the price of energy within the energy community ecosystem. 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). As energy production, use and storage continue to decentralize and to be managed at the local level, the utility and necessity of blockchain enabled smart meters will continue to increase. There are also strong social benefits associated with energy communities as new value streams and business model opportunities are unlocked between the members.

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. This can be relevant especially to supermarket chains conducting bill validation. Energy billing is not perfect: different stakeholders are often involved (energy supplier, distribution system operator, network operator), measurements can have gaps and measurements traveling over PLC have a degree of error. When there are gaps in data, the utility selects algorithms to fill in those gaps. Replacing existing metering infrastructure or having a secondary "ghost" measurement in parallel can be one way to change the status quo. As a benchmark, one leader in this space (Utilisave in the USA) does analytics on 16,000 properties and is approaching $1 billion in recoveries due to billing errors.

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5.1.4 Artificial Intelligence for Smart Electric Load Management

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Artificial Intelligence for Smart Electric Load Management	Smart meters/controls, AI software	Medium-High	None	Medium-High	Low

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. In this emerging field, proponents often make the analogy that if it is accepted that AI can give us self-driving cars (more complex), then it shouldn't be hard to accept that AI can deliver efficiencies in the operation of our buildings (less complex). That buildings are ecosystems of interconnected components and they can be combined to turn systems from reactive to proactive while balancing better energy consumption and occupant comfort.

One example of artificial intelligence applied to buildings is Brainbox AI (accompanying images). This system targets building HVAC. 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 behavior and energy flows across time. After a 3-month training period, a series of 25 algorithms begin operation in parallel (with varying priorities) with the operational settings/algorithms of the existing BMS. The prerequisite for Brainbox AI is the existence of a building management system. Larger buildings are preferred (5,000 m^2) as the impact delivered is higher. Retail points of 1,000 m^2 have been implemented. Average savings are approximately 25% (reduction of total energy costs) and reduction of carbon footprint of 30%. The company reports a 60% improvement in occupant comfort and an immediate payback period after the 3-month training period by offering the solution at zero cost in a business model where energy savings are shared after the trial period.

5.1.5 Microclimate Design and Simulation using Nature-Based Solutions

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Microclimate Design and Simulation using Nature-Based Solutions	Simulation software	Medium-High	New construction or major retrofit	Medium-High, following the implementation of identified solutions	Low

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Urban heat islanding can be reduced via the use of vegetation for shading and as a tool to change wind vectors. Such principles are also possible at the building level where the "Vertical Gardens" in Milan are a familiar image. 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 accompanying image (top) is of a new IKEA realized in the Vienna city center. The building has 160 trees planted on its roof and façade and achieved a GREENPASS Platinum Certification Rating. The below accompanying image is a simulation of one of eight submissions to an urban regeneration project. The orientation of buildings, their height, the materials used in their construction, the use of water and use of vegetation each affect the microclimate in any given space. Through design decisions, the comfort, temperature, humidity and other variables in such spaces can be controlled to varying degrees. What GREENPASS does is to provide a methodology, a set of indicators, and a database on greenery options so that decision makers can include and document for evidence these parameters in design or retrofit decisions. In commercial shopping centers or even for individual buildings, such software can be used to consider both the life-cycle cost (planting + curation over time) and benefit to any greening of parking, rooftop, entry or open area spaces. The methodology and tool would be most appropriate for large shopping centers or within analysis of urban area districts or projects where supermarkets are embedded within the community.

5.1.6 Building and Urban Area Dynamic Energy Simulation

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Building and Urban Area Dynamic Energy Simulation	Simulation software	Medium-High	New construction or major retrofit	Medium-High, following the implementation of identified solutions	Low

The energetic performance, daylighting and comfort of buildings can be simulated in various software environments. Such tools can be used for both design and retrofit decisions. Models can be calibrated with real time information if buildings are in operation. The most effective simulations are dynamic energy simulations which account for building performance across time considering internal and external environmental conditions. 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 across time. Within the last few years, software environments have expanded from the analysis of individual buildings (top image) to the analysis of groups of buildings / urban areas (bottom image). The most advanced environment (IES ICL) can construct digital twins for urban areas to assess both the performance of sets of assets to include their demand on the electrical grid. Such analysis can answer questions such as what is the new annual energetic consumption if a PV shading structure is constructed in the parking area coupled to the installation of EV charging points and the retrofit of the atrium skylights, coupled to LED light installation and installation of chillers? Can the existing grid infrastructure support 10 new EV points?

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How often and how much air conditioning demand will be present? How much heating demand? Will there be energy surplus produced? Does the building meet near zero energy classification?

5.1.7 Asset Management Software

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Asset Management Software	Asset management software, smart controls	High	None	Medium-High	Low

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. For a fleet of buildings, what are sustainability / performance metrics in total or per square meter? What technological systems are present across the fleet? What is the carbon footprint? At what location or for what type of technology intervention would attain the greatest impact with respect to various metrics? What locations have met efficiency targets, and which have not? How can my organization meet carbon neutral targets by 2030? For stakeholders interested in such fleet/asset management solutions, GEMS (Global Energy Management Solution) developed by Boston Scientific in collaboration with the National University of Galway, UL360 and Turbo Buildings by UL are good starting points.

It is also possible to couple fleet management to fleet modelling in the previously mentioned IES ICL environment (accompanying images) portfolio manager functionality. This makes possible a digital twin of fleet assets. With that, one can manage existing portfolio performance (aggregated or site-specific) and simulate potential energy or carbon reduction measures (aggregated or site-specific). This, in turn, can be used to develop a credible plan (year by year or otherwise) to meet a low carbon pledge or sustainability target. The modelling of building assets is not a major barrier. 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.

5.1.8 Regular Maintenance of Energy Users

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Regular maintenance of energy users	None	High	None	Medium-High, depending on baseline maintenance practices	Low

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

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

5.2 Energy Supply

This section focuses on measures for improving energy supply of the supermarket, which mainly corresponds to the exploitation of a more sustainable source of power and heat compared to the conventional ones.

5.2.1 Rooftop Photovoltaic Plant

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Rooftop photovoltaic plant	Photovoltaic modules and related accessories	High	Availability of space on rooftop with suitable structural characteristics, absence of urbanistic constraints	High, potentially 100% of the energy needs can be covered with a carbon-free source	High

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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 sizing and design of the photovoltaic plant can be done in different ways as concerns the integration with the grid; for instance:

- they can provide electricity only to the supermarket without the possibility of feeding excess power to the national grid; in this case the plant shall be sized with the aim of minimizing the excess electricity production that would otherwise be lost and not economically rewarded, or a suitable electricity storage system shall be foreseen to allow the reuse of the electricity produced in a different moment; the environmental and economic benefit is constituted by the reduction of the purchase of electricity from the grid with the associated emissions and costs; further economic incentives may also be foreseen;
- they can supply all the electricity produced to the national grid, with the supermarket purchasing all the needed electricity from the grid; in this case, the economic benefit is constituted by the tariff paid by the grid operator to the supermarket to purchase the whole electricity production of the plant, whereas the environmental benefit is related to the introduction in the grid of power produced from a renewable source;
- they could work according to a net metering approach, i.e. the produced power is self-consumed in the plant and excess electricity production is fed to the grid, from where it can be withdrawn in a different period; the environmental and economic benefit is constituted by the reduction of the purchase of electricity from the grid with the associated emissions and costs, applied to the whole electricity production of the plant.

The selection of one of the above-presented approaches, in addition to technical reasons, can also be influenced by the national legislation and/or the grid regulation, which may allow or favor one or another solution.

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On average, the installation of photovoltaic modules on a roof requires an area in the range of 8-15 m^2/kWp; on the other hand, the average electricity production varies in the range 800-1,600 kWh/kWp/y from North to South of Europe. The production of electricity of the plant varies at hourly and monthly level depending on the level of solar radiation; in the case of supermarkets, photovoltaic plants are particularly suitable since the maximum electricity production is in months with maximum electric load from product refrigeration and space cooling.

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5.2.2 Building-Integrated Photovoltaic Modules

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Building-Integrated Photovoltaic Modules	Photovoltaic modules and related accessories	Medium-High	Availability of space, absence of urbanistic constraints	Medium-High	High

BIPV are building elements that serve a structural purpose and which simultaneously generate energy from the sun. The most common element is solar glass and the most common configuration is to sandwich and fuse crystalline solar cells between glass layers in typical glass construction methods. The same techniques can be used on opaque construction elements. There are also existing and emerging transparent BIPV technologies which operate by depositing narrow strips of photovoltaic material within the glass (but still allowing the passage of light and thus transparency) or by methods that divert parts of the energy producing light spectrum to the frame elements and allowing the remaining light spectrum to pass uninterrupted. The most common applications for BIPV include 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. Although most think of glass with black crystalline cells checkered into the aesthetic appearance, BIPV now has a near infinite amount of design variables to include color of glass, color of cells, size of cells, spacing of cells, type of finish and color if opaque, and degree of transparency and color if transparent. In shopping centers, Atriums/entryways and skylights are appropriate applications. The horizontal orientation is optimal and often the glass being replaced is non-performant with respect to today's available glass technologies. In some cases, it is possible to use the BIPV elements to produce energy, improve the U-value for winter insulation and to control the thermal gains in summer conditions to reduce demand on cooling systems.

The cost and performance of BIPV is dependent on its location, orientation, and type of element being designed and the functionalities and characteristics associated with that element. What is different with BIPV is that it is a dual-purpose item (structural purpose + energy production) and as such, ROI calculations are best considered when isolating the difference in cost between a non-BIPV element and its BIPV alternative. As general considerations, over their lifespan (30 years) BIPV elements are net profitable (e.g. they create more energy production value than they cost). When compared with non-BIPV alternatives, they are typically more cost competitive (e.g. have a payback period) of between 7-10 years. When coupled to any incentives present for the use or renovation with such a type of construction element, the payback period is typically 2-3 years. In very general terms, if one is thinking of deploying a transparent BIPV technology, one could estimate 30-50 W/m^2. If one instead is deploying a non-transparent crystalline BIPV technology, one could estimate between 80-120 W/m^2. Enough power must be generated to allow an inverter to function properly. Unless micro-inverters are deployed, typically 50 m^2 for amorphous installations and 30 m^2 for crystalline installations would be the minimum recommended installation sizes.

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5.2.3 Photovoltaic Modules on Parking Lots

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Photovoltaic modules on parking lots	Photovoltaic modules and related accessories	High	Availability of space on parking lots, absence of urbanistic constraints	Medium-High, depending on the size of the parking area	Medium

The same considerations done in the previous paragraph for the installation of photovoltaic modules on the rooftop of the building hosting the supermarket, also apply for another location that can be of interest, i.e. the external parking, if present.

In this location, photovoltaic modules can be installed on shelters that have the double purposes of shading vehicles and self-producing electricity for the nearby supermarket. 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.

The size of this solution is by design smaller compared to the previously proposed one, being limited to shelters having a maximum area of 20-30 m^2; however, in case a large number of parking lots are present, this solution can be replicated modularly, reaching large areas and a high installed power.

5.2.4 Micro-Wind Power Production Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Micro-wind power production systems	Micro-wind turbine and related accessories	Medium-High	Suitable conditions in terms of wind availability, absence of urbanistic constraints	Medium	High

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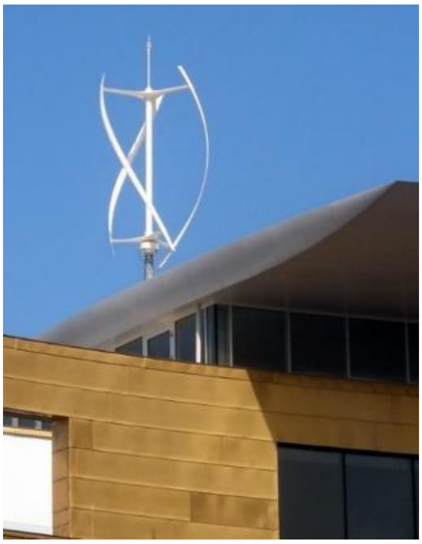

Micro-wind power production systems are typically based on a small vertical-axis turbine installed on the building rooftop in order to produce power from the wind kinetic energy. Compared to utility-scale wind turbines, which have typically horizontal axis, these turbines have lower efficiency but work with wind from any direction and within a wider speed range; moreover, they produce less noise, which is a benefit in urban areas. Typical sizes of vertical axis wind turbines range from 1 to 100 kW.

All the considerations done for the rooftop photovoltaic plant apply also to micro-wind plants in terms of plant sizing, integration with the grid, environmental and economic benefits. The main differences are related to space needs, which are much lower for wind compared to solar, and distribution of power generation throughout the year, which is less predictable but on average more constant during the year for wind compared to solar.

5.2.5 Solar Thermal for Toilets' Hot Water Production

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Solar thermal for toilets' hot water production	Solar thermal panels, hot water storage tanks	High	Availability of space on rooftop, absence of urbanistic constraints	Low	Medium-Low

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Another opportunity for integration of energy from solar sources in supermarkets is related to the use of solar radiation to heat water for sanitary purposes, i.e. for toilets for clients and toilets/showers for employees. 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.

Solar collectors 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.

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. The area needed for the proposed installation is estimated at around 20-30 m^2.

The benefits of the implementation of such a system are related to the reduction of consumption of electricity and/or fuels (depending on the existing sanitary hot water production system) for water heating, with associated reduction of emissions and costs.

5.2.6 Cogeneration/Trigeneration

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Cogeneration / Trigeneration	Cogeneration plant (engine, turbine, etc.), heat exchangers, absorption chiller (for trigeneration)	High	Presence of contemporary high electric and thermal loads, absence of environmental/permitting constraints	Potentially 100% of the energy inputs can be covered	High

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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.

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.

Cogeneration can be based on many different technologies, including:

- internal combustion engines fueled with natural gas, biogas or liquid biofuels;
- gas turbines fueled with natural gas, biogas or liquid biofuels;
- steam systems (boilers + turbines) fueled with solid biomass;
- fuel cells fed, emerging solution, based on natural gas.

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. 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.

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).

Both the power, the heat and the cold produced in the plant can be used internally to the supermarket or 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.

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5.2.7 Reactive Power Compensation Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Reactive power compensation systems	Capacitors	High	Presence of significant capacitive loads	Low	Medium-Low

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.

It is therefore recommended to supermarkets to check the current power factor of their electricity system, by analyzing 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.

The main solution adopted for power factor correction is the 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. The specific location of the capacitors needs to be evaluated 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 is to install the capacitors in parallel to its switchboards instead of installing a larger battery of capacitors at supermarket level.

5.2.8 Waste-to-Energy Solutions

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Waste-to-Energy Solutions	Pyrolysis plant	Medium	Sufficient waste availability for the specific technology	Medium	Medium

An upcoming area of interesting technologies for supermarkets are pyrolysis waste to energy solutions. Such 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).

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.

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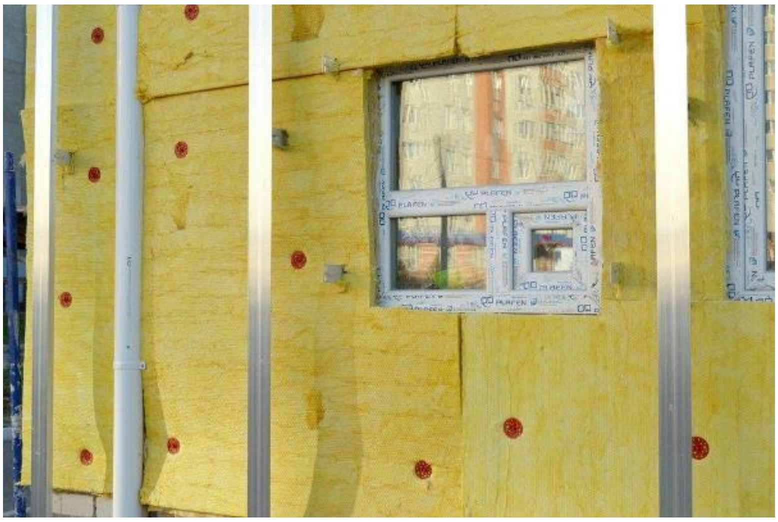
A second solution is called the HERU, which is starting as a domestic-scale pyrolysis solution (for nearly all materials except gas and metal) and has also been deployed at a small farm and small restaurant setting. The units use pyrolysis to attain syngas and hot water. The inventors claim that units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

5.3 Heating, Ventilation, Air Conditioning

This section focuses on solutions to reduce the thermal energy demand of the supermarket and to minimize the energy input needed to cover such energy demand.

5.3.1 Improvement of Building Envelope Thermal Insulation

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Improvement of Building Envelope Thermal Insulation	Thermal insulation material; high-performance windows/doors	High	Low baseline energy performance of supermarket building	Medium-High, depending on baseline conditions of the building	High



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. This usually involves a high cost and implies a long payback but may be of interest in case the building hosting the supermarket is old, with low energy performance or in presence of incentives for this kind of intervention.

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.

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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.

As concerns other parts of the building envelope, 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. These two concepts imply that the replacement of old and inefficient windows, such as single-glazed ones and those with aluminum frame and no thermal break could be replaced with more efficient models (PVC frames, aluminum frames with thermal break, equipped with double-glazing and/or low emissivity/solar control glass).

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.

5.3.2 High Efficiency Reversible Heat Pumps

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
High-Efficiency Reversible Heat Pumps	Heat pump	High	Low-efficiency HVAC system	Medium-High, depending on baseline conditions of the HVAC system	Medium-High

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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.

This may be the case, for example, of reversible heat pumps used for both heating and cooling; indeed, old models were characterized by a lower nominal efficiency compared to the nominal one of new models, and moreover have lost efficiency during the years.

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. 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.

Indeed, the efficiency of a heat pump varies, in addition to the technological aspects that have significantly improved during the last years, such as design of evaporators, pipes and condensers, adoption of high-efficiency electric motors and inverters for compressors and fans (which are the main components of a heat pump), on the ambient conditions. The use of a source having a relatively constant temperature during the year like the ground or a water body allows significant benefits in terms of COP increase.

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This measure is applicable, in one of the three technological options, 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.

5.3.3 Condensing Gas-Fired Boilers for Heat Production

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Condensing Gas-Fired Boilers for Heat Production	Condensing boiler	High	Availability of natural gas supply network	Medium-High, depending on baseline conditions of the HVAC system	Medium-High

For supermarkets where heating needs are covered with old conventional boilers using diesel or natural gas, the replacement of the old boiler with a new natural gas fired condensing boiler is of interest in order to increase heat production efficiency and decrease fuel supply costs.

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. Indeed, condensing boilers 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. 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.

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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.

5.3.4 Biomass Boilers for Heat Production

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Biomass Boilers for Heat Production	Biomass boiler	High	Local availability of biomass material, availability of spaces (including fuel storage), absence of environmental constraints	Medium-High, depending on baseline conditions of the HVAC system	Medium-High

As an alternative to the previous measure, for supermarkets where heating needs are covered with old conventional boilers using diesel or natural gas, the installation of a biomass-based boiler could be of interest. The type of biomass shall be identified according to the availability of suitable materials in the local context, and may range from wood pellets, which are commercially available worldwide, to biomass chips or wood logs whose availability is variable in different areas.

The technological features of biomass boilers depend on the type of material to be burnt; pellet-fueled 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.

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.

Another drawback of this technology is the larger space needed for the boiler and the auxiliary equipment (e.g. fuel storage) compared to other boilers and heating technologies. Based on the pros and cons presented for this solution, it is recommended to carry out a feasibility study including a cost-benefit analysis before proceeding with the implementation of this measure.

5.3.5 Heat Recovery from Products' Refrigeration Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Heat Recovery from Products' Refrigeration Systems	Heat exchangers	Medium-High	Size matching between refrigerators' and HVAC systems	Medium	Medium

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Another sustainable source of heat, worth being considered in a supermarket to increase the level of energy efficiency is constituted by waste heat from products' refrigeration systems. As outlined in section 5.5 of this document, these 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 recovery could be carried out directly, by adding an auxiliary condenser to the existing ones and modifying 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.

5.3.6 Air Handling Units with Heat Recovery Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Air Handling Units with integrated heat recovery system	Air Handling Unit, heat exchangers	High	Absence of heat recuperators in Air Handling Units	Medium-Low	Medium

The system typically adopted in supermarkets to supply heating and cooling to the building is constituted by Air Handling Units (AHUs), which 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.

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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.

This can be obtained in different ways, including mixing and recirculation of part of the exhaust air with fresh air, which is however limited for air quality reasons, and contactless heat exchange through different devices such as:

- recuperator heat exchanger, usually plate-type with cross-flow between hot and cold air;
- 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;
- 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.

One of the proposed heat exchange solutions is almost always feasible in AHUs in supermarkets; the main benefits are related to the lower electricity/fuel consumption for heating and cooling purposes.

5.3.7 Free Cooling and Evaporative Cooling

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Free Cooling and Evaporative Cooling	AHU control systems, heat exchangers	Medium-High	Suitable ambient climate conditions (temperature, humidity)	Medium-Low, depending on local climate conditions	Medium

In addition to the previously mentioned opportunity for the reduction of energy consumption for heating and cooling, applicable especially during periods with high demand for heating and cooling, this measure proposes another opportunity related to mid-seasons, i.e. free 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

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for supermarkets. In both cases, constraints related to indoor air quality and legionella should be carefully taken into account.

5.3.8 High Efficiency Motors and VFD Control in Ventilation Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
High-Efficiency Motors and VFD Control in Ventilation Systems	Electric motors, VFD	High	Presence of old and inefficient motors with on-off or throttling control system	Medium-Low	Medium-Low

In the description of the previous measures focus was set on the production and use of heat and cold for the control of the indoor air quality in the supermarket. This opportunity is, on the other hand, related to the fans used in the AHUs for ventilation of the building.

Indeed, 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 opportunity presented in this paragraph is on the other hand aimed at allowing a flexible operation to the fans through the whole range of ventilation rates and with proportional variation of the absorbed power. This can be obtained through the installation of a control system for fans that 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.

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5.3.9 High-Efficiency Pumping Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
High-Efficiency Pumping Systems	Pumps, motors, VFD	High	Presence of old and inefficient motors with on-off or throttling control system	Medium-Low	Medium-Low

The same considerations done in the previous paragraph regarding ventilation fans are applicable to pumps used to distribute the hot/refrigerated water in the supermarket, where significant electricity savings could be obtained through the replacement of the electric motors and the control of the water pumping through VFD. Also, in this case, the benefits are in the range of 10-30% for VFD control and 5-10% for electric motors replacement.

5.3.10 Smart Control of HVAC Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Smart Control of HVAC Systems	Sensors, HVAC control software or BMS	High	HVAC systems suitable for integration with BMS	Medium	Medium-Low

This opportunity is strongly linked to the previous ones, since the installation of temperature, humidity and other (e.g.: carbon monoxide concentration) sensors throughout the whole supermarket building,

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feeding the monitored data to a smart HVAC control system of to a Building Management System (BMS) would provide significant benefits in terms of energy consumptions.

Indeed, 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.

The control logics, i.e. the inputs to be provided to the inverters based on the parameters monitored from the sensors, shall be defined and improved based on the experience in managing the HVAC systems of the specific supermarkets, taking into account many factors including the characteristics of the HVAC systems, of the distribution piping, of the building envelope, etc.

5.3.11 Improvement of Air-Tightness

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Improvement of Air-Tightness	Doors	High	Single-door entrance, space availability for two-door vestibule	Medium-Low, depending on location and climate conditions	Medium-Low

As discussed in the previous opportunities for improvement, every time that the heated (or cooled in summer) indoor air is exchanged with outdoor air, an energy loss in the building energy system is introduced. This occurs both in the controlled ventilation that occurs in AHUs and in the unavoidable but uncontrolled exchange of air that occurs at the supermarket entrance.

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

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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 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.

5.3.12 Air Curtain at Building Entrance

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Air Curtain at Building Entrance	Air blower	High	Single-door entrance (applicable also to two-door vestibule)	Medium-Low, depending on location and climate conditions	Medium-Low

Linked to the previous opportunity, 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. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines an air door as "a continuous broad stream of air circulated across a doorway of a conditioned space. The air stream layer moves with a velocity and angle such that any air that tries to penetrate the curtain is entrained."

This can be performed by installing an air blower facing downwards on the entrance (between the two doors if the previous measure is implemented); this 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.

5.3.13 Low-Flow Aerators on Toilet Water

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Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Low-flow aerators on toilet water	Aerators	High	None	Medium-Low, depending on location and climate conditions	Low

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.

5.4 Lighting

This section focuses on the increase of the energy efficiency level of lighting systems and on their smart control to minimize energy consumption for lighting.

5.4.1 LED Lighting in Indoor/Outdoor Spaces

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
LED Lighting of Indoor/Outdoor Spaces	LED lamps	High	Use of non-LED lamps (e.g. fluorescent)	Medium	Medium-High

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.

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Compared to neon fluorescent lamps, which were the formerly most adopted lighting technology, LED can reduce electricity consumption by up to 65%, with positive impacts on colour rendering, light distribution and even air conditioning, since their lower power leads to a reduction of thermal load 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.

Moreover, LEDs have a longer operational lifetime, up to 50,000 h and more compared to maximum 15,000 h of neon lamps, thus reducing operation and maintenance costs in addition to energy consumptions and related costs.

LED lamps are available for retrofitting of practically all types of lamps, from neon tubes (the typical replacement at constant luminous flux is 24 W LED for each 58 W neon tube) to incandescent lamp (typical replacement is 10 W LED for each 100 W incandescent bulb), to metal vapor lamps typically used outdoors (typical replacement is 250 W LED for each 400 W sodium vapor lamp).

5.4.2 Solar-Powered Lighting Poles in Outdoor Areas

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Solar-Powered Lighting Poles in Outdoor Areas	LED lamps with PV panel	High	Use of non-LED lamps (e.g. sodium vapor, halogen)	Medium	Medium-High

As mentioned in the previous paragraph, LEDs are suitable for indoor and outdoor areas; as concerns external lighting, a further opportunity exists for supermarkets, i.e. 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.

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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.

5.4.3 Natural Lighting Sensors in Highly Fenestrated Areas

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Natural Lighting Sensors in Highly-Fenestrated Areas	Sensors	High	High availability of natural lighting, absence of lighting control systems	Low	Medium-Low

For areas of the supermarket provided with large windows, the maximization of the use of daylight as an alternative to electric lighting is an interesting opportunity. 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.

5.4.4 Timers on Indoor Lighting Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Timers on Indoor Lighting Systems	Timers	High	Switchboards and power supply lines suitable for installation of timers	Low	Medium-Low

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.

This applies also to lamps installed within refrigerated cabinets, that typically remain constantly switched on.

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5.4.5 Movement Sensors

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Movement Sensors	Sensors	High	Power supply lines suitable for installation of sensors for multiple lamps control	Low	Medium-Low

Following the two previous opportunities, which are mainly related to areas typically open to the public, this paragraph focuses on a possible solution that is more applicable for service areas like warehouses, changing rooms, toilets, etc.

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; similarly to the application of natural lighting sensors and dimming devices, this does not impact on the lifetime of LED lamps, but allows significant energy savings.

The location of the sensors and the switch-off timing shall be done based on a careful analysis of the room with the aim of minimizing energy consumption contemporarily guaranteeing the safety of persons in the room.

5.4.6 Smart Control of Lighting Systems in Indoor/Outdoor Areas

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Smart Control of Lighting Systems in Indoor/Outdoor Areas	Sensors, Lighting management software or BMS	Medium-High	Lighting control sensors suitable for integration with BMS	Low	Medium-Low

An integrated approach to lighting, similar to the one proposed for HVAC in the previous section and based on the application of all the solutions proposed for lighting in the previous paragraphs, could lead to even higher benefits in terms of energy savings.

This could be implemented into a dedicated software (Lighting Management Systems or into a more general Building Energy Management System, covering also other utilities), 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. Moreover, the system could be used to switch on and off lamps remotely every time that this is needed for instance for maintenance or surveillance purposes, may record the time elapsed from the installation of each lighting body to monitor the lifetime vs. the declared one, and if integrated with the energy monitoring system could evaluate energy consumptions of lighting, also evaluating savings compared to the baseline situation to obtain energy efficiency incentives where present and applicable to LEDs.

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5.5 Products Refrigeration

This section focuses on the solutions for energy efficiency in the products refrigeration area, in terms of reduction of energy demand for refrigeration and high-efficiency chill production.

5.5.1 Advanced Design of Refrigerated Cabinets

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Advanced Design of Refrigerated Cabinets	Doors/strip curtains, control systems,	High	Use of open refrigerated cabinets; use of anti-sweat electric heaters	Medium-High	Medium

Similarly to the approach presented for HVAC, where the first interventions in logical order is the improvement of the thermal performance of the building envelope, also in the case of products refrigeration the first option for energy efficiency is constituted by the reduction of the energy demand of the refrigerated cabinets.

This can be done through different solutions that are presented in the present paragraph, which mainly deal with the minimization of energy losses from doors, such as:

- 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; depending on the location, type of cabinet and opening frequency, savings due to this measure can reach 30% of the baseline consumption for cabinets' refrigeration; this measure is also expected to avoid overcooling of the aisle where refrigerated cabinets are located, thus increasing thermal comfort for clients;
- where the installation of doors is not feasible, a couple of options exist to limit the infiltration of warm air from outdoor environment, such as the installation of single or multiple air curtains (similar to those presented in HVAC section for the building entrance), of strip

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curtains (made of transparent and flexible material) or of night blinds (to be closed during supermarket closing hours);

- as concerns the glass of the refrigerated cabinets' doors, to avoid condensation anti-sweat electric heaters are typically used; the improvement of their control system to reduce power absorption, or better the adoption of an anti-fogging glass, i.e. a glass treated with a specific coating to avoid condensation, is therefore highly beneficial;
- regarding frozen food cabinets, the adoption of control systems for defrost can reduce the electricity consumption of these devices, whose main scope is to contrast freezing on the evaporator tubes;
- as concerns lighting in cabinets, in addition to the replacement of non-LED with LED lamps following the solutions described in the previous section, benefits can be achieved by switching off or reducing the luminous flux of lamps during closing hours (or when no clients are present, thanks to movement/presence sensors), and also by installing cabinets' lighting systems out of the refrigerated area, in order to minimize their heating load and the consequent consumption for cooling.

5.5.2 High Efficiency Refrigeration Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
High-Efficiency Refrigeration Systems	Compressors/condensers, refrigerating fluids	High	Low-efficiency of existing refrigeration systems	Medium-High, depending on baseline refrigerator efficiency	High

After having minimized the energy demand for products' refrigeration, e.g. thanks to the measures presented in the previous section, focus can be shifted to solutions for the minimization of energy consumption, i.e. high-efficiency refrigeration systems.

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This target can be reached by 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 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%.

As concerns 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.

In addition, regarding 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.

5.5.3 Use of Centralized instead of Standalone Refrigerating Equipment

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Use of Centralized instead of Standalone Refrigerating Equipment	Piping, remote outdoor unit for compressors/ condensers	High	Use of standalone refrigerators	Medium	Medium-High

As seen in the previous measures, in most cases the refrigeration of products located in cabinets for sale purposes and in cold storage rooms is carried out with centralized refrigeration systems, 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 evaporators, located in the refrigerated spaces), connected through insulated pipes, where refrigerant fluid flows.

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In some cases, the external unit is represented by a chiller package that contains all the components needed for the refrigerating cycle (evaporator, compressor, condenser) and produces refrigerated water that is distributed and fed to the refrigerated storages. This solution has the benefit that the refrigerant fluid circuit is sealed at the equipment production and the related piping is shorter, thus the leakages of organic fluid are lower.

In other, less efficient, cases, standalone refrigerators are applied, which are refrigerated cabinets and/or freezers with all refrigeration cycle components integrated, which only need power supply to work. This shares, with the previously mentioned solution, the benefit of having a refrigerating circuit sealed and short, with the consequent minimization of fluid losses, but also implies a lower efficiency compared to centralized systems, as well as the fact that all the waste heat generated by the standalone refrigerator is released into the supermarket, thus implying a higher load for the HVAC systems, at least during the cooling season. It is therefore recommended to reduce as much as possible the use of this kind of refrigerators, giving priority to the use of centralized systems with remote refrigerating units.

5.5.4 Advanced Maintenance of Products Refrigeration Systems

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Advanced Maintenance of Products Refrigeration Systems	None	High	None	Medium-High, depending on baseline maintenance practices	Low

The adoption of a regular maintenance on refrigeration systems allows keeping them at the best operating conditions in terms of efficiency and minimization of power absorption; the most important maintenance actions include the following items:

- minimization of 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;
- cleaning of 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 of 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 of 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.

5.6 Other Areas

This last section focuses on areas of the supermarkets not covered by the previous sections, i.e. warehouses and internal logistics, offices, lifts.

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5.6.1 Retrofitting of Lifts

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Retrofitting of Lifts	Electric motors, VFD, regenerative drives, LED lamps	High	Presence of lifts without the proposed efficiency systems	Low	Medium

Elevators present several opportunities for the reduction of energy consumption; these opportunities are partially related to measures already proposed for different areas of the supermarket in the previous sections, and include:

- the replacement of existing electric motors with high efficiency motors to reduce the power input at constant mechanical output;
- the installation of VFD on electric motors, provided with auto-standby device; this allows 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;
- the installation of regenerative drives that accumulate energy during the braking phase to be used in the next operational cycle instead of dissipating it through braking resistors;
- the optimization of the counter-balance system, which reduces the load of the drive system, thus allowing a reduction of motors' size and of electricity consumption;
- the switch to LED lamps for cabin lighting, to be switched of when the elevator is not in use, through the use of sensors;
- the minimization of the ventilation rate (where present) when the lift is not in use.

These actions can be implemented as retrofitting of existing elevators or considered in case of replacement of the whole lifting system as key characteristics of the new equipment.

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5.6.2 Retrofitting of Internal Logistic Equipment

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Retrofitting of Internal Logistic Equipment	Electric forklifts, batteries, chargers	High	Use of old/inefficient forklifts/chargers	Low	Medium

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.

Although these devices are more efficient compared to fuel-based ones, the retrofitting of the fleet of forklifts can allow significant energy savings due to the adoption on new models of energy efficiency improvements including:

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

5.6.3 Retrofitting of Office Equipment

Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Retrofitting of Office Equipment	High-efficiency office equipment, LED lamps, HVAC systems	High	Use of old/inefficient devices in offices	Low	Medium-Low

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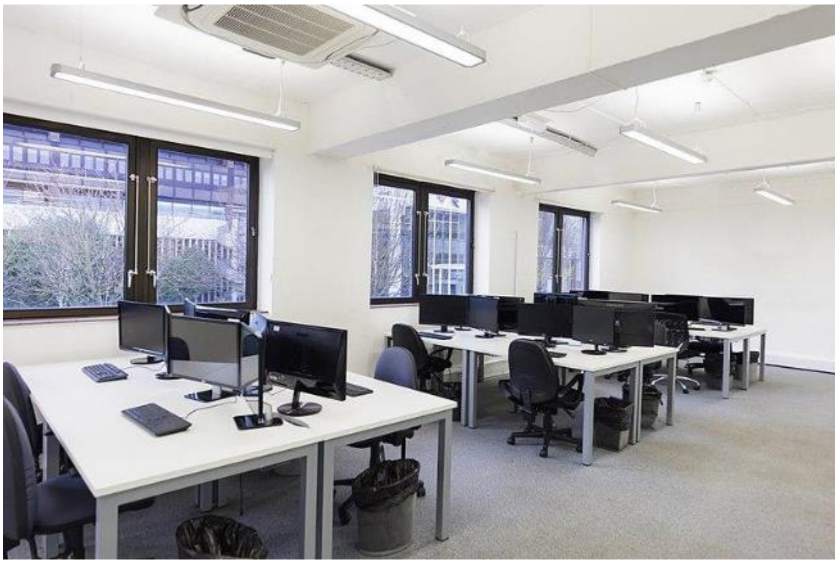

Although having a limited impact on the energy balance of the supermarket, offices also present a certain potential for the improvement of energy efficiency. Measures that are worth being implemented include, among others:

- switch to LED lamps as suggested for other areas of the supermarket;
- use of high efficiency heating and cooling systems as suggested for other areas of the supermarket;
- use of computers, monitors and printers with low energy consumption; use shared printers and limit as much as possible printing;
- definition of 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.).

In addition, when purchasing new office equipment, it is recommended to 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. This can easily be done, for most standard equipment, by assessing the energy efficiency label of the device issued by the producer in compliance with the EU EcoDesign Directive and choosing equipment with the highest possible energy efficiency class and the minimum annual estimated energy consumption: such data are reported on the energy label and determined under standard operating conditions for all similar equipment, therefore allowing an easy comparison.

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6. Summary and Ranking of Identified Measures

The following Table 6.1 summarizes the main features of the identified energy efficiency measures, grouped by category and briefly providing details on the technological components needed, the maturity of the proposed solution, the pre-requisites for application, the impact of the measure on supermarkets' energy balance and the level of investment cost needed.

Table 6.1:Summary of Identified Energy Efficiency Measures

Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Overall Energy Management	Energy audit and implementation of an Energy Management System	None	High	None	Depending on identified and adopted actions	Low
	Monitoring of electricity consumption at main switchboards	Electricity meters EMS software	High	None	Medium High, depending on attention paid to monitored data	Low
	Blockchain Enabled Smart Meters	Smart meters EMS software	Medium-High	None	Medium-High, depending on attention paid to monitored data	Low
	Artificial Intelligence for Smart Electric Load Management	Smart meters/controls AI software	Medium-High	None	Medium-High	Low
	Microclimate Design and Simulation using Nature-Based Solutions	Simulation software	Medium-High	New construction or major retrofit	Medium-High, following the implementation of identified solutions	Low
	Building and Urban Area Dynamic Energy Simulation	Simulation software	Medium-High	New construction or major retrofit	Medium-High, following the implementation of identified solutions	Low

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Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
	Asset Management Software	Asset management software Smart controls	High	None	Medium-High	Low
	Regular maintenance of energy users	None	High	None	Medium-High, depending on baseline maintenance practices	Low
Energy Supply	Rooftop photovoltaic plant	Photovoltaic modules and related accessories	High	Availability of space on rooftop with suitable structural characteristics, absence of urbanistic constraints	High, potentially 100% of the energy needs can be covered with a carbon-free source	High
	Building-Integrated Photovoltaic Modules	Photovoltaic modules and related accessories	Medium-High	Availability of space, absence of urbanistic constraints	Medium-High	High
	Photovoltaic modules on parking lots	Photovoltaic modules and related accessories	High	Availability of space on parking lots, absence of urbanistic constraints	Medium-High, depending on the size of the parking area	Medium
	Micro-wind power production systems	Micro-wind turbine and related accessories	Medium-High	Suitable conditions in terms of wind availability, absence of urbanistic constraints	Medium	High
	Solar thermal for toilets' hot water production	Solar thermal panels, hot water storage tanks	High	Availability of space on rooftop, absence of urbanistic constraints	Low	Medium-Low

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Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
	Cogeneration/Trigeneration	Cogeneration plant (engine, turbine, etc.), heat exchangers, absorption chiller (for trigeneration)	High	Presence of contemporary high electric and thermal loads, absence of environmental/permitting constraints	Potentially 100% of the energy inputs can be covered	High
	Reactive power compensation systems	Capacitors	High	Presence of significant capacitive loads	Low	Medium-Low
	Waste-to-Energy Solutions	Pyrolysis plant	Medium	Sufficient waste availability for the specific technology	Medium	Medium
Space Heating and Cooling, Ventilation	Improvement of Building Envelope Thermal Insulation	Thermal insulation material; high-performance windows/doors	High	Low baseline energy performance of supermarket building	Medium-High, depending on baseline conditions of the building	High
	High-Efficiency Reversible Heat Pumps	Heat pump	High	Low-efficiency HVAC system	Medium-High, depending on baseline conditions of the HVAC system	Medium-High
	Condensing Gas-Fired Boilers for Heat Production	Condensing boiler	High	Availability of natural gas supply network	Medium-High, depending on baseline conditions of the HVAC system	Medium-High

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Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
	Biomass Boilers for Heat Production	Biomass boiler	High	Local availability of biomass material, availability of spaces (including fuel storage), absence of environmental constraints	Medium-High, depending on baseline conditions of the HVAC system	Medium-High
	Heat Recovery from Products' Refrigeration Systems	Heat exchangers	Medium-High	Size matching between refrigerators' and HVAC systems	Medium	Medium
	Air Handling Units with integrated heat recovery system	Air Handling Unit, heat exchangers	High	Absence of heat recuperators in Air Handling Units	Medium-Low	Medium
	Free Cooling and Evaporative Cooling	AHU control systems Heat exchangers	Medium-High	Suitable ambient climate conditions (temperature, humidity)	Medium-Low, depending on local climate conditions	Medium
	High-Efficiency Motors and VFD Control in Ventilation Systems	Electric motors, VFD	High	Presence of old and inefficient motors with on-off or throttling control system	Medium-Low	Medium-Low
	High-Efficiency Pumping Systems	Pumps, motors, VFD	High	Presence of old and inefficient motors with on-off or throttling control system	Medium-Low	Medium-Low
	Smart Control of HVAC Systems	Sensors HVAC control software or BMS	High	HVAC systems suitable for integration with BMS	Medium	Medium-Low

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Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
	Improvement of Air-Tightness	Doors	High	Single-door entrance, space availability for two-door vestibule	Medium-Low, depending on location and climate conditions	Medium-Low
	Air Curtain at Building Entrance	Air blower	High	Single-door entrance (applicable also to two-door vestibule)	Medium-Low, depending on location and climate conditions	Medium-Low
	Low-flow aerators on toilet water	Aerators	High	None	Medium-Low, depending on location and climate conditions	Low
Lighting	LED Lighting of Indoor/Outdoor Spaces	LED lamps	High	Use of non-LED lamps (e.g. fluorescent)	Medium	Medium-High
	Solar-Powered Lighting Poles in Outdoor Areas	LED lamps with PV panel	High	Use of non-LED lamps (e.g. sodium vapor, halogen)	Medium	Medium-High
	Natural Lighting Sensors in Highly-Fenestrated Areas	Sensors	High	High availability of natural lighting, absence of lighting control systems	Low	Medium-Low
	Timers on Indoor Lighting Systems	Timers	High	Switchboards and power supply lines suitable for installation of timers	Low	Medium-Low
	Movement Sensors	Sensors	High	Power supply lines suitable for installation of sensors for multiple lamps control	Low	Medium-Low
	Smart Control of Lighting Systems in Indoor/Outdoor Areas	Sensors Lighting management software or BMS	Medium-High	Lighting control sensors suitable for integration with BMS	Low	Medium-Low

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Category	Measure	Technology	Maturity of Solution	Pre-Requisites	Impact on Energy Balance	Investment Cost
Refrigeration of Products	Advanced Design of Refrigerated Cabinets	Doors/strip curtains, control systems,	High	Use of open refrigerated cabinets; use of anti-sweat electric heaters	Medium-High	Medium
	High-Efficiency Refrigeration Systems	Compressors/condensers, refrigerating fluids	High	Low-efficiency of existing refrigeration systems	Medium-High, depending on baseline refrigerator efficiency	High
	Use of Centralized instead of Standalone Refrigerating Equipment	Piping, remote outdoor unit for compressors/condensers	High	Use of standalone refrigerators	Medium	Medium-High
	Advanced Maintenance of Products Refrigeration Systems	None	High	None	Medium-High, depending on baseline maintenance practices	Low
Other Areas	Retrofitting of Lifts	Electric motors, VFD, regenerative drives, LED lamps	High	Presence of lifts without the proposed efficiency systems	Low	Medium
	Retrofitting of Internal Logistic Equipment	Electric Forklifts, batteries, chargers	High	Use of old/inefficient forklifts/chargers	Low	Medium
	Retrofitting of Office Equipment	High-efficiency office equipment, LED lamps, HVAC systems	High	Use of old/inefficient devices in offices	Low	Medium-Low

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7. Conclusions

The aim of the present SUPER-HEERO D2.1 was to create a catalogue with the most relevant and easy to replicate energy efficiency measures to be promoted by SUPER-HEERO renovation approach, based on a high-level analysis of typical supermarkets' energy systems and equipment. It constitutes the main input to SUPER-HEERO D2.2, which will focus on guidelines for the implementation of energy efficiency measures in supermarkets according to their size, estimated sales volume, staff amount, kind of products, etc., covering both technical and financial aspects.

The analysis done in this document is articulated into five main steps (identification of supermarkets' typical energy balance, definition of typical energy consumption level (electricity/heat), analysis of typical breakdown of energy consumption, selection of key areas for energy efficiency improvement, elaboration of energy efficiency measures' catalogue).

The results of the analysis have highlighted how supermarkets are one of the retail sectors with the highest energy consumption mainly due to refrigeration equipment, space heating/cooling and lighting, with an average final energy consumption in the range between 320 and 800 kWh/m^2/y. In all the studies available in literature, products refrigeration, HVAC and lighting are the three main responsible users in the energy balance, followed by other uses (kitchen, offices, internal logistics, where present).

The catalogue of energy efficiency measures is therefore articulated into six categories, corresponding to the three above mentioned energy uses ("heating, ventilation, air conditioning", "lighting", "product refrigeration"), plus two more general categories ("overall energy management" and "energy supply") and "other" areas. In the current version of D2.1, the catalogue of energy efficiency measures is constituted by 42 interventions.

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