WP2

D2.2: State of the art in the Smart electricity for Buildings

Co-funded by
the European Union

101144027 — SEBCoVE — ERASMUS-EDU-2023-PEX-COVE

SEB CoVE
SMART ELECTRICITY FOR BUILDINGS

D2.2: STATE OF THE ART IN THE SMART ELECTRICITY FOR BUILDINGS

SEBCoVE

SMART ELECTRICITY FOR BUILDINGS

Table of Contents

Co-funded by
the European Union

Co-funded by the European Union

REVISION HISTORY

Rev.	Date	Author	Document Sponsor	Revision Summary
0	04/06/2024	FC, BC	IPP	First Edition
1	04/06/2024	FC, BC	IPP	Adding other partner contributions
2	28/06/2024	CA	IPP	Document quality check
3	17/07/2024	CA	IPP	Layout, inserted disclaimer

REVIEWERS

Rev.	Date	Author	Document Sponsor	Reviewed
0	28/06/2024	Alexandros Paspatis	IPP	YES
1	28/06/2024	Vaggelis Pombodakis, External Reviewer	IPP	YES

“State-of-the-art in advanced electrical sector skills and HVET/VET in Europe and in the World”

Summary

The SEBCoVE project, which is dedicated to the establishment of regional centres of vocational excellence within the smart electricity for buildings sector, includes the document entitled D2.2 "State-of-the-art in advanced electrical sector skills and HVET/VET in Europe and in the World." The report delineates the current state-of-the-art in a variety of pertinent areas related to Smart Electricity in Buildings, such as energy management and efficiency, building automation and control systems, occupant comfort and well-being, availability of data and expertise (HVET/VET) for analytics, security and privacy concerns, and integration with smart grids and energy markets and overall analysis. The current circumstances in the countries of the project's participants (Greece, Spain, Portugal, Italy, North Macedonia, Germany, and Netherlands) are also emphasized in addition to a comprehensive general analysis.

Introduction

- Background: The SEBCoVE project aims to develop hubs for vocational excellence in smart electricity for buildings, supporting regional specialization and establishing international knowledge hubs for VET systems.
- Objectives: The project seeks to create resilient and future-proof VET systems, develop regional centres of vocational excellence (CoVEs), support smart specialization, and establish a curriculum based on EU VET standards.
- Purpose of the Report: To analyse the current state-of-the-art regarding the several different surrounding factors of smart electricity for buildings.

Research Methodology

- Topics of Interest Definition: Initial scoping of the topic and selection of relevant topics and subtopics.
- Selection of Relevant Literature: Starting by conducting a thorough search for pertinent literature in the field of study. Making use of search engines and databases to locate pertinent sources, such as review articles and essential papers. Review articles have the potential to contextualize other publications in the field and offer a more comprehensive perspective on the subject matter. Some relevant websites and law decrees were also analysed.
- Analysis of Selected Relevant Literature: After selecting the corpus of literature, they is an analysis of each, individually, and then it is decided if that literature is relevant to each of the initially defined topics.
- Writing and Citing: After defining if the literature is relevant to any of the defined topics it is written and properly cited, at all times.

Key Findings

- Smart Electricity in Buildings: An ever-growing attention to modernization is acting as a catalyst to the increase of smart buildings. These require more attention than ever before and are rapidly being implemented across the world.

- Different trades and skills: These emerging smart buildings require collaboration across several different professionals. There is a need for professionals skilled in building automation (for controlling lighting, HVAC, and other devices), data analysts are crucial to interpret sensor data and identify energy saving patterns, electrical and mechanical engineers are indispensable, and expertise in renewable energy sources (RES) is also crucial, such as photovoltaic (PV) panel experts. Software developers and IT specialists could also collaborate by implementing smart algorithms. Management skills are always necessary, needing a collaboration between all these trades for an effective system.

Implications and Recommendations

- Implications: The scoping of the state-of-the-art helps in analyzing the current field of smart electricity in buildings and finding potential gaps in the skills/trades sector.
- Recommendations: Periodically scope new potential changes, especially since technology and laws surrounding it are constantly changing.

Connection with Other Activities

Defining Potential Skills and Trades: Establish a base structure in which some specific professions need to collaborate to form a complete and functional building automation system.

Regional Scenario Analysis

Apart from a generalized global analysis, each partner’s regional structure for smart electricity in buildings is individually highlighted.

Conclusion

The SEBCoVE project report analyses smart electricity for buildings technology in detail. Regional CoVEs that encourage regional specialization and build resilient and

Co-funded by
the European Union

future-proof VET systems are the project's main goal. A comprehensive literature evaluation and analysis covers energy management, building automation, occupant comfort, data availability, security, and smart grid integration. Implementing smart building systems requires a variety of skills and crafts. These include building automation, data analysis, engineering, RES, software, and management. The paper stresses professional teamwork, reflecting the field's interdisciplinary nature. Due to rapid technological and legal developments, there is an emphasis on field monitoring and adaptation. It is suggested to establish a foundation for professions to collaborate on a building automation system. The study includes a general analysis and regional studies for the project's partner countries, highlighting their specific circumstances and requirements. This regional focus helps the project create vocational excellence hubs for regional specialization. For establishing smart electricity system development and implementation, the SEBCoVE project report is useful. It provides a detailed assessment of the existing state-of-the-art, identifies skills/trades sector deficiencies, and suggests future advances.

Abstract

The SEBCoVE project is focused on creating regional CoVEs in the smart electricity for buildings sector. A key component of this initiative is the D2.2 report, which provides a comprehensive overview of the current state-of-the-art in various areas related to smart electricity in buildings, including energy management, building automation, occupant comfort, data analytics, security, privacy, and integration with smart grids. The project's objectives include the development of resilient vocational education and training (VET) systems, regional CoVEs, and a curriculum based on EU VET standards. The report's methodology encompasses defining relevant topics, selecting, and analysing pertinent literature, and ensuring proper citation. The findings underscore the growing importance of smart buildings and the need for multidisciplinary collaboration. The report also offers implications and recommendations, emphasizing the need for regular updates due to the rapidly evolving nature of technology and related legislation.

1. Introduction to Smart Electricity in Buildings

Smart buildings are a significant advancement in the field of current architecture and infrastructure management, encompassing a diverse variety of jobs and skills around the world. It represents a shift away from traditional electrical systems and toward intelligent, networked frameworks that balance efficiency, sustainability, and technology [1], [2]. This paradigm shift necessitates to a comprehensive integration of information from numerous domains [1]. First and foremost, it necessitates the expertise of electrical engineers, who are in charge of designing and implementing the intricate networks that provide energy to smart buildings. Their understanding of safety protocols, electrical principles, and emerging technologies is critical to developing robust infrastructures capable of meeting the demands of a digitalized society [3]. Likewise, smart electricity requires a deep integration of computer science and data analytics. These domain experts apply their knowledge to develop software, algorithms, and data-driven insights that increase system reliability, forecast consumption trends, and optimize energy use [3]. Furthermore, the successful implementation of smart buildings is important to the intersection of architectural and construction management disciplines. Working together, architects and construction managers ensure that the physical buildings can readily accommodate the technology parts required for smart power while meeting safety, aesthetics, and regulatory standards. The cornerstone of this transformation is sustainability, which requires an understanding of environmental science, RES integration, and green building approaches. Sustainable design experts strive to minimize a building's environmental impact while maximizing resource and energy use [3], [4]. Simultaneously, cyber security professionals are critical in defending smart electrical systems from cyber-attacks while also ensuring the security and privacy of private information transferred and stored in networked systems [5].

Worldwide, the prediction is that the number of smart buildings will jump to 115 million, an increase of about 150% when compared to the existing number in 2022 (45 million) [6], [7]. It is presumed that above 90% of industries will also be automated in some capacity [6], be it through sensors, IoT devices, or automated tasks, with the total cost of industry automation accounting for nearly 95% of total automation implementation costs [6]. Factors such as air quality are also important to consider when automating buildings since it is estimated that enhancing ventilation and air quality increases work productivity by around 8-11% [6].

The path to smart energy in buildings imposes a diverse set of skills and crafts, each contributing a unique perspective and level of knowledge to the ultimate goal of creating strong, intelligent, and sustainable built environments. It is an international collaborative effort that brings experts together with the common goal of innovation and progress. The importance of multidisciplinary collaboration in shaping the future of our built environment cannot be overstated as smart buildings spread, fuelled by technical advancements and a growing emphasis on sustainability.

2. Overview of Technological Infrastructure and Connectivity

This analysis is more focused on each individual partner, which in turn, overall, paints a picture of a generalized overview.

2.1. Smart Building Infrastructure Scenario

As a consensus, most countries appear to be adopting smart building infrastructure, Portugal being no exception, and its industry and real estate markets are currently embracing the digital era. The widespread availability of high-speed internet and the emerging 5G networks support the integration and performance of smart building technologies [8].

Regarding personal homes, when inquiring owners about their principal motive behind either acquiring or building smart homes, the main reasons are comfort and security, with energy management/savings and luxury being other significant factors [9]. Although the number of smart homes has significantly expanded in the last decade, the total of smart homes in Portugal still accounts for less than 1%, due to the assumption by most locals that building automation is still a luxury [10]. Despite the small total number of homes in Portugal that are automated, the increase is still significant, and it is being further ignited by the European Commission's latest building efficiency directives (Energy Performance of Buildings Directive EU/2024/1275 [11] and Energy Efficiency Directive EU/2023/1791 [12]), which aims to contribute to carbon neutrality by 2050, motivated by factors such as the fact that over 40% of energy consumed in Europe is used in buildings and around 80% is for cooling, heating and hot water [11]. Regarding the industry aspect of automation, the scenario could not be any different, with as far as 86% of established industry brands implementing some sort of automation into their manufacturing process, be it through sensors, IoT devices or automated tasks [13]. Furthermore, an official national report by the National Statistics Institute concludes that 7.9% actively use Artificial Intelligence in automated tasks and 28.2% use it to analyse data [14].

Currently, the Greek government provides funding and support for the conversion of buildings into smart buildings, with the objective of addressing the current limited adoption of the smart building scenario, particularly in older buildings. The activities that are funded include the installation of fibre optic networks, the enhancement of the interconnection with public electricity and gas networks, and the implementation

Co-funded by
the European Union

of modern heating systems [15]. Conversely, the tourism sector is characterized by the prevalence of smart building scenarios, particularly smart homes, in new hotels and luxury residences.

The Spanish Smart Buildings deployment model is similar to other EU countries. This can be summarized by developing national policies and regulations that comply with the common European policy framework and determining how to act in crucial areas like industrial, technological, economic, and social. Administrative organization and structures, specific needs and aims, and other elements that explain European country disparities, as well as the country's environment and development state, are considered.

Already addressed are European legislation and rules. EED for all industries, EPBD promote NZEBs through BAS, IoT, and enhanced EMS. The EPBD's latest Smart Readiness Indicator (SRI) assesses buildings' ability to respond to grid signals, adapt to occupant needs, and enhance energy efficiency. Horizon Europe and Digital Europe fund smart building projects. National building policies in Spain promote home automation in new buildings, resulting in constant growth even during economic downturns. Spain's Smart Cities approach [16] is a global benchmark that emphasizes business support, governance, and standards. Smart cities need smart buildings. Others, like the National Plan for Smart Cities (2015), optimized public ICT policies to boost economic growth. España Digital 2026 [17] is the current digital transformation roadmap, with a governance approach that ensures public and private agents' discussion and engagement for a smooth transition.

The Technical construction Code (CTE) [18] is one of Spain's most important construction laws that affects smart building adoption. It sets minimum quality, energy efficiency, and sustainability standards for Spanish buildings, including lighting and HVAC systems. The Electrotechnical Regulations for Low Voltage (REBT) [19] and the Regulation of Thermal Installations in Buildings (RITE) [20] also regulate building automation systems. Spain also revised (Royal Decree 390/2021) [21] the technical criteria and methodology for energy rating calculation and building energy certification documents. Spanish Smart Buildings must advance across various dimensions, as required by policies. Technological advancements (monitoring smart technology innovations along chain values), investment and funding (to support R&D and implementation), education (to train a skilled workforce), interoperability and standards (to integrate systems and control), sustainability and environmental considerations (to meet national and global climate goals), and user engagement and acceptance Government and regulatory bodies like the Ministry of Transport, Mobility, and Urban Agenda (MITMA), the Ministry of Economic Affairs and Digital Transformation, and the Spanish Association for Standardization, as well as industry associations like AMETIC, technology providers, construction and real estate companies and professionals, energy providers, research and academia, and end-users. A yearly Intelligent Buildings Congress [22] has set the standard for smart buildings in Spain, displaying the latest technologies and solutions. Worth noting. The 2013 congress has become a major smart building event in Spain. This broad structure is vital, even though it is a continuing effort with room for improvement. The general scenario for smart building development in Spain involves retrofitting existing structures, collaborating between the chain value and regulators, and implementing sustainable, climate-adaptive technologies that can be replicated and scaled across the country while considering regional specificities.

Technological infrastructure and connection enable the building's systems and gadgets to integrate, communicate, and connect. The high-speed, low-latency, and wide connection of 5G technology drives the smart building revolution. The España Digital 2026 [17] strategy is divided into eleven strategic axes. Infrastructure and technologies promote 5G technologies, cybersecurity, data economy, AI, and digital connection. These goals apply to smarter cities and structures. In instance, Spain is implementing 5G and other sophisticated telecommunications technologies, albeit unevenly. By 2025, localities with over 20,000 people will have 5G technology, and 75% of Spaniards will have 5G SA coverage.

Connectivity and integration technologies are available to Spanish installers and specialists. However, the implementation and accompanying structures are not necessary in all buildings and are not generally employed, especially in residential buildings. Tertiary buildings over 290 kW must integrate energy management and control systems under this regulation. About 10% of Spanish structures are automated. The current regulation on the installation, refurbishment, and maintenance of Common Telecommunications Infrastructures (ICT) applies to all buildings in Spain, except single-family houses [23]. These cabling infrastructures ensure that building occupants can access a variety of telecommunication services, including telephony, television, and the Internet. Despite the lack of a formal regulation, these infrastructures are helping meet new needs like building automation, which digitalizes and connects residential buildings. Some building improvements, like IoT for home automation, can be made without major infrastructural changes.

The Netherlands are adopting advanced smart building technologies. By 2020, the Netherlands had emerged as a leader in this field within Europe. Known for its embrace of innovation, the country has witnessed a significant rise in smart building projects, particularly in major cities like Amsterdam, Eindhoven, and Rotterdam [24].

The effectiveness of smart electricity systems in buildings hinges on robust digital connectivity. The introduction of new 5G spectrum bands is playing a crucial role, increasing average traffic capacity per user by approximately 40% in the Netherlands [25]. Statistics from Statistics Netherlands reveal that about three-quarters of the population have integrated at least one smart device into their homes. Among these, smart meters for utilities such as water, gas, and electricity are the most prevalent [26].

At a global event on November 22, 2022, in Munich, Germany, the company CONCR was awarded second place among the top three smart buildings, showcasing Germany's significant investment in this sector [27], [28]. Essential technologies for smart buildings include robust digital connectivity and Broadband Power Line, which effectively measures energy quality and supports electric vehicles and microgrids [29].

North Macedonia's ICT sector thrives on competitive firms, skilled English-speaking workforce, solid telecom infrastructure, and low corporate taxes. However, outsourcing dependence faces challenges as wages rise, necessitating ICT infrastructure and digital skills investments to retain talent. Tax incentives aim to attract youth to IT. Developing a knowledge economy is crucial for local competitiveness. Smart building adoption grows in urban areas like Skopje, Veles, Kavadarci, leveraging IoT, sensors, and networks for energy efficiency. Technologies include IoT monitoring, adaptive lighting, efficient HVAC, and security systems. High-speed internet aids deployments, with Wi-Fi and 5G linking IoT devices. Government promotes energy efficiency through subsidies and EU-aligned regulations, supporting smart city projects. Skopje leads smart city initiatives integrating modern infrastructure. Public-private partnerships drive investment, while regulations ensure quality and security in smart technologies [30].

Italy's construction sector is dominated by residential buildings, making up 92% of total properties, with the remaining 8% being non-residential structures. Energy consumption in the sector decreased to 30.7 million tonnes of oil equivalent (Mtep) in 2020, a 6.8% drop from 2017. Residential buildings in Italy consumed an average of 170 kWh/m² per year in 2021, below the EU average. Thermal energy accounted for 79%, with electric energy comprising 21%. Non-residential buildings averaged 230 kWh/m² annually, 8% below the EU average, with thermal energy at 68% and electric at 32%. Over half of Italy's buildings were built before 1970, posing challenges for energy efficiency. With a deep restructuring rate of 0.85% annually, potential yearly consumption reductions of 4-5.5 TWh and CO2 emissions reductions of 0.8-1.1 million tonnes are achievable. However, 62.3% of residential buildings fall into energy class F or G, with approximately 90% rated below class D. In the non-residential sector, 37.8% are in energy class F or G, with around 80% below class D.

Italy is swiftly adopting smart building technologies such as IoT devices, sensors, and advanced networks to enhance energy efficiency, security, and comfort. These systems enable real-time monitoring and control of building functions, optimizing energy usage. Smart meters and energy management systems provide detailed insights into consumption patterns, while IoT-equipped HVAC systems ensure efficient temperature control.

Italy's robust network infrastructure supports these advancements, including widespread broadband and mobile connectivity, alongside the ongoing rollout of 5G networks that enhance IoT device connectivity. Common protocols like Wi-Fi, Bluetooth, Zigbee, and LoRaWAN facilitate seamless data exchange among devices [31], [32].

Driven by energy efficiency incentives and regulations, Italy's smart building market is expanding, particularly in commercial buildings seeking cost savings. Government support through incentives and regulations further stimulates innovation and deployment of smart building solutions.

2.2. Connectivity Standards and Protocols

Regarding Portugal's technological infrastructure and connectivity standards align with global best practices to ensure efficient and reliable communication both domestically and internationally. However, the country’s relative progress is slightly slower than that of its European Union Member States counterparts, ranking 15th out of 27 in digitalization, connectivity infrastructure, and protocols [33].

In Portugal, technological infrastructure emphasizes standards and protocols such as IPv6 for internet communication, fiber optic technology for high-speed connectivity, and Ethernet standards for wired LANs, while also prioritizing adherence to cloud computing standards like those by ISO and NIST and utilizing IoT protocols such as MQTT and CoAP to facilitate seamless communication among IoT devices [34]. Other protocols include Wi-Fi, widely used for wireless communication, Zigbee and Z-Wave [35], popular in smart homes and automation due to their low power consumption, Bluetooth Low Energy (BLE) for short-range communication [36] and IoT devices and LoRaWAN / NB-IoT for long range low power IoT applications [37], suitable for smart cities and buildings.

In Greece, the most widely used protocol in smart buildings, and especially for those targeted to touristic utilization, is KNX [38].

In Spain, as in any other country, the connectivity of buildings is in accordance with global availability and best practices in Europe and the world. This includes BACnet and LonWorks for BAS, ModBus for EMS, and Haystack Standard (open source). Additionally, Wi-Fi, Zegbee, Z-Wave, Bluetooth, BLE, Matter, and MQTT are utilized in home automation and inmotics.

The Netherlands is a leader in implementing connectivity technologies in Europe, with 98% 4G coverage for high-capacity fixed broadband networks. Emphasis is now on 5G spectrum bands, with the country ranking 2nd in connectivity according to the 2022 DESI report [39]. The Netherlands utilizes various connectivity protocols, including LoRaWAN, IoT, and 5G, being the first to adopt LoRaWAN for long-range, low-power applications [40]. IoT is ideal for devices needing reliable but infrequent data transmission [41]. The country's infrastructure is ready for data-intensive 5G applications [42], making it a model of digital integration in Europe.

Co-funded by the European Union

Germany excels in smart building technologies for energy efficiency, user comfort, and maintenance. In 2024, it achieved 100% 4G network coverage and 85% internet coverage, with 37 million households expected to have internet by year's end [43]. Germany employs various connectivity protocols, including TCP/IP, IPv6, Wi-Fi, Bluetooth Low Energy, and Zigbee [44], [45]. Additionally, Deutsche Telekom's 5G coverage reached 95% and is projected to cover 99% of the population by 2025 [46], [47].

North Macedonia is advancing its smart building infrastructure through diverse connectivity standards and protocols. These include Wi-Fi for high-speed internet, Bluetooth and Zigbee for reliable short-range communication, and LoRaWAN for long-distance IoT connectivity with extended battery life. NB-IoT and LTE-M utilize cellular networks for wide-area coverage, while Ethernet and Thread support stable wired and mesh networking solutions. These technologies are crucial for enhancing smart building capabilities, with plans to deploy 5G networks by 2027 to further bolster IoT performance under AEC oversight [48].

Italy's smart building market saw a substantial €6.5 billion investment in 2021, up 44% from 2020. Energy solutions accounted for €4 billion, with safety and comfort technologies following at €1.1 billion and €1 billion, respectively. Automation and monitoring platforms received €2.4 billion, a modest increase of 2.2% since 2020. Looking ahead to 2026, the Italian smart building sector anticipates a 150% growth trajectory. Three scenarios outline potential investments: The Base Scenario forecasts €10.7 billion, considering challenges like rising costs and labor shortages. The Trend Scenario predicts €13.2 billion based on recent market trends. The Accelerated Scenario projects €21 billion, driven by favorable conditions boosting technology adoption. Italy employs diverse connectivity standards: Wi-Fi for high-speed LAN connectivity, Bluetooth/BLE for short-range communication, and Zigbee for low-power automation. Z-Wave operates in sub-1 GHz frequencies, LoRaWAN supports long-range, low-power communication, and 5G enables high-speed, low-latency connections. Ethernet/PoE provide reliable wired connections, while BACnet and Modbus integrate building systems. These technologies are pivotal for advancing Italy's smart building infrastructure, enhancing efficiency and connectivity across residential and non-residential sectors alike [31], [49], [50], [51].

2.3. Different Functions and Performances

The existing smart buildings in Portugal leverage advanced technological infrastructure and connectivity to enhance many functions and performances, optimizing energy efficiency, security, and comfort – essentially the motives for adopting building automation. These buildings integrate IoT devices and sensors to monitor and control energy usage, adjusting lighting and HVAC systems in real time to reduce costs and environmental impact. They also employ smart security systems, utilizing cameras and access controls integrated with data analytics to enhance safety [52]. Moreover, existing smart buildings in Portugal can offer occupants personalized experiences, with features like automated climate control and customizable lighting settings based on individual preferences, ultimately fostering a more sustainable and comfortable living, or working environment [53].

In the touristic housing industry, particularly in Greece, the primary functions of smart building applications include heating, ventilation, shading, illumination, and security/safety.

The current smart buildings in Spain allow for the same basic or common functionalities in this rapidly evolving sector, including complete real-time control of all building facilities and systems through infrastructure and connectivity. This is done to improve energy efficiency, achieve higher levels of building automation, and provide the best possible comfort for people. Incorporate sensors, cameras, electronic controllers, efficient thermal systems, and similar devices to achieve these objectives. In Spain, water is a scarce resource that must be utilized in the most responsible manner possible. Consequently, the control of irrigation, the reuse of rainfall, and the recycling of wastewater are unique areas of interest in the context of general building automation. Nevertheless, these technologies and functionalities are not mandatory. Another critical area is climatization, as Spain is experiencing significant impacts from climate change, including extended summers and more frequent heatwaves.

Leading adoption of smart building technologies in Europe, the Netherlands improves comfort and energy economy. By means of smart buildings with automated systems for heating, ventilation, lighting, cleaning, and sanitizing, Dutch rules help to save CO2 emissions by up to 20% [54]. Smart ventilation controls with CO2, humidity, and temperature sensors are crucial to enhance energy consumption and indoor air quality; these might possibly save up to 60% in energy [55].

Germany is rapidly developing smart buildings for better management, sustainability, and environmental health. The country promotes energy efficiency, encouraging investments to reduce energy waste, lower costs, and improve the environment [56]. Smart buildings use real-time data from sensors monitoring heating, ventilation, air conditioning, and air quality to maintain stability and identify improvements [57]. RES, like solar panels and wind turbines, are increasingly integrated to produce and store energy, reducing carbon emissions and enhancing sustainability [58]. The German government aims to cut energy use by up to 80% by 2050, as buildings currently account for 40% of energy consumption and 36% of CO2 emissions in the EU [59]. North Macedonia aims to enhance energy efficiency, promote sustainability with eco-friendly materials, improve quality of life through enhanced connectivity and security, and support economic growth by fostering innovation and SMEs [48].

Smart buildings in Italy, like those in advanced regions, integrate various technologies to boost efficiency, sustainability, comfort, and safety. They focus on energy efficiency through EMS and smart grids, using RES like solar panels and wind turbines. Environmental sustainability is supported by green certifications, water management, and automated waste systems. Automation includes BAS, smart lighting, and advanced HVAC. Sensors monitor temperature, humidity, and air quality for comfort. Safety features include surveillance, access control, and fire safety. IoT and robust networks enhance connectivity for data collection and system interoperability. Data analytics enable predictive maintenance and optimize energy use. Health and wellness are addressed with air quality monitoring, natural light, and ergonomic design. Compliance with building codes and standards is ensured. Examples include Green Pea in Turin, Bosco Verticale in Milan, and Unipol Tower in Bologna, known for their advanced energy systems [31], [32], [51].

3. Energy Management and Efficiency

On top of a general overview of the topic of building energy management and efficiency, this and the following topics also focus on the specific trades and skills surrounding the topic.

3.1. Strategies for Energy Management and Optimization within Smart Buildings

Energy management and optimization within smart buildings require diverse set of skills and expertise. Professionals skilled in building automation systems are essential for controlling lighting, HVAC, and other energy-consuming devices [4], [60], [61]. Data analysts play a crucial role in interpreting sensor data to identify patterns and optimize energy usage [4], [61]. Electrical and mechanical engineers are pivotal in designing and maintaining energy-efficient systems, while knowledge of RES technologies such as solar panels is necessary for integrating sustainable energy sources. Given Portugal’s focus on RES [60], this expertise in solar panels and other sustainable technologies is highly valuable. Collaboration with software developers and IT specialists is essential for implementing smart algorithms and connectivity solutions for remote monitoring and control [9], [61]. Effective communication and project management skills are also vital for coordinating the efforts of various professionals involved in energy management initiatives to ensure successful implementation and ongoing optimization of energy efficiency strategies within smart buildings [61]. The collaboration between all these professionals is crucial to comply with the previously mentioned European Commission building directives [11], [12].

Energy management in smart buildings in Greece is primarily concerned with the optimization of heating, shading, and lighting to meet the requirements of users and ensure the most efficient operation.

Spanish installers must be energy management and optimization experts for smart constructions. Water, lighting, HVAC, electrical, and automation and control systems require training, retraining, and upskilling.

The Integrated National Energy and Climate Plan 2021-2023 (PNIEC) includes intelligent building initiatives [62]. One focuses on improving household energy efficiency for industry. Another project aimed at owners and society promotes domestic appliance rejuvenation and public initiatives to support it. The PNIEC also promotes RES in transportation, heating and ventilation, and electricity to reduce fossil fuel use. By 2030, RES should supply 42% of Spain's electricity.

The Netherlands is a leader in this innovation [63], [64]. Success depends on skilled professionals: automation engineers for system installation and configuration [65], data scientists for sensor data analysis, energy efficiency experts to identify and address waste, and sustainable architects for energy-saving building designs [66].

Germany invests heavily in AI for smart buildings, employing advanced algorithms and machine learning to efficiently analyze data, identify improvements, optimize energy consumption, and predict sensor values for system control [67].

North Macedonia is actively advancing strategies to enhance energy efficiency in smart buildings, aiming to reduce consumption and promote sustainability. Local adaptations include optimizing HVAC systems for the region's climate diversity. RES accounted for 22.9% of electricity in 2019, with hydropower dominating (86.6%). Solar energy potential remains untapped despite being high in the region. Aligning with national policies on RES, ongoing infrastructure developments like high-speed internet and 5G are essential for supporting smart building technologies and achieving sustainability goals [30], [48].

Energy management in smart buildings utilizes IoT devices like sensors and smart meters for real-time monitoring and management of energy consumption. Automated systems such as BMS and DSM optimize energy use automatically. Integrating RES and ESS balances supply and demand, while efficiency improvements minimize energy losses. Advanced analytics including predictive maintenance and machine learning predict energy needs and optimize operations. User engagement provides real-time energy information and incentivizes energy-saving behaviors. Compliance with energy regulations and pursuit of green building certifications enhance sustainability efforts [51], [68].

3.2. Integration of RES and Energy Storage Systems (ESS) and Environmental Realities of each region

Integrating RES and ESS in the case of Portugal involves a nuanced understanding of its environmental realities. With ample sunlight, photovoltaic panels offer significant potential, supported by decreasing costs and improving performance [69].

However, Portugal's intermittently windy coastline also presents opportunities for wind power integration. While both RES mitigate greenhouse gas emissions, they may require ESS to address intermittency issues [70]. ESS is not only an efficient tool in providing flexibility, but it is proven as a consensual way of reducing energy wastage [70]. However, these storage solutions have environmental implications for their production and disposal. Portugal's environmental capacity for RES deployment must be carefully assessed to prevent ecological harm, particularly in protected areas. Hybridization with other sources, such as hydroelectricity, offers stability but necessitates infrastructure investments and environmental trade-offs, like alterations to river ecosystems [71].

For numerous years, the Greek government has provided financial assistance for the installation of PV systems in both residential and commercial structures. However, the power grid's hosting capacity has been restricted in recent times, prompting the government to only provide support for the installation of new PV systems when they are paired with batteries. Additionally, zero feed-in mechanisms are frequently employed in commercial structures to address the hosting capacity issue by supporting the distribution networks. Solar water heating has been extensively adopted in residential buildings, even in older structures, as a result of the extended sunshine period throughout the year.

Spanish structures are gradually incorporating RES. Energy-efficient renewable HVAC systems are most popular. New installations and existing installations in residential and commercial buildings must be distinguished. Novel installations provide efficient installation development. Aerothermal energy is Spain's most popular installation. Aerothermal systems use external air energy to produce sustainable heating, ventilation, and domestic hot water. The CTE [3] recognizes aerothermal energy as a RES in Spain if it meets performance criteria. Current installations are limited by architectural possibilities, distances, and proportions. Combining technologies is sometimes best. A "hybrid" or "hybrid generator" supplies heating and/or domestic hot water to a building by integrating at least two energy sources, usually RES and conventional. The appliance is controlled by a system. The hybrid system's control optimizes efficiency.

Solar thermal energy was regulated and encouraged at the start of this century, leading to a considerable increase in installations in new and existing Spanish buildings. Thermal apparatus hybridization, such as heat pump integration into boilers or photovoltaic integration, is being promoted. Recent price drops have made solar PV systems more affordable for Spanish building owners. Solar PV systems in buildings are conceivable, but they must overcome technical, financial, and legal hurdles and gain the support of building owners and other stakeholders. The Spanish market for building-integrated PV systems is still evolving, with continual efforts to simplify and improve acceptance. Finally, Spain has a lot of renewable gas potential, including biogas, biomethane, green hydrogen, SNG, and others, which might be used for large-scale decarbonization.

The Netherlands is committed to enhancing its RES and ESS. It leads globally in offshore wind energy, utilizing sea winds to power buildings sustainably [72]. Despite limited solar radiation, the country also relies on photovoltaic solar energy with installations on fields and rooftops [73]. To manage ESS, battery systems and pumped hydroelectricity are used, storing energy chemically in batteries or generating electricity through turbines when needed [74]. While these systems have high initial costs and environmental impacts, they reduce dependence on fossil fuels and create jobs in the environmental sector, contributing to national growth [75].

Germany is a global leader in integrating RES and ESS into smart buildings. Solar panel distribution varies due to the country's diverse climate, with the sunnier south benefiting more than the humid, colder north [76]. ESS, especially through lithium-ion batteries, is crucial for their high energy density and long-life cycle. Natural gas and biomass are also valuable, especially in agricultural areas [77], [78]. The EUREF Campus in Berlin exemplifies this integration, using solar panels, battery storage, and a gas boiler to meet its energy needs [79].

North Macedonia has launched an investment platform for a just energy transition, marking a significant shift from coal dependence to a low-carbon future. The EBRD is aiding in its development, coordinating international partnerships. Led by the Minister of Economy, the platform aims to phase out coal power, install 1.7 GW of RES by 2030, bolster grid and storage, and support affected communities. This aligns with North Macedonia’s commitment to slash greenhouse gases by 82% from 1990 levels. Economic benefits are expected, with entry into green value chains boosting competitiveness. However, regions reliant on coal face uneven impacts, necessitating support for economic diversification and human capital. To realize this vision, around €3 billion in investments by 2030 are targeted, mainly through private sector mobilization, aided by initiatives like the Climate Investment Fund [48].

Italy is actively incorporating RES and ESS into its energy strategy to foster sustainability and resilience. Given Italy's unique environmental and economic landscapes, it is essential to tailor the integration of these technologies to optimize benefits while addressing local challenges. By adopting customized approaches that account for regional variations and environmental capacities, Italy can effectively harness the potential of RES and ESS, ensuring the development of a robust and sustainable energy system [68], [80], [81], [82].

3.3. Regional Policies and Regulations Promoting Energy Efficiency in Buildings

As a European member, Portugal abides by the previously mentioned directives on the Energy Performance of Buildings [11] and Energy Efficiency [12]. Furthermore, other widespread measures specific to Portugal include the lawful decree DL nº101-D/2020 [83], which establishes the applicable requisites to improve building energy efficiency and regulates the certification of buildings in this regard. Other relevant documents include Decree 138-G/2021, which is crucial for monitoring indoor air quality in business and service facilities. It specifies protection thresholds, reference conditions, compliance criteria, pollutant measuring methods, and standard enforcement. In addition, Decree 138-H/2021 establishes technician roles and skills in the Building Energy Certification System (SCE) and energy certificate registration fees. Additionally, Decree 138-I/2021 enhances energy performance criteria for building envelopes and technical systems according to different usage types and technical characteristics. These directives ensure standards and promote building design and operation improvements to improve environmental sustainability and energy efficiency. Additionally, dispatches nº 6476-B/2021 and nº 6476-E/2021 offer additional instructions on quality verification, comfort, and energy performance standards. This extensive regulatory framework shows a commitment to sustainable development and occupant well-being in built spaces.

The circular economy action plan [84] has been devised by the Greek Ministry of Environment and Energy to address all sustainable production, consumption, and waste management.

The transposition of the European Energy Efficiency directive in buildings and the Energy Efficiency directive in Spain is carried out through:

- Royal Decree 1027/2007, of July 20, which approves the Regulation of Thermal Installations in Buildings (RITE) [20];
- Royal Decree 314/2006, of March 17, which approves Technical Building Code of Spain [18];
- Royal Decree 390/2021, of June 1, which approves the basic procedure for the certification of the energy efficiency of buildings [21].

The regulations provide the structure and criteria for energy efficiency in all building types and national energy certification. Royal Decree 36/2023 [85] established an Energy Savings Certificate system to provide economic incentives and aid to home, industrial, and commercial customers that switch to energy-efficient technologies. Another relevant national rule, Royal Decree 842/2002, approves the Low-Voltage Electrotechnical Regulations (REBT) [19]. The latest versions of this code offer general specifications for appropriate systems and installations for building automation and control. This Code also defines electrical installation and company responsibilities and skills. The circular economy stresses long-term sharing, leasing, reusing, repairing, refurbishing, and recycling of materials and products. It applies numerous key ideas to address global issues including climate change, waste, and pollution, including the regeneration of natural systems, the preservation of products and resources, and the reduction of waste and pollution. This idea and its methods are gaining acceptance in Spain, Europe, and the world. Spain has advanced circular economy principles due to governmental strategies and legislation. This underpins the Spanish Strategy for Circular Economy (EEEC), commonly known as Circular Spain 2030 [86], which describes the circular economy transition. Spain can reduce its dependence on other nations and boost its competitiveness and resilience by adopting circular practices. The policy creates an inter-ministry committee and council to coordinate circular economy efforts and prioritizes construction. The Royal Decree on Packaging and Packaging Waste implements the PPWR Directive [87], affecting all sectors. Organizations must meet Extended Producer Responsibility (EPR) requirements. After new restrictions, Spain will continue to shift to a sustainable, circular economy.

To promote energy efficiency in smart buildings, the Netherlands enforces regional policies and regulations focused on material recycling and the circular economy, enhancing sustainability and environmental health [88]. Since 2009, the BREEAM-NL certification has set minimum energy efficiency standards, supported by the Circular Economy Law, which promotes material recycling in construction [89]. The country emphasizes using recycled materials, biomaterials, selective deconstruction, and design for disassembly to reduce waste and extend building lifespans [90]. These policies set a global example for fostering a sustainable and ecological future.

Implementing smart buildings in Germany involves adhering to regional policies and national regulations to reduce energy consumption, lower greenhouse gas emissions, and promote the circular economy. The German GEG law enforces strict measures to enhance building energy efficiency, requiring sustainable materials and circular construction practices for new buildings [91]. The government supports these initiatives with financing programs for building renovations, promoting RES systems and sustainable construction [92]. Additionally, the German Federal Environment Agency advocates the circular economy by encouraging the use of recycled materials in smart building construction [93].

North Macedonia's Makedonska Kamenica and Chesinovo Obleshevo have initiated Energy Savings Performance Contracts (ESCOs) with Makedonski Telekom. Facilitated by the EBRD's Regional Energy Efficiency Programme (REEP), supported by the EU and Energy Community, these contracts upgrade street lighting with high-efficiency LEDs financed by Makedonski Telekom. Municipalities repay investments solely through guaranteed energy savings over about six years. The Energy Efficiency Law, enacted in February with EBRD and EU support, enables ESCOs in North Macedonia, fostering green investments and economic development.

Italy's "Strategia per la Riqualificazione Energetica del Parco Immobiliare Nazionale" (STREPIN) includes a metric known as the "Virtual Rate of Deep Restructuring," currently set at 0.85% [50]. This metric reflects potential energy savings of 0.332 million tons of oil equivalent per year, representing the scale of redevelopment if all incentivized interventions were deep renovations. At a national level, Italy has implemented significant legislative measures to enhance energy efficiency in buildings. Article 135-bis of the Law of November 11, 2014 (No. 164) mandates comprehensive passive building physics requirements. Recently, Legislative Decree

Co-funded by the European Union

No. 207, enacted on December 9, 2021, transposed the European Directive 2018/1972 into national law, reinforcing regulations under the Consolidated Building Act (Presidential Decree 380/2001). Italy's National Energy and Climate Plan (NECP) aligns with the EU's "Fit for 55" package, targeting a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels, with carbon neutrality by 2050 as a long-term goal. Key legislative acts include the Environmental Consolidated Act (Legislative Decree No. 152/2006) and the Climate Decree (Legislative Decree No. 111/2019), focusing on climate change mitigation and air quality improvement. Italy also allocates funds through annual Budget Laws, including initiatives like the Italian Climate Fund established in 2022. Regionally, Italian regions have implemented stringent building codes and funding incentives to promote energy efficiency. For example, Lombardy has adopted rigorous building standards, while Emilia-Romagna supports RES adoption through local regulations and financial mechanisms.

Italy leverages EU programs such as the European Green Deal Investment Plan and Horizon Europe to support sustainability efforts, providing financial aid and facilitating technology transfer for energy-efficient projects nationwide.

4. Building Automation and Control Systems

Once again, this topic provides a generalized overview, but with a specific focus on the project partner regions.

4.1. Description of Automation Systems for HVAC, Lighting, and other Building Functions

Many technologies suited to certain climates and building infrastructures are included in building automation systems. Regarding HVAC automation, sensors track indoor temperatures around the clock and modify heating and cooling systems to balance comfort and energy efficiency [94]. Comparably, sensors in lighting automation control light levels and optimize the use of natural light, therefore lowering energy usage [95].

Beyond these uses, irrigation [96], access control [97], and security systems [97] are all included in centralized control platforms under the umbrella of building automation. Drawing from disciplines like electrical engineering, HVAC technology, and cyber security, professionals with building automation and control system experience must be proficient in system design, installation, and maintenance. Buildings everywhere want to increase sustainability and efficiency while generally raising residents' quality of life.

The primary HVAC operations in Greece are ventilation during the summer months and the necessary shading to enhance occupant comfort. This is due to the country's climate. Automation systems, particularly KNX, are currently being installed to automate shading and cooling systems and achieve optimal results, despite the fact that they are present in the majority of structures, including those that are over 40 years old.

Centralized systems that monitor, control, and record the functions of building services systems, including HVAC, lighting, security, and fire protection, are referred to as Building Automation and Control Systems (BAS or BACS). This is applicable to residential, tertiary, or industrial facilities, and it features unique technologies and functionalities.

4.2. Utilization of Building Management Systems, Smart Boards, and Advanced Control Algorithms

A progressive method of building automation and control is represented using smart boards, sophisticated control algorithms, and building management systems. Centralized centres for coordinating and integrating several building subsystems, including energy management, security, lighting, and HVAC, are building management systems. Real-time monitoring and improvement of building operations are made possible by this centralized control, which improves building performance generally, occupant comfort, and energy efficiency [98].

Working as interactive displays, smart boards give users easy-to-use interfaces to communicate with the building management system and deliver real-time information on energy consumption, indoor environmental conditions, and other pertinent factors. As an example, in home buildings, by increasing tenant involvement and knowledge, this encourages energy-saving habits and raises building efficiency (as well as potential demand response) [98], [99], [100].

By combining artificial intelligence, machine learning, and data analytics, advanced control algorithms enhance the capabilities of building management systems even further [100]. Through pattern identification, trend prediction, and building operation optimization for maximum comfort and efficiency, these algorithms examine data gathered from sensors and meters. Predictive maintenance algorithms, for example, can foresee equipment breakdowns, saving downtime and maintenance expenses; demand response algorithms, on the other hand, can dynamically modify energy use in reaction to grid conditions, maximizing energy savings and grid stability [101].

Professionals with expertise in software development, data analytics, and building automation and control systems are essential to the effective implementation and application of these technologies throughout not only Portugal but every country. They design, install, and manage these systems simultaneously to guarantee smooth integration and continuous optimization to satisfy the changing requirements of contemporary buildings and their occupants.

To accomplish the aforementioned objectives, smart buildings/houses are equipped with BMS systems and compliant devices, such as air conditioning, external/internal shading, ventilators, and monitoring devices. However, this has resulted in the necessity for technicians to receive training on these technologies, particularly the installation, configuration, and programming of BMS.

4.3. Innovative Approaches to Building Automation

In Portugal, according to DL nº 101-D/2020, any building with HVAC, cooling, or heating systems with a combined power of more than 290 kW must include automated building controls to minimize energy wastage until the end of 2025. Parties that do not comply are liable to substantial fines [102].

In addition, Portugal is at the forefront of developing cutting-edge methods for building automation, namely in the areas of sustainable construction and smart building technology. Notable efforts involve the extensive utilization of sustainable energy sources such as solar panels and wind turbines (Portugal is one of the few countries that has the potential to be self-sufficient in RES alone in the near future. In March 2024, Portugal was supplied solely by RES for three straight days [103]), incorporating of energy management systems to enhance energy efficiency, allocation of resources towards smart grid infrastructure for effective energy distribution, deployment of advanced building automation and control systems, and encouragement of green building certifications (via a program named “Support Program for Sustainable Buildings” [104]).

Hotels and luxury villas in the Greek islands are prime examples of fully automated spaces that are equipped with security, ventilation, lighting, shielding, and heating systems. Voice-enabled and remote controls are among the features that contribute to the convenience of the occupants.

Due to the diversity of climatic zones and other considerations, thermal installations in buildings in Spain are given specific study to improve energy efficiency, protection, and well-being. The fundamental regulatory framework, the RITE [20], started in 2007 with requirements from the European Directives on energy efficiency, energy efficiency in structures, and RES promotion. The RITE was updated in 2021 to meet current criteria and incorporate new European Energy Labelling and Ecodesign regulations. This has led to many thermal installation standards that will help Spain's PNIEC reduce primary energy consumption by 39.5% [62]. Thus, the RITE and other PNIEC measures like renovating residential equipment, promoting energy efficiency in tertiary buildings and cold generating equipment, and installing large air conditioning systems in tertiary buildings (including public infrastructures) are essential for achieving this goal. The RITE also comprises installation company regulations and technical guidelines for configuration, installation, servicing, and inspection specialists. New technical instruction covers installation automation. In this new technical instruction, non-residential buildings with a rated useful output for heating, cooling, combined heating and ventilation, or combined cooling and ventilation installations over 290 kW must have BACS, similarly to Portugal, when technically and economically feasible. These systems must continuously monitor, document, evaluate, and adapt energy use.

- Benchmark energy performance and report to managers for decision-making.
- Enable interoperability and communication with associated technical installations.

To maximize energy generation, distribution, storage, and consumption, residential buildings can include similar control functions and constant electronic monitoring. Whatever the size or capacity of the installations, the BACS must be tailored to the buildings' needs. The BACS must operate establishments according to regimes that maximize sanitation and wellbeing while minimizing energy use. This will account for the building's inactivity, space usage, equipment operating regimens at top performance, and maximum RES and residual energy use. The building's generic and regulated "Use and Maintenance Manual" must include automation and control system instructions.

Finally, the current Spanish RITE, which includes new thermal installation, BACS, and professional intervention requirements, will help build the most intelligent buildings and meet national and European sustainability goals.

Co-funded by
the European Union

5. Occupant Comfort and Well-Being

Once again, there are specific points to all regions regarding this topic.

5.1. Consideration of Indoor Air Quality, Thermal Comfort, and Lighting Design

Achieving optimal occupant comfort and well-being in built environments relies on the expertise of skilled professionals across various trades. HVAC technicians and building engineers ensure indoor air quality by maintaining proper ventilation, filtration, and pollutant control in heating, ventilation, and air conditioning (HVAC) systems [94], [105]. In Portugal, these measurements and installations should be done according to the aforementioned Decree 138-G/2021. These technicians collaborate with insulation installers and window technicians to enhance thermal comfort [105] through effective insulation and heat transfer minimization. Lighting designers, electricians, and interior designers can work together to create lighting schemes that balance visual comfort, productivity, and energy efficiency, considering factors such as natural daylighting, artificial lighting sources, and lighting controls [95]. By integrating their skills and expertise, these professionals contribute to creating environments that promote occupant well-being, comfort, and productivity.

Particularly significant are the factors of thermal comfort, air quality, and illumination design. In Greece, thermal comfort may be regarded as the most critical factor, as the country generally has high air quality indexes. However, illumination becomes a concern in more intricate building examples.

Spain has HVAC regulations that establish parameters for thermal comfort and air quality. The fundamental regulation is the RITE [20]. It establishes the technical specifications for thermal installations, which include the safety standards, energy efficiency, and welfare and hygiene requirements that HVAC systems must adhere to. For instance, HVAC systems must prioritize energy efficiency while simultaneously guaranteeing the thermal condition of the environment, indoor air quality, hygiene, and acoustics. Different indoor air quality (IAQ) categories have been established for tertiary (commercial, public, and other) buildings, depending on the use of the building or specific functional spaces that must be achieved at a minimum. There are the following:

- IAQ 1 (optimal quality air): day-care hospitals, clinics, and laboratories.

- IAQ 2 (good quality air): offices, residences (common localities of hotels and similar, nursing and student residences), reading rooms, museums, court rooms, teaching and similar classrooms, and swimming pools.
- IAQ 3 (medium quality air): commercial buildings, cinemas, theatres, assembly halls, hotel rooms, and similar establishments, as well as restaurants, cafes, bars, party rooms, gyms, sports venues (excluding swimming pools), and computer rooms.
- IAQ (low quality air): not considered in any application.

The design of the HVAC systems and the appropriate thermal enclosure of the local or building are combined to achieve thermal comfort. Indoor air quality remains a pending issue, even though users, installers, and engineers have become more cognizant of this aspect because of the COVID-19 pandemic.

Spain has compiled the primary regulations for illumination in buildings in the CTE [18]. The fundamental requirements for the energy efficacy of lighting installations in buildings are delineated in this CTE. It specifies that buildings must have sufficient lighting installations to satisfy the energy efficiency requirements and the demands of their users. The lighting design enables the integration of artificial light systems with natural light, contingent upon the orientation, time of day, type of building, season of the year, and other factors. The prescribed parameters can be achieved through a variety of technical solutions, which are becoming increasingly precise. Therefore, the selection of an illumination control protocol is currently of considerable significance. Even more so, in structures that adhere to NZEB standards (such as BREEAM and LEED). Dali, as well as 0-10V, DMX, or PWM, are frequently employed in Spain to manage and control lamps and luminaries. Lastly, the REBT [19] establishes the technical and safety conditions that electrical installations connected to a supply network must generally satisfy, which includes all types of lighting installations in buildings.

Architecture in the Netherlands prioritizes clients' well-being by optimizing indoor air quality, thermal comfort, and lighting. These factors are crucial for health, productivity, and harmony [106]. The Venlo City Council building, constructed in 2018, exemplifies green building success [107]. The Netherlands adheres to EU air quality standards, limiting pollutants like sulfur dioxide and nitrogen dioxide [108],

Co-funded by
the European Union

[109]. Innovative strategies like geothermal energy reduce energy use and emissions, enhancing thermal comfort [110]. Smart buildings maximize natural light with large windows and efficient artificial lighting, using sensors to minimize energy consumption [111], [112].

German architecture prioritizes optimal indoor air quality, thermal comfort, and lighting design. Ventilation systems with heat recovery renew indoor air, remove pollutants, and monitor CO2 levels alongside air purification. Automated systems adjust temperature and lighting to ensure ideal thermal comfort [113], [114]. Germany adheres to EU air quality standards [115], and according to Umwelt Bunesamt, it met these standards for the fifth consecutive year in 2022, except for two stations in Munich and Essen that exceeded the nitrogen dioxide (NO2) limits [108].

5.2. Implementation of Occupant-centric Technologies such as Smart Sensors and personalized Control Interfaces

Occupant-centric technologies like smart sensors and personalized control interfaces tailor building environments to individual preferences. Smart sensors monitor conditions and occupancy, enabling real-time adjustments to heating, lighting, and ventilation [116]. Personalized interfaces empower occupants to customize their environment via smartphones [117], enhancing comfort, energy efficiency, and overall building performance [116], [117]. A major potential benefit is the awareness raised among users [116], [118].

In the context of smart houses, smart sensors can determine whether the occupants are present or have departed, thereby optimizing energy consumption (e.g., by shutting down the refrigeration system). Additionally, ventilation can be achieved through smart sensor-based identification (e.g., humidity).

Occupant-centric technologies have the potential to significantly reduce building energy consumption while improving the overall occupant experience. For example, occupant-centric control systems can use real-time data from interior and exterior factors to optimize building operations, such as HVAC, lighting, and energy management, to minimize energy waste. Also, "human-in-the-loop technologies" involve the integration of human feedback and preferences into building control systems, allowing for more personalized and efficient building operations.

In Spain occupant-centric technologies are mostly used in tertiary buildings and selected spaces or functionalities, although home automation solutions, including occupant-centric functionalities and technologies, are progressively more sophisticated and affordable, gaining in attractive for some informed owners and residents [119].

The Netherlands excels in implementing user-focused technologies in smart buildings. For example, the Edge in Amsterdam uses smart sensors to monitor space usage and automatically adjust systems like lighting and HVAC [120], achieving a 98.36% sustainability score with BREEAM-NL [89]. Similarly, the Rabobank Headquarters in Utrecht allows users to personalize temperature, lighting, and other settings through custom control interfaces [121].

A study in Germany highlighted the importance users place on effective communication with building operators and the optimization of building systems to meet their needs [122]. The EUREF Campus in Berlin exemplifies this approach by implementing smart systems like real-time data-collecting sensors and customizable control interfaces, enabling users to quickly adjust temperature, ventilation, and lighting for enhanced comfort [79].

5.3. Cultural or Climatic Factors Influencing Approaches to Occupant Comfort in Different Regions

In Portugal, resident comfort is largely approached by cultural and climatic considerations. The mild winters and hot, dry summers of Portugal's Mediterranean climate influence building methods and architectural design to maximize thermal comfort. Thick walls, little windows, and tiled roofs are common elements of traditional Portuguese architecture that help to insulate against heat and encourage natural circulation [123], [124]. Building designs featuring elements like covered courtyards and terraces that let residents comfortably enjoy outdoor settings are also influenced by cultural preferences for outdoor living spaces and social gatherings [124]. Portuguese modern methods to occupant comfort still give natural ventilation, passive cooling techniques, and the incorporation of green areas first priority in order to lessen the effects of the climate and promote a sense of community and environment [123], [124].

Spain has diverse climates, including Mediterranean (East and south), continental Mediterranean (Center), and oceanic Mediterranean climates (North). These different climatic conditions affect occupants' thermal comfort and adaptation and are basically incorporated to different regulations related with construction and the energy, together with geographical factors, such as position and altitude above the sea. The CTE [18] is the basic regulation. It contains a basic document (DB H1) on Energy Saving with conditions for the control of energy demand in buildings, in which 6 basic climatic zones have been defined. These are identified by means of a letter, corresponding to the climatic severity of winter, and a number, corresponding to the climatic severity of summer. These zones determine energy parameters that apply specifically to buildings located in such areas and their systems. In addition, many cultural factors, traditions, and acute regional diversity impact the preferred type of residential buildings, the appliances used, using habits, etc.

Culture and climate are fundamental in Dutch architecture. Given the colder temperatures and high humidity, building designs must cater to these conditions. Summers are mild, and winters are very cold, necessitating strategies for both thermal comfort and air quality. Natural ventilation is crucial in warmer months, while intelligent sensors for temperature, CO2, and presence, along with efficient heating and insulation, are essential in winter [125], [126] Dutch value natural light, reflected in architecture with large windows. Dutch design is minimalist, featuring open spaces, simple designs, and durable, natural materials like wood, stone, and plants, emphasizing a strong connection with nature [127].

Germany's cultural and climatic factors strongly influence its approach to building construction, given its northern hemisphere location. With cold winters and mild summers, the focus is on ensuring occupant comfort and well-being while enhancing energy efficiency and sustainability. Thermal insulation is widely used to minimize heat loss in winter and maintain comfortable temperatures in summer. Efficient heating and cooling systems such as gas boilers, heat pumps, and high-efficiency air conditioning are prevalent, catering to local infrastructures. Harnessing natural ventilation aided by bioclimatic design reduces reliance on mechanical systems and improves indoor air quality.

To promote energy efficiency and reduce CO2 emissions, Germany prioritizes the use of recycled and renewable materials alongside efficient water and energy management systems [128], [129]. CUBE Berlin exemplifies these principles with its innovative design featuring interconnected geometric surfaces that optimize light

Co-funded by the European Union

absorption and reflection. Equipped with an AI-driven central unit known as the “brain” and 3,750 sensors, the building adjusts lighting, ventilation, and cooling systems based on user data. Solar radiation is harnessed for cooling purposes, complemented by special solar-coated windows that minimize heat gain. The building also generates around 50% of its total energy demand through RES, showcasing its commitment to sustainability [130].

Italy experiences a diverse climate, ranging notably from north to south. Building comfort is influenced by key factors such as humidity, noise, lighting, ergonomics, and construction materials. Climate change increasingly impacts human activities, particularly affecting internal comfort and energy considerations within the building sector [68].

6. Availability of Data and Expertise (HVET/VET) for Analytics in each region

For this topic, there is a bigger focus on qualification levels 3 and 4, but not disregarding higher education trades and skills.

6.1. Current VET/HE Offerings and Shortages – VET/HE Recommendations, Policies, or Programs

Particularly at the EQF levels 3 and 4, while still very uncommon, Portugal is placing increasing focus on VET/HE offers to satisfy the demands of smart energy in buildings. Aiming to fill the gap in the industry for qualified experts, current VET programs frequently concentrate on practical skills in building automation, RES, and energy management. Undergraduate degrees in energy engineering, sustainable architecture and environmental sciences are among the HE programs, which give students theoretical understanding and chances for smart energy technology research. Some associations provide building automation courses and respective certifications in Portugal, such as ATEC (Formation Academy). However, there is still a significant shortage of certified professionals specific to this area. Most technicians or operators are certified in other fields not specific to building automation, such as general electricians. Regarding specific building certifications, many entities provide evaluation across the world, such as WakeTech, JohnsonControls, etc. Overall, available data is very scarce in this regard, most specifically to Portugal.

At present, there are no EQF 3/4 offerings in Greece that encompass the smart home/building functions detailed in this document. Training programs that are currently in existence are primarily developed by purveyors of specialized equipment with the objective of instructing technicians on their products. The sector would benefit from a more structured training program.

The Education Departments of Spain's Autonomous Communities offer initial VET (i-VET) programs for young people seeking their first professional certificate. The Ministry of Education [131], VET, and Sports oversees the VET system and issues valid Spanish titles. i-VET programs, aligned with EQF 3–EQF5, provide industry-approved professional qualifications. Autonomous communities can adjust VET programs to meet regional needs based on education, industry, and job market data. Key sectors include Energy & Water, Installation & Maintenance, Building & Civil

Works, Transport & Vehicle Maintenance, and Computer Science & Communications. Notable i-VET programs include Technician in Telecommunication Installations (EQF4), Superior Technician in Electrotechnical and Automated Systems (EQF5), and Basic Professional Degree in Housing Facilities Maintenance (EQF3). Specialized courses include IoT Installation and Maintenance (EQF4) and Cybersecurity (EQF5).

Spain's Autonomous Communities also run continuing VET (c-VET) programs for workforce retraining. The National Public Service of Employment [132] collaborates with the Ministry of Labor and Social Economy and the National Foundation of Training for Employment to manage these programs. c-VET offers professional credentials and specialties similar to i-VET but focuses on employability. Any accredited VET institution can provide c-VET courses. Specialized training for smart electricity in buildings is more flexible and diverse within c-VET, with courses in Energy Efficiency in Buildings (EQF5), Installation of IoT Systems (EQF5), and more. Regional offerings vary.

Spanish universities are adapting to the demand for higher-level experts in smart buildings and cities. Engineering and sciences degrees now include smart building integration, new materials, BIM, building simulation, cybersecurity, big data, and connected systems. While there are no undergraduate degrees specifically for smart buildings, postgraduate programs offer specialized training. Examples include the Master in Smart and Sustainable Urban Infrastructures at UDIMA University and the Master in Intelligent Energy and Transport Systems at Sevilla and Malaga Universities.

The Netherlands excels in data collection on VET and HE. The NRO (National Institute for Research in Vocational Education) tracks course offerings, enrollments, completion rates, and student skills [133]. The EU promotes continuous training for VET/HE teachers [134]. In 2015, 68.5% of Dutch students had higher education, surpassing the EU average of 47.3% [135]. A 2019 CEDEFOP report showed that 79% of graduates find jobs within a month. These statistics highlight the country's high-quality, specialized courses and strong social support systems [136].

Germany has a robust education system that offers a wide range of courses at the EQF 3/4 level, along with a comprehensive data collection system on VET and HE.

The Federal Institute for Vocational Training (BIBB) oversees the collection and dissemination of education data in Germany, providing insights into course offerings and qualification trends [137]. The European Union advocates for the development of continuous training programs for VET/HE teachers and instructors [134]. Germany's successful VET model highlights the high qualifications of its professionals, highly valued in the job market. In 2019, Germany boasted a low unemployment rate of 5.8% among individuals aged 15 to 24, significantly below the EU-27 average of 15.1% [138].

Italy boasts many training opportunities aligned with the analysis's scope, categorized into energy management and efficiency, building automation and control systems, and occupant comfort and wellbeing, detailing profiles with competences and EQF levels, predominantly ranging from EQF levels 3 to 5. Italy provides comprehensive national-level training options within the SEB sector, indicating a robust response from the education system to market demands, including regulatory compliance and certifications. Additionally, various upskilling courses offered by professional associations or companies complement these offerings. Regulatory standards, including UNI (Italian Institute for Standardisation) norms aligned with CEN and ISO standards, such as UNI CEI 11352, UNI CEI EN ISO 50001, UNI CEI EN 15900, and UNI CEI EN 16247 series, underscore Italy's adherence to EU directive 2012/27/EU on energy efficiency under national decree 102/2014 [31], [49], [80], [81].

7. Security and Privacy Concerns

The evolution to an all-digital world creates several security challenges.

7.1. Discussion of Cybersecurity Challenges and Solutions for Smart Building Systems

As smart building technologies become more popular, the cybersecurity risks and solutions debate become increasingly important. Smart building systems, which incorporate diverse technologies such as IoT devices, sensors, and automation systems, are subject to cybersecurity risks that may jeopardize data privacy, operational integrity, and even physical safety [5]. A 2019 study stated that, in 2019, as far as 38% of smart buildings were targeted by some sort of malicious attack [139], with the most common being spyware, worms, phishing, and ransomware. Around 90% of these attacks are remotely employed. Common issues include illegal access to sensitive information, system control manipulation, and crucial service disruption [5], [140]. To solve these issues, experts stress the significance of integrating strong cybersecurity measures throughout the lifecycle of smart building systems, such as safe design methods, encryption protocols, access controls, and frequent security audits and updates [5], [140], [141]. Furthermore, raising cybersecurity awareness and training among building inhabitants and personnel is critical for reducing human-related threats like social engineering assaults. Collaboration among industry players, government agencies, and cybersecurity specialists is critical for designing and implementing effective cybersecurity policies, standards, and regulations that are customized to the specific requirements of smart building settings [5], [141]. By emphasizing cybersecurity and implementing proactive measures, stakeholders can improve smart building systems' resilience and trustworthiness in the face of growing cyber threats.

Greece adheres to the European framework for cybersecurity in critical domains, which also encompasses the digitization of the housing/building sector. It is imperative to enforce NIS2 [142]. The Dutch national cybersecurity center addresses this with strong authentication, restricted data access, and encryption. Additionally, the Netherlands collaborates with the EU on the NIS2 directive to enhance digital resilience [143]. To address these challenges, the German Federal Ministry of the Interior and Community has developed a comprehensive strategy focusing on four key areas: society, private industry, government, and EU/international affairs, encompassing a total of 44 strategies across these sectors [144].

Italy's smart building systems encounter significant cybersecurity challenges due to their reliance on interconnected IoT devices, networks, and systems. These devices often lack robust security features, making them susceptible to cyber-attacks that can compromise building networks and lead to data breaches. The complex and interconnected nature of these systems increases the difficulty of managing comprehensive security measures, with inconsistent security protocols across devices further complicating protection efforts. Insider threats from employees or contractors with system access also pose risks, as they can unintentionally or intentionally breach security measures. To address these challenges, implementing regular updates, strong authentication, encryption, network segmentation, and standardized security protocols are essential. Compliance with international standards, regular audits, and employee training on cybersecurity best practices are crucial for mitigating risks and ensuring robust security in smart building environments. Advanced threat detection systems using AI can enhance real-time monitoring and response capabilities to safeguard against evolving cyber threats effectively [31], [51], [81].

7.2. Consideration of Data Privacy Regulations and Measures to Protect Occupants' Personal Information

Regulations governing data privacy and safeguards for inhabitants' personal information must be carefully considered in the context of smart buildings [145]. Sensitive information misuse or unauthorized access is more likely when these systems gather and process enormous volumes of data from sensors, Internet of Things devices, and other sources. Organizations are required by applicable data privacy laws [145], including the GDPR (General Data Protection Regulation) [146] in the European Union, to protect the privacy of their users. This includes putting strong data encryption, access restrictions, and anonymization methods into place to guarantee that personal data is gathered, kept, and utilized sensibly. In smart building environments, trust is also built, and a privacy-conscious culture is fostered by open communication and transparency with building occupants about data-collecting procedures and privacy regulations. Other significant regulations in this regard include the EU Cyber Resilience Act (CRA) [147], the Digital Operational

Co-funded by
the European Union

Resilience Act (DORA) [51], and the Cyber Incident Reporting for Critical Infrastructure Act (CIRCIA) [149].

BMS may contain sensitive information, including the daily activities of the occupants, health information, and metrics, as well as access to the building's safety and security system. Significant threats may be posed to the occupants by the exposure of such information or third-party access to such functions.

In the Netherlands, data use must comply with the GDPR, which mandates explicit consent, transparency, and security in data processing [146]. Key measures include data minimization—collecting only necessary data, using firewalls and encryption for protection, and informing users about data use while seeking their authorization [150]. Germany also adheres to GDPR [146]. After a 2022 survey among smart building users, it was found that only 20% are aware of their data being extensively used [151]. To address this, smart buildings should prioritize minimizing data collection to essential information, avoiding unnecessary data acquisition. Implementing robust security measures such as firewalls and encryption is crucial for data protection. It is also vital to inform users about data usage and obtain explicit consent from them regarding its utilization [152]. The German Building Automation Technology Association provides guidelines to ensure smart buildings adhere to stringent data protection regulations [153].

In Italy, data privacy regulations, primarily governed by the GDPR, are pivotal for smart buildings to safeguard occupants' personal information. Operators must adhere to stringent requirements for lawful, transparent, and purpose-specific processing of personal data, ensuring explicit consent from occupants for data collection and usage. Strong data security measures, including encryption, regular audits, and access controls like multi-factor authentication, are crucial to prevent unauthorized access and protect sensitive information. Clear data governance policies, emphasizing data minimization and anonymization techniques, alongside staff training on privacy best practices, promote transparency, accountability, and trust. Compliance with GDPR [146] not only safeguards personal data but also enhances the integrity and reliability of smart building operations, fostering a secure environment that respects privacy and builds occupant confidence.

7.3. Regional Perspectives on Security and Privacy Regulations Impacting Smart Building Deployment

Portugal abides by internationally defined laws, such as the ones mentioned above in 6.2. Furthermore, Portugal also has a national law regarding security and privacy, namely decree nº 46/2019 [154], which establishes measures to be taken to assure privacy and self-security, and countermeasures to take in the event of a cyber-attack. However, most of Portugal's security measures align with the GDPR.

Spain has established a comprehensive cybersecurity policy framework that encompasses a variety of regulations and initiatives aimed at improving the security of its cyberspace. The deployment of smart buildings may be affected by certain regulations. Initially, there is a National Cybersecurity Strategy and a cybersecurity regulatory framework that encompasses the Cybersecurity Law Code. Additionally, there are Responsible Agencies, including the Spanish National Cybersecurity Institute, INCIBE [155]. This intricate framework is consistent with the European policies that were previously mentioned.

Despite the current regulatory framework, compliance is occasionally low, and cyberspace threats are on the rise. There are suggestions to centralize cybersecurity management, promote international cooperation, create a culture of cyber responsibility, and invest in research and development in the cybersecurity sector. As smart buildings are heavily dependent on interconnected systems and the exchange of data, cybersecurity policies, regulations, and general recommendations must be adapted and/or specifically developed for this sector and its stakeholders or ecosystem. At present, these resources are unavailable. Investing in research and development (R&D) in the cybersecurity sector may lead to the development of innovative solutions that are specifically designed to meet the requirements of intelligent buildings as they are implemented.

The German Federal Information Security Agency offers dedicated resources to enhance data security in smart buildings [156].

In Italy, smart building deployment varies by region due to economic, cultural, and technological factors. Northern regions like Lombardy and Emilia-Romagna lead in adopting advanced technologies, focusing on strict GDPR compliance and investing in cybersecurity. Southern regions like Calabria and Sicily are gradually embracing smart buildings, balancing technology adoption with economic constraints and promoting data privacy awareness. Central Italy, including Tuscany and Lazio, integrates privacy regulations into smart building projects through collaborative efforts among public, academic, and private sectors. Throughout Italy, adherence to GDPR ensures that smart building advancements prioritize occupant privacy and security, aligning with national and European standards for a secure and innovative environment [31], [80], [81].

8. Integration with Smart Grids and Energy Markets

Buildings can be an active part of modern electricity grids and need to be accounted for when planning grid aspects.

8.1. Role of Smart Buildings in Demand Response Programs and Grid Flexibility

By using their sophisticated automation and communication capabilities to modify energy use in reaction to supply and demand fluctuations in the electricity grid, smart buildings can be extremely important to demand response programs and system flexibility, as previously stated in 4.2. [157], [158]. Demand response programs allow smart buildings to take part in programs where electricity users willingly reduce their energy consumption in return for cash incentives or other advantages [158], [159], [160]. Smart buildings can, for instance, momentarily cut energy use by lowering lighting, modifying HVAC settings, or moving non-essential loads to off-peak hours during periods of high demand or high RES production [159], [161]. Smart buildings enable utilities, balance the supply and demand of electricity, lessen the need for expensive infrastructure upgrades, and include more RES into the grid by engaging in demand response [158], [161]. Additionally, smart buildings improve system flexibility by acting as dispersed energy sources that may produce and consume electricity. By use of technology such as ESS, electric car chargers, and rooftop solar panels, smart buildings can store or provide extra energy to the grid, therefore enhancing the general resilience and dependability of the power system [159], [160], [161].

In Greece, presently, the installation of PV systems and ESS devices are the primary concerns in smart buildings. Demand response programs, apart from night electricity tariffs, have not yet been extensively implemented in the country.

The Netherlands is a leader in implementing these methods. For example, Tenet develops intelligent buildings that automatically adjust energy use through various HVAC systems based on network price levels [162]. A study by Utrecht University's energy science master's program found that buildings using demand response can reduce energy consumption by up to 20% [163].

The Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS exemplifies demand response implementation using AI, machine learning, and big

Co-funded by
the European Union

data to optimize services for diverse buildings, prioritizing user-centered approaches [164].

In Italy, smart building deployment varies by region due to economic, cultural, and technological factors. Northern regions like Lombardy and Emilia-Romagna lead in adopting advanced technologies, focusing on strict GDPR compliance and investing in cybersecurity. Southern regions like Calabria and Sicily are gradually embracing smart buildings, balancing technology adoption with economic constraints and promoting data privacy awareness. Central Italy, including Tuscany and Lazio, integrates privacy regulations into smart building projects through collaborative efforts among public, academic, and private sectors. Throughout Italy, adherence to GDPR ensures that smart building advancements prioritize occupant privacy and security, aligning with national and European standards for a secure and innovative environment [31], [165].

8.2. Integration of Smart Meters and other Grid-Connected Devices for Energy Management

The smooth running of smart grids and efficient energy management depend substantially on integrating smart meters and other grid-connected devices. Because smart meters give real-time information on energy use, utilities and customers can track usage trends, spot inefficiencies, and improve energy-saving practices [160], [166]. Smart meters allow utilities and consumers to communicate with one another in two directions, enabling dynamic pricing plans, demand response programs, and grid balancing projects [159], [166]. Moreover, improving energy management capabilities are achieved through grid-connected devices like smart thermostats, appliances, and RES, which allow remote control and automation of energy-consuming devices depending on grid conditions, energy costs, and user preferences. Sustainability, cost savings, and grid dependability are all promoted by this integration of a more responsive and efficient energy environment [166].

In Greece, the local DSO is currently engaged in a comprehensive project to implement smart meters, which will facilitate the future of demand-side management schemes.

Germany integrates smart meters and network-connected devices to enhance energy management in smart buildings. These meters deliver real-time, precise data on energy consumption, enabling efficient identification and correction of energy inefficiencies. Integrated with smart thermostats and lighting systems, they automate energy usage based on weather conditions and occupancy patterns, further optimizing energy efficiency [167].

North Macedonia holds significant promise for enhancing efficiency and reliability in energy distribution as from few years ago started to implement smart meters in crucial sectors including house and buildings end users. Smart meters enable real-time monitoring of energy consumption, providing both consumers and utilities with accurate data to optimize usage patterns and reduce waste.

The Smart Readiness Indicator (SRI) and other certifications like LEED, WELL, Fitwel, BREEAM, GRESB, and EPD are mechanisms used in the EU to certify the smartness, sustainability, and environmental impact of buildings [68].

8.3. Regional Differences in the Interaction between Smart Buildings and Energy Markets

In March 2024, Portugal contributed to the digitalization of European electricity networks with interchangeable solutions that connect homes and office buildings alike to the electricity network [168]. This included the development of interoperable technologies and energy applications, such as the Wattch.r app in Portugal, which provides daily suggestions for consumers to reduce their carbon footprint and optimize electricity consumption. Additionally, the project contributed to the development of standards and policies strengthening the resilience of the European energy infrastructure, addressing issues like the war in Ukraine and the growing electrification of energy consumption [168].

Regarding Greece, at present, smart buildings are not involved in the energy market. However, the anticipated adoption of energy communities and aggregators may enable smart buildings to participate in the energy market and capitalize on the available services.

On one side, Smart Grids are essential for Spain's energy transformation goals and challenges. Three key measures are being implemented to achieve this: modernizing distribution networks, integrating RES, and managing production decentralization. Endesa, a major utility, received €500 million from the European Investment Bank to upgrade its distribution networks with smart technologies [169]. Spain has nearly

Co-funded by the European Union

completed the implementation of smart meters to all consumers, unlike other European countries. Monitoring and automating High Voltage/Low Voltage substations can improve maintenance and enable decentralized generation and consumption. However, industry regulation and infrastructure capacity to support production decentralization remain the biggest challenges. Smart buildings (and smart cities) in Spain use advanced technologies to increase efficiency, sustainability, and user experience. Decentralized production and intelligent integration of RES require smart networks. Smart buildings will increasingly rely on decentralized energy management and RES. Smart networks and smart structures could improve RES distribution and consumption, lowering system strain and increasing sustainability.

In the Netherlands, regional variations affect how smart buildings interact with energy markets, with electricity prices and availability of RES differing across areas. The country aims to swiftly transition to a carbon-neutral economy, as highlighted by the International Energy Agency in 2020. To achieve this, the Netherlands plans ambitious reductions: 49% by 2030 and 95% by 2050. However, challenges include heavy reliance on fossil fuels and energy-intensive industries, posing significant hurdles to this transformation [170].

Germany's diverse electrical grid infrastructure impacts the development of smart buildings. Regions with extensive RES penetration, like solar and wind, utilize demand response and local ESS to maximize RES utilization and enhance energy efficiency. In areas with older networks, scheduling and ESS methods are prioritized to prevent network overload [171]. Additionally, Germany promotes solar balconies with over 400,000 plug-in solar systems installed, supported by a robust solar culture and government incentives [172].

In North Macedonia, Greece, Bulgaria, Serbia, and Albania, smart buildings interact differently with energy markets due to varying infrastructure, policies, and market dynamics. North Macedonia focuses on integrating smart building technologies with the energy grid, developing regulatory frameworks for smart meters and grid-connected devices to optimize energy use. Greece leads in smart grid deployment, using advanced metering and RES integration. Serbia follows with efforts to improve energy efficiency and adopt RES. Bulgaria and North Macedonia are modernizing energy infrastructure with smart technologies, enhancing efficiency and reliability.

Albania, at an early stage, explores smart grid technologies to improve energy efficiency and reliability, albeit more slowly than its neighbours.

The integration of smart grids and energy markets in Italy involves stakeholders such as Terna, various DSOs, energy suppliers, consumers, and regulatory bodies. Challenges include grid stability due to RES variability and cybersecurity issues from increased digitalization. Investment in infrastructure and innovative technologies is crucial. Despite these challenges, opportunities such as improved energy efficiency, increased RES use, and consumer empowerment are significant. Enel's and Terna's smart grid projects highlight the transformative potential. Italy's commitment to innovation, regulation, and collaboration is driving a more efficient, reliable, and consumer-centric energy system, paving the way for a sustainable energy future [31], [51], [81].

Conclusions

This report outlines the current state-of-the-art in high-level vocational education and training (HVET/VET) and advanced electrical sector skills within the context of smart buildings. This document emphasizes the transformative potential of smart electricity systems to improve the efficiency, sustainability, and comfort of buildings.

The report emphasizes several critical areas:

- Efficiency and Energy Management: The optimization of energy consumption in smart buildings necessitates the integration of advanced energy management strategies, RES, and ESS. This encompasses the implementation of smart meters and other grid-connected devices to cultivate an energy environment that is both responsive and efficient.
- Building Automation and Control Systems: Automation technologies are essential for the operation of HVAC, lighting, and other building functions. The optimal operation and energy savings are guaranteed by the use of advanced control algorithms, building management systems, and smart sensors.
- Occupant Comfort and Well-Being: It is imperative to improve indoor air quality, thermal comfort, and illumination by implementing occupant-centric technologies. Additionally, occupant contentment is enhanced by the incorporation of cultural and climatic factors and personalized control interfaces.
- Data Analytics and Expertise: The successful implementation and administration of smart building systems are contingent upon the availability of data and the proficiency in data analytics. The report underscores the necessity of ongoing development of VET/HE programs to meet the current shortages and future demands.
- Security and Privacy: It is of the utmost importance to address cybersecurity challenges and guarantee data privacy. The document examines the regulations and measures that are required to safeguard the personal information of occupants during the deployment of smart building technologies from a regional perspective.

- The interaction between smart grids and energy markets, as well as the function of smart buildings in demand response programs, is essential for the sustainability and flexibility of the grid. This integration is influenced by regional differences in technological adoption and regulatory frameworks.

The results of this report underscore the importance of a robust regulatory framework, continuous updates to educational programs, and multidisciplinary collaboration in order to effectively navigate the swiftly changing landscape of smart building technologies. The SEBCoVE initiative attempts to establish the foundation for future advancements and the widespread adoption of smart electricity systems in buildings by prioritizing sustainability, efficiency, and occupant-centric approaches.

Glossary

Advanced Metering Infrastructure (AMI)

A system that measures, collects, and analyzes energy usage, enabling two-way communication between utilities and customers.

Artificial Intelligence (AI)

The use of machine learning and algorithms in systems to enable automation, predictive analysis, and decision-making capabilities in smart homes and buildings.

Building Management System (BMS)

A control system that manages the mechanical, electrical, and electromechanical services in a building, including HVAC, lighting, power systems, and security.

Closed-Circuit Television (CCTV)

A surveillance system using video cameras to transmit a signal to a specific, limited set of monitors. Unlike broadcast television, the signal is not openly transmitted but is intended for observation and security purposes within a specific area.

Control Systems

Electronic systems that manage, command, direct, or regulate the behavior of other devices or systems within a building or home.

Coefficient of Performance (COP)

A measure of the efficiency of a heat pump, calculated as the ratio of heating or cooling provided to the electrical energy consumed. A higher COP indicates greater efficiency.

Demand-Side Management (DSM)

Programs and strategies designed to influence consumer demand for electricity through efficiency measures, load shifting, and incentives.

Demand Response (DR)

Programs and technologies designed to adjust consumer power consumption in response to supply conditions, such as peak demand periods.

Digital Video Recorder (DVR)

A device that records video in a digital format to a disk drive or other storage medium. DVRs are used in digital CCTV systems to store and manage footage.

Distributed Energy Resources (DER)

Small-scale power generation or storage technologies (e.g., solar panels, wind turbines, batteries) located close to where energy is used.

Distribution System Operator (DSO)

An entity responsible for operating the distribution network that delivers electricity from the transmission system to end consumers.

Dynamic Electricity Pricing (DEP)

A rate structure in which electricity prices vary depending on the time of day, encouraging users to shift consumption to off-peak periods.

Energy Management System (EMS)

A system used to monitor, control, and optimize the performance of the generation and/or consumption of energy in a building or home.

Energy Performance Certificate (EPC)

A document certifying the energy performance of a building, often required in the European Union, showing the building's energy efficiency on a scale from A (most efficient) to G (least efficient).

Energy Use Intensity (EUI)

A measure of a building's energy efficiency, calculated as the amount of energy consumed per square foot of building space. Lower EUI indicates better energy performance.

Energy Storage System (ESS)

A system, such as a battery, that stores energy generated by renewable sources for later use, enhancing self-consumption and providing backup power during periods of low generation or high demand.

Grid Modernization

Upgrading the traditional power grid with digital technology to improve reliability, efficiency, and sustainability.

Grid-Tied System

An electricity generation system (e.g., solar panels) that is connected to the public utility grid. Such systems can export excess power to the grid and draw from it when necessary.

Heat Pump

A device that transfers heat from one location to another, providing heating in winter and cooling in summer by reversing its operation. It operates on the principle of refrigeration.

Home Automation

The integration of technology into the home to allow for the automatic and remote control of various household systems, such as lighting, heating, and security.

Home Network

A network that connects various smart devices in a home, typically through Wi-Fi, Ethernet, or other communication protocols.

Home Photovoltaic (PV) Systems

Solar power systems installed on residential properties to convert sunlight into electricity for home use or storage.

Home Batteries

Energy storage devices used in residential settings to store electricity generated from renewable sources like solar panels for later use.

Internet of Things (IoT)

A network of interconnected devices that communicate and exchange data with each other via the internet, enabling smart home and building automation.

Inverter

A device that converts the DC electricity generated by solar panels into AC electricity for use in the home or export to the grid.

IoT Security

Measures and technologies designed to protect IoT devices and networks from cyber threats and unauthorized access.

Microgrid

A localized grid that can disconnect from the traditional grid to operate autonomously and ensure power reliability.

Net Metering

A billing mechanism that allows consumers who generate their own electricity (e.g., through solar panels) to feed excess electricity back into the grid and receive credits. These credits can be used to offset the electricity they draw from the grid when their generation is insufficient.

Net Billing

A system where consumers generate electricity and sell any excess to the utility at a predetermined rate. Unlike net metering, the compensation rate for excess electricity may differ from the retail rate, and consumers receive a monetary payment rather than credits.

Nearly Zero Energy Building (nZEB)

A building with very high energy performance where the nearly zero or very low amount of energy required is covered to a very significant extent by energy from renewable sources, including energy produced on-site or nearby.

Net Zero Energy Building (NZEB)

A building that produces as much energy as it consumes over the course of a year. This balance is achieved through a combination of energy efficiency measures and on-site renewable energy generation.

Lighting Control Systems

Automated systems that control lighting based on various inputs like occupancy, daylight availability, and user preferences to enhance energy efficiency and comfort.

Occupancy Sensors

Devices that detect the presence of people in a room and trigger automated actions, such as turning lights on or off or adjusting the thermostat.

Off-Grid System

A PV system not connected to the public electricity grid, relying entirely on solar panels and battery storage to meet energy needs.

Remote Access

The ability to control and monitor home automation systems from a distance using internet-connected devices like smartphones, tablets, or computers.

Retail Electricity Provider (REP)

A company that sells electricity to end consumers, often in competitive markets where consumers can choose their provider based on price and service offerings.

Scenes

Pre-set configurations that adjust multiple devices simultaneously to create a desired environment

Self-Consumption

The use of electricity generated on-site (e.g., from solar panels) directly by the consumer, reducing the need to purchase electricity from the grid.

Smart Appliances

Household devices that can communicate with the grid to optimize energy use, often responding to real-time price signals.

Solar Charge Controller

A device that regulates the voltage and current coming from the solar panels to the battery, preventing overcharging and extending battery life.

Spot Electricity Market (SEM)

A market for buying and selling electricity for immediate delivery, typically within a day, where prices can be highly volatile based on real-time supply and demand.

Supervisory Control and Data Acquisition (SCADA)

A control system architecture that uses computers, networked data communications, and graphical user interfaces for high-level process supervisory management.

Smart Appliances

Household devices that are internet-enabled, allowing for remote control and integration into home automation systems.

Smart Buildings

Buildings equipped with advanced systems for managing energy, security, and comfort, using integrated technologies to enhance efficiency and user experience.

Smart Electricity

The use of advanced technologies and systems to monitor, control, and optimize the consumption and generation of electricity in buildings and homes.

Smart Meters

Electronic devices that record electricity consumption in intervals and communicate this information back to the utility for monitoring and billing purposes.

Smart Locks

Electronic locks that can be controlled remotely, often integrated into a home automation system for enhanced security and convenience.

Thermostat

A device that regulates temperature within a building or home, with smart versions allowing for remote control and programmable settings.

Uninterruptible Power Supply (UPS)

A device that provides backup power to critical systems in a building during short-term power outages, protecting against data loss and equipment damage.

Virtual Net Metering

A system that allows multiple users or locations to benefit from a single renewable energy system. Credits from the shared system's electricity generation are distributed among the participants.

Virtual Power Plant (VPP)

A system that integrates various distributed energy resources, such as solar panels and batteries, to function as a single power plant, optimizing generation and consumption.

Voice Assistants (VoA)

AI-powered devices that respond to voice commands, used to control various smart home systems and provide information or perform tasks.

Wireless Sensor Networks (WSN)

Networks of spatially distributed sensors that monitor and record environmental conditions, facilitating data collection and system automation in smart buildings.

Zero Feed-In

A policy or system setting where consumers generating their own electricity (e.g., solar power) do not export any excess electricity to the grid. Any surplus energy is either stored (e.g., in batteries) or wasted, ensuring no electricity is fed back into the utility grid.

Zero Net Energy (ZNE)

A building or system that produces as much energy as it consumes, often through a combination of energy efficiency measures and renewable energy generation.

Zigbee

A wireless communication standard used for home automation, known for its low power consumption, robust mesh networking capabilities, and support for a wide range of devices.

References

[1] M. S. Aliero, M. Asif, I. Ghani, M. F. Pasha, and S. R. Jeong, “Systematic Review Analysis on Smart Building: Challenges and Opportunities,” *Sustainability*, vol. 14, no. 5, p. 3009, Mar. 2022, doi: 10.3390/su14053009.

[2] B. Krishnakumar *et al.*, “Smart Building Management with IoT and AI: Energy-Efficient and Cost-Effective Solutions,” in *2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, IEEE, Dec. 2023, pp. 1249–1254. doi: 10.1109/UPCON59197.2023.10434659.

[3] A. Latifah, S. H. Supangkat, and A. Ramelan, “Smart Building: A Literature Review,” in *2020 International Conference on ICT for Smart Society (ICISS)*, IEEE, Nov. 2020, pp. 1–6. doi: 10.1109/ICISS50791.2020.9307552.

[4] A. M. Al-Ghaili, H. Kasim, N. M. Al-Hada, B. N. Jorgensen, M. Othman, and J. Wang, “Energy Management Systems and Strategies in Buildings Sector: A Scoping Review,” *IEEE Access*, vol. 9, pp. 63790–63813, 2021, doi: 10.1109/ACCESS.2021.3075485.

[5] G. Stamatescu, I. Stamatescu, N. Arghira, and I. Fagarasan, “Cybersecurity Perspectives for Smart Building Automation Systems,” in *2020 12th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, IEEE, Jun. 2020, pp. 1–5. doi: 10.1109/ECAI50035.2020.9223152.

[6] HarkSYS, “Smart Building Stats: Why building owners and operators should care about their energy usage and IoT.” Accessed: May 14, 2024. [Online]. Available: https://harksys.com/blog/smart-building-stats-why-building-owners-and-operators-should-care-about-their-energy-usage-and-iot/

[7] EMarketer, “Smart building deployments are headed through the roof.” Accessed: May 14, 2024. [Online]. Available: https://www.emarketer.com/content/smart-building-deployments

[8] J. P. Mohan, N. Sugunaraj, and P. Ranganathan, “Cyber Security Threats for 5G Networks,” in *2022 IEEE International Conference on Electro Information Technology (eIT)*, IEEE, May 2022, pp. 446–454. doi: 10.1109/eIT53891.2022.9813965.

[9] D. Minoli, K. Sohraby, and B. Occhiogrosso, “IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems,” *IEEE Internet Things J*, vol. 4, no. 1, pp. 269–283, Feb. 2017, doi: 10.1109/JIOT.2017.2647881.

[10] Idealista, “Casas Inteligentes em Portugal.” Accessed: May 14, 2024. [Online]. Available: https://www.idealista.pt/news/imobiliario/habitacao/2023/04/28/57660-casas-inteligentes-em-portugal-ha-maior-procura-e-margem-para-crescer

[11] Europa - European Union, “Energy Performance of Buildings Directive EU/2024/1275.” Accessed: May 14, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401275&pk_keyword=Energy&pk_content=Directive

[12] Europa - European Union, “Energy Efficiency Directive EU/2023/1791.” Accessed: May 14, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766

[13] PWC, “Indústria 4.0 - Principais Resultados em Portugal.” Accessed: May 14, 2024. [Online]. Available: https://www.pwc.pt/pt/temas-actuais/industria-40/principais-resultados.html

[14] Instituto Nacional de Estatística, “Industry in Portugal - Automation and AI,” 2024.

[15] Greek Government, “Greece Smart Readiness.” Accessed: Jun. 04, 2024. [Online]. Available: https://greece20.gov.gr/?calls=smart-readiness-etoimotita-ypodomon-gia-exypna-ktiria

[16] Mineco, “Spanish Smart Cities Model.”

[17] Mineco, “Agenda España Digital 2026,” 2024, Accessed: Jun. 04, 2024. [Online]. Available: https://portal.mineco.gob.es/es-es/ministerio/estrategias/Paginas/00_Espana_Digital.aspx

[18] Ministerio da Vivienda y Agenda Urbana, “CTE.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.codigotecnico.org/

[19] Boletín Oficial del Estado, “REBT.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/biblioteca_juridica/codigos/codigo.php?modo=2&id=326_Reglamento_electrotecnico_para_baja_tension_e_ITC

[20] Boletín Official del Estado, “RITE.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/buscar/doc.php?id=BOE-A-2007-15820

[21] Boletín Oficial del Estado, “Real Decreto 390/2021. Proceso para la certificación de edificios.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/buscar/act.php?id=BOE-A-2021-9176

[22] Grupo Tecma Red, “V Congresso de Edificios Inteligentes,” 2024, Accessed: Jun. 04, 2024. [Online]. Available: https://www.congreso-edificiosinteligentes.es/

[23] Boletín Oficial del Estado, “Real Decreto 346/2011. ICT.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/buscar/act.php?id=BOE-A-2011-5834

[24] Omdia, “The Netherlands leads for smart building technologies in Europe.” Accessed: Jun. 25, 2024. [Online]. Available: https://omdia.tech.informa.com/om006209/the-netherlands-leads-for-smart-building-technologies-in-europe

[25] E. J. Oughton, Z. Frias, S. van der Gaast, and R. van der Berg, “Assessing the capacity, coverage and cost of 5G infrastructure strategies: Analysis of the Netherlands,” *Telematics and Informatics*, vol. 37, pp. 50–69, Apr. 2019, doi: 10.1016/j.tele.2019.01.003.

[26] CBS, “Nearly three quarters of the Dutch population use smart devices .”

[27] ConcR, “Smart concrete monitoring with IoT sensors.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.concr.de/

[28] BIM World MUNICH, “Here are the Top 3 SMART BUILDING / SMART CONSTRUCTION Innovators 2022! .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.bim-world.de/here-are-the-top3-smart-building-smart-construction-innovators-2022

[29] P. Mlýnek, M. Rusz, L. Benešl, J. Sláčik, and P. Musil, “Possibilities of Broadband Power Line Communications for Smart Home and Smart Building Applications,” *Sensors*, vol. 21, no. 1, p. 240, Jan. 2021, doi: 10.3390/s21010240.

[30] S. H. Khajavi, M. Tetik, Z. Liu, P. Korhonen, and J. Holmström, “Digital Twin for Safety and Security: Perspectives on Building Lifecycle,” *IEEE Access*, vol. 11, pp. 52339–52356, 2023, doi: 10.1109/ACCESS.2023.3278267.

[31] International Energy Agency, “Italy 2023.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.iea.org/reports/italy-2023/executive-summary

[32] Fortune Business Insights, “Europe Smart Building Market.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.fortunebusinessinsights.com/europe-smart-building-market-105128

[33] United States of America Internation Trade Administration - Trade GOV, “Information and Communications Technology - Portugal - Country Commercial Guide,” 2024. Accessed: May 14, 2024. [Online]. Available: https://www.trade.gov/country-commercial-guides/portugal-information-and-communications-technology

[34] M. Jia, A. Komeily, Y. Wang, and R. S. Srinivasan, “Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications,” *Autom Constr*, vol. 101, pp. 111–126, May 2019, doi: 10.1016/j.autcon.2019.01.023.

[35] C. M. Ramya, M. Shanmugaraj, and R. Prabakaran, “Study on ZigBee technology,” in *2011 3rd International Conference on Electronics Computer Technology*, IEEE, Apr. 2011, pp. 297–301. doi: 10.1109/ICECTECH.2011.5942102.

[36] J. Tosi, F. Taffoni, M. Santacatterina, R. Sannino, and D. Formica, “Performance Evaluation of Bluetooth Low Energy: A Systematic Review,” *Sensors*, vol. 17, no. 12, p. 2898, Dec. 2017, doi: 10.3390/s17122898.

[37] J. Haxhibeqiri, E. De Poorter, I. Moerman, and J. Hoebeke, “A Survey of LoRaWAN for IoT: From Technology to Application,” *Sensors*, vol. 18, no. 11, p. 3995, Nov. 2018, doi: 10.3390/s18113995.

[38] KNX, “KNX Greece.” Accessed: Jun. 04, 2024. [Online]. Available: https://knx.gr/

[39] Digital Economy and Society Index (DESI), “Shaping Europe’s digital future. .” Accessed: Jun. 25, 2024. [Online]. Available: https://digital-strategy.ec.europa.eu/en/library/digital-economy-and-society-index-desi-2022

[40] I-Scoop, “The Netherlands is the first country to have nationwide LoRa IoT network coverage. .” Accessed: Jun. 25, 2024. [Online]. Available: https://www.i-scoop.eu/the-netherlands-is-the-first-country-to-have-nationwide-lora-iot-network-coverage/

[41] Statista Market Forecast, “Internet of Things - Netherlands .” Accessed: Jun. 25, 2024. [Online]. Available: https://www.statista.com/outlook/tmo/internet-of-things/netherlands

[42] E. J. Oughton, Z. Frias, S. van der Gaast, and R. van der Berg, “Assessing the capacity, coverage and cost of 5G infrastructure strategies: Analysis of the Netherlands,” *Telematics and Informatics*, vol. 37, pp. 50–69, Apr. 2019, doi: 10.1016/j.tele.2019.01.003.

[43] Statista, “Digital & Connectivity Indicators - Germany | Forecast. .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.statista.com/outlook/co/digital-connectivity-indicators/germany#banking

[44] BLE A 595 WW., “Bluetooth® Low Energy radio transmitter 4-channel, white | BLE A 595 WW. .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.jung-group.com/en-DE/Bluetooth-Low-Energy-radio-transmitter-4-channel-white/BLE-A-595-WW

[45] Z-Wave, “Zigbee | Z-Wave Europe - The leading european distributor for Smart Home products. .” Accessed: Jun. 26, 2024. [Online]. Available: https://zwave.eu/zigbee/

[46] APDC, “Cobertura 5G da Deutsche Telekom alcança os 95% na Alemanha. .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.apdc.pt/noticias/atualidade-internacional/cobertura-5g-da-deutsche-telekom-alcanca-os-95--na-alemanha

[47] Telekom, “Corporate Website: Information about the Group | Deutsche Telekom. (.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.telekom.com/

[48] OECD/Eurostat, “Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation,” *The Measurement of Scientific, Technological and Innovation Activities.* , vol. 4th, pp. 33–109, 2018, doi: 10.1787/9789264304604-en.

[49] International Energy Agency, “2023 Energy Policy Review.” Accessed: Jun. 26, 2024. [Online]. Available: https://iea.blob.core.windows.net/assets/71b328b3-3e5b-4c04-8a22-3ead575b3a9a/Italy_2023_EnergyPolicyReview.pdf#:~:text=URL%3A%20https%3A%2F%2Fiea.blob.core.windows.net%2Fassets%2F71b328b3

[50] MIMIT, “STREPIN.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.mimit.gov.it/images/stories/documenti/STREPIN_2020_rev_25-11-2020.pdf

[51] Trade.GOV, “Italian Smart City Market.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.trade.gov/market-intelligence/italian-smart-city-market

[52] M. J. F. Silva, F. Salvado, P. Couto, and Á. V. e Azevedo, “Roadmap Proposal for Implementing Building Information Modelling (BIM) in Portugal,” *Open Journal of Civil Engineering*, vol. 06, no. 03, pp. 475–481, 2016, doi: 10.4236/ojce.2016.63040.

[53] I. M. Lopes and P. Oliveira, “Can a small city be considered a smart city?,” *Procedia Comput Sci*, vol. 121, pp. 617–624, 2017, doi: 10.1016/j.procs.2017.11.081.

[54] Microlab, “Smart Building Project.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.microlab.nl/en/smart-building-project

[55] G. Guyot, M. H. Sherman, and I. S. Walker, “Smart ventilation energy and indoor air quality performance in residential buildings: A review,” *Energy Build*, vol. 165, pp. 416–430, Apr. 2018, doi: 10.1016/j.enbuild.2017.12.051.

[56] BMWK, “Energy Efficiency Platform.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.bmwk.de/Redaktion/EN/Textsammlungen/Energy/energy-efficiency-platform.html

[57] Fraunhofer, “Smart Building .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.bau.fraunhofer.de/en/fieldsofresearch/smartbuilding.html

[58] D. Minoli, K. Sohraby, and B. Occhiogrosso, “IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems,” *IEEE Internet Things J*, vol. 4, no. 1, pp. 269–283, Feb. 2017, doi: 10.1109/JIOT.2017.2647881.

[59] DEOS AG., “Smart Building: start into the future with building automation! ,” 2024, Accessed: Jun. 26, 2024. [Online]. Available: https://www.deos-ag.com/en/blog/smart-building-smart-automation-for-commercial-buildings/

[60] F. Bandeiras, M. Gomes, P. Coelho, and J. Fernandes, “Towards net zero energy in industrial and commercial buildings in Portugal,” *Renewable and Sustainable Energy Reviews*, vol. 119, p. 109580, Mar. 2020, doi: 10.1016/j.rser.2019.109580.

[61] D. Mariano-Hernández, L. Hernández-Callejo, A. Zorita-Lamadrid, O. Duque-Pérez, and F. Santos García, “A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis,” *Journal of Building Engineering*, vol. 33, p. 101692, Jan. 2021, doi: 10.1016/j.jobe.2020.101692.

[62] Boletín Oficial del Estado, “Resolución para la adopción del PNIEC,” 2024, Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-5106

[63] Netmore Group, “Netmore and SPIE Netherlands Enter Into a Strategic Partnership For Smarter Buildings .” Accessed: Jun. 25, 2024. [Online]. Available: https://netmoregroup.com/news/netmore-and-spie-netherlands-enter-into-a-strategic-partnership/

[64] IO, “Pioneering Dutch innovations lead the way toward a greener urban living .” Accessed: Jun. 25, 2024. [Online]. Available: https://innovationorigins.com/en/pioneering-dutch-innovations-lead-the-way-toward-a-greener-urban-living/

[65] M. Gibescu, “Economic potential of Demand Response for office buildings in the Netherlands,” 2023. Accessed: Jun. 25, 2024. [Online]. Available: https://studenttheses.uu.nl/handle/20.500.12932/43936

[66] L. Chamari, P. Pauwels, E. Petrova, and E. Tu, “Brains for Building’s Energy Systems Study of data needs and requirements in smart buildings.” Accessed: Jun. 25, 2024. [Online]. Available: https://pure.tue.nl/ws/portalfiles/portal/202674663/B4B_WP4_D4.03_Data_Needs_and_Requirements_1.pdf

[67] AIML Programming, “AI Energy Optimization for German Smart Buildings. .” Accessed: Jun. 26, 2024. [Online]. Available: https://aimlprogramming.com/services/ai-

[68] Chambers, “Cilmate change regulations 2023 Italy.” Accessed: Jun. 26, 2024. [Online]. Available: https://practiceguides.chambers.com/practice-guides/climate-change-regulation-2023/italy

[69] A. Foles, L. Fialho, and M. Collares-Pereira, “Techno-economic evaluation of the Portuguese PV and energy storage residential applications,” *Sustainable Energy Technologies and Assessments*, vol. 39, p. 100686, Jun. 2020, doi: 10.1016/j.seta.2020.100686.

[70] F. Castro, J. Soares, B. Canizes, and Z. Vale, “A Brief Review on Optimal Network Planning Considering Energy Storage Systems and Uncertainty,” in *2023 International Conference on Future Energy Solutions (FES)*, IEEE, Jun. 2023, pp. 1–6. doi: 10.1109/FES57669.2023.10182511.

[71] A. Botelho, P. Ferreira, F. Lima, L. M. C. Pinto, and S. Sousa, “Assessment of the environmental impacts associated with hydropower,” *Renewable and Sustainable Energy Reviews*, vol. 70, pp. 896–904, Apr. 2017, doi: 10.1016/j.rser.2016.11.271.

[72] Van Oord, “Constructing one of the largest offshore wind farms in the Netherlands .” Accessed: Jun. 25, 2024. [Online]. Available: https://www.vanoord.com/en/projects/constructing-one-largest-offshore-wind-farms-netherlands/

[73] R. Quax *et al.*, “Assessment of spatial implications of photovoltaics deployment policies in the Netherlands,” *Solar Energy*, vol. 243, pp. 381–392, Sep. 2022, doi: 10.1016/j.solener.2022.07.048.

[74] H. S. de Boer, L. Grond, H. Moll, and R. Benders, “The application of power-to-gas, pumped hydro storage and compressed air energy storage in an electricity system at different wind power penetration levels,” *Energy*, vol. 72, pp. 360–370, Aug. 2014, doi: 10.1016/j.energy.2014.05.047.

[75] Government NL, “The future of fossil fuels | Renewable energy .” Accessed: Jun. 25, 2024. [Online]. Available: https://www.government.nl/topics/renewable-energy/the-future-of-fossil-fuels

[76] Fraunhofer ISE, “R&D for Energy Transition - Fraunhofer Institute for Solar Energy Systems ISE .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.ise.fraunhofer.de/en.html

[77] Energy-Storage News, “Germany: Smart Power 67MWh battery storage system online soon. .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.energy-storage.news/germany-67mwh-battery-storage-system-with-sma-inverters-close-to-completion/

[78] K. Hansen, B. V. Mathiesen, and I. R. Skov, “Full energy system transition towards 100% renewable energy in Germany in 2050,” *Renewable and Sustainable Energy Reviews*, vol. 102, pp. 1–13, Mar. 2019, doi: 10.1016/j.rser.2018.11.038.

[79] EUREF AG., “Home.” Accessed: Jun. 26, 2024. [Online]. Available: https://euref.de/en/welcome/

[80] International Energy Agency, "Smart grids." Accessed: Jun. 26, 2024. [Online]. Available: https://www.iea.org/energy-system/electricity/smart-grids

[81] Europa EU, "Smart grids and meters."

[82] Arera, "Arera." Accessed: Jun. 26, 2024. [Online]. Available: https://www.arera.it/

[83] Diário da República, "Diário da República, 1.^{a} série PRESIDÊNCIA DO CONSELHO DE MINISTROS," 2020. Accessed: May 14, 2024. [Online]. Available: https://diariodarepublica.pt/dr/detalhe/decreto-lei/101-d-2020-150570704

[84] Greek GOV, "OIKONOMA." Accessed: Jun. 04, 2024. [Online]. Available: https://ypen.gov.gr/wp-content/uploads/2021/03/NEO_SXEDIO_DRASIS_KUKLIKH_OIKONOMIA.pdf

[85] Boletín Oficial del Estado, "Sistema de Certificados de Ahorro Energético." Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/buscar/doc.php?id=BOE-A-2023-2027

[86] Miteco, "EEEC. España Circular 2030." Accessed: Jun. 04, 2024. [Online]. Available: https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/estrategia.html

[87] Boletín Oficial del Estado, "RD 1055/2022 de envases y residuos de envases." Accessed: Jun. 04, 2024. [Online]. Available: https://www.boe.es/buscar/act.php?id=BOE-A-2022-22690

[88] Government.NL, "Ministry of Economic Affairs and Climate Policy ." Accessed: Jun. 25, 2024. [Online]. Available: https://www.government.nl/ministries/ministry-of-economic-affairs-and-climate-policy

[89] NL Home, "Netherlands Home." Accessed: Jun. 25, 2024. [Online]. Available: https://www.breeam.nl/

[90] Government.NL, "Circular Economy NL." Accessed: Jun. 25, 2024. [Online]. Available: https://www.government.nl/topics/circular-economy

[91] Gesetze, "GEG - nichtamtliches Inhaltsverzeichnis. ." Accessed: Jun. 26, 2024. [Online]. Available: https://www.gesetze-im-internet.de/geg/

[92] Förderdatenbank, "Förderprogramme." Accessed: Jun. 26, 2024. [Online]. Available: https://www.foerderdatenbank.de/FDB/DE/Foerderprogramme/foerderprogramme.html

[93] G. Schiller, F. Müller, and R. Ortlepp, "Mapping the anthropogenic stock in Germany: Metabolic evidence for a circular economy," *Resour Conserv Recycl*, vol. 123, pp. 93–107, Aug. 2017, doi: 10.1016/j.resconrec.2016.08.007.

[94] H. M. Ali and R. M. Aldaiyat, "Intelligent HVAC systems for smart modern building," *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 9, no. 3, p. 90, Jul. 2021, doi: 10.21533/pen.v9i3.2102.

[95] N. H. Baharudin, T. M. N. T. Mansur, R. Ali, and N. F. A. Sobri, "Smart lighting system control strategies for commercial buildings: a review," *International Journal of Advanced Technology*

and Engineering Exploration, vol. 8, no. 74, pp. 45–53, Jan. 2021, doi: 10.19101/IJATEE.2020.S2762173.

[96] J. Gutierrez, J. F. Villa-Medina, A. Nieto-Garibay, and M. A. Porta-Gandara, “Automated Irrigation System Using a Wireless Sensor Network and GPRS Module,” *IEEE Trans Instrum Meas*, vol. 63, no. 1, pp. 166–176, Jan. 2014, doi: 10.1109/TIM.2013.2276487.

[97] V. Graveto, T. Cruz, and P. Simöes, “Security of Building Automation and Control Systems: Survey and future research directions,” *Comput Secur*, vol. 112, p. 102527, Jan. 2022, doi: 10.1016/j.cose.2021.102527.

[98] G. Qiang, S. Tang, J. Hao, L. Di Sarno, G. Wu, and S. Ren, “Building automation systems for energy and comfort management in green buildings: A critical review and future directions,” *Renewable and Sustainable Energy Reviews*, vol. 179, p. 113301, Jun. 2023, doi: 10.1016/j.rser.2023.113301.

[99] X. Jin, K. Baker, D. Christensen, and S. Isley, “Foresee: A user-centric home energy management system for energy efficiency and demand response,” *Appl Energy*, vol. 205, pp. 1583–1595, Nov. 2017, doi: 10.1016/j.apenergy.2017.08.166.

[100] G. Halhoul Merabet *et al.*, “Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques,” *Renewable and Sustainable Energy Reviews*, vol. 144, p. 110969, Jul. 2021, doi: 10.1016/j.rser.2021.110969.

[101] B. Hartono, S. P. Mursid, and S. Prajogo, “Review: Home energy management system in a Smart Grid scheme to improve reliability of power systems,” *IOP Conf Ser Earth Environ Sci*, vol. 105, p. 012081, Jan. 2018, doi: 10.1088/1755-1315/105/1/012081.

[102] WiseBuilding, “Smart Buildings - Are you prepared?” Accessed: May 14, 2024. [Online]. Available: https://wisebuilding.pt/edificios-inteligentes-esta-preparado/

[103] REN, “Renewable energy supplies Portugal for three days running.” Accessed: May 14, 2024. [Online]. Available: https://www.apren.pt/en/renewable-energy-supplies-portugal-for-three-days-running/

[104] Portugal Government, “Programa de Apoio a Edifícios Mais Sustentáveis.” Accessed: May 14, 2024. [Online]. Available: https://www.portugal.gov.pt/pt/gc23/comunicacao/noticia?i=programa-de-apoio-a-edificios-mais-sustentaveis

[105] A. Afram and F. Janabi-Sharifi, “Review of modeling methods for HVAC systems,” *Appl Therm Eng*, vol. 67, no. 1–2, pp. 507–519, Jun. 2014, doi: 10.1016/j.applthermaleng.2014.03.055.

[106] Nieman, “Bouwregelgeving.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.nieman.nl/specialismen/bouwregelgeving/

[107] Motor24, “Conheça o edifício verde do mundo.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.motor24.pt/motores/ecologia/conheca-edificio-verde-do-mundo/377315/

Co-funded by
the European Union

[108] European Comission, “Air.” Accessed: Jun. 25, 2024. [Online]. Available: https://environment.ec.europa.eu/topics/air_en

[109] Government.NL, “Air quality standarsds.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.government.nl/topics/air-quality/air-quality-standards

[110] A. K. Raue, “NATVENT BUILDINGS VERSUS HVAC BUILDINGS-A NEW DUTCH THERMAL COMFORT GUIDELINE,” 2024.

[111] R. Apanaviciene, R. Urbonas, and P. A. Fokaides, “Smart Building Integration into a Smart City: Comparative Study of Real Estate Development,” *Sustainability*, vol. 12, no. 22, p. 9376, Nov. 2020, doi: 10.3390/su12229376.

[112] Global Designing Cities Initiative, “Lighting Design Guidance .” Accessed: Jun. 25, 2024. [Online]. Available: https://globaldesigningcities.org/publication/global-street-design-guide/utilities-and-infrastructure/lighting-and-technology/lighting-design-guidance/

[113] A. Yüksel, M. Arıcı, M. Krajčík, M. Civan, and H. Karabay, “A review on thermal comfort, indoor air quality and energy consumption in temples,” *Journal of Building Engineering*, vol. 35, p. 102013, Mar. 2021, doi: 10.1016/j.jobe.2020.102013.

[114] “Indoor air quality, thermal comfort and daylight. Analysis of residential buildings regulations in eight EU member states.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.researchgate.net/publication/274695177_Indoor_air_quality_thermal_comfort_and_daylight_Analysis_of_residential_buildings_regulations_in_eight_EU_member_states

[115] Umweltbundesamt., “Germany complied with air quality limit values nearly everywhere in 2022 .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.umweltbundesamt.de/en/press/pressinformation/germany-complied-air-quality-limit-values-nearly

[116] J. Shah and B. Mishra, “Customized IoT Enabled Wireless Sensing and Monitoring Platform for Smart Buildings,” *Procedia Technology*, vol. 23, pp. 256–263, 2016, doi: 10.1016/j.protcy.2016.03.025.

[117] P. Inyim, M. Batouli, M. Reyes, T. Carmenate, L. Bobadilla, and A. Mostafavi, “A Smartphone Application for Personalized and Multi-Method Interventions toward Energy Saving in Buildings,” *Sustainability*, vol. 10, no. 6, p. 1744, May 2018, doi: 10.3390/su10061744.

[118] A. Monacchi, F. Versolatto, M. Herold, D. Egarter, A. M. Tonello, and W. Elmenreich, “An open solution to provide personalized feedback for building energy management,” *J Ambient Intell Smart Environ*, vol. 9, no. 2, pp. 147–162, Feb. 2017, doi: 10.3233/AIS-170422.

[119] Statista, “Smart Home-Spain.” Accessed: Jun. 04, 2024. [Online]. Available: https://es.statista.com/outlook/dmo/smart-home/spain

[120] The Edge, “Edge.” Accessed: Jun. 25, 2024. [Online]. Available: https://edge.tech/developments/the-edge

[121] Rabobank, “Particulieren.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.rabobank.nl/particulieren

[122] J. Hahn, S. Heiler, M. B. Kane, S. Park, and W. Jensch, "The Information Gap in Occupant-Centric Building Operations: Lessons Learned from Interviews with Building Operators in Germany," *Front Built Environ*, vol. 8, May 2022, doi: 10.3389/fbuil.2022.838859.

[123] J. L. Parracha, J. Lima, M. T. Freire, M. Ferreira, and P. Faria, "Vernacular earthen buildings from Leiria, Portugal – Architectural survey towards their conservation and retrofitting," *Journal of Building Engineering*, vol. 35, p. 102115, Mar. 2021, doi: 10.1016/j.jobe.2020.102115.

[124] J. Fernandes, R. Mateus, L. Bragança, and J. J. Correia da Silva, "Portuguese vernacular architecture: the contribution of vernacular materials and design approaches for sustainable construction," *Archit Sci Rev*, vol. 58, no. 4, pp. 324–336, Oct. 2015, doi: 10.1080/00038628.2014.974019.

[125] KNMI, "About KNMI," 2024, Accessed: Jun. 25, 2024. [Online]. Available: https://www.knmi.nl/over-het-knmi/about

[126] I. Sakellaris *et al.*, "Perceived Indoor Environment and Occupants' Comfort in European 'Modern' Office Buildings: The OFFICAIR Study," *Int J Environ Res Public Health*, vol. 13, no. 5, p. 444, Apr. 2016, doi: 10.3390/ijerph13050444.

[127] Holland.com, "Dutch Design: what it is and why it's so important to Dutch culture ." Accessed: Jun. 25, 2024. [Online]. Available: https://www.holland.com/global/tourism/get-inspired/current/dutch-design/dutch-design-reflects-our-culture

[128] S. Q. da S. Hirashima, A. Katzschner, D. G. Ferreira, E. S. de Assis, and L. Katzschner, "Thermal comfort comparison and evaluation in different climates," *Urban Clim*, vol. 23, pp. 219–230, Mar. 2018, doi: 10.1016/j.uclim.2016.08.007.

[129] Britannica, "Germany - Climate, Temperate, Rainfall ." Accessed: Jun. 26, 2024. [Online]. Available: https://www.britannica.com/place/Germany/Climate

[130] Reset.org, "The CUBE Berlin: Office Building With a 'Brain' – Digital for Good ." Accessed: Jun. 26, 2024. [Online]. Available: https://en.reset.org/the-cube-berlin-building-with-brain/

[131] F. y D. Ministerio da Educácion, "Sistema de FP y oferta de títulos de FP." Accessed: Jun. 04, 2024. [Online]. Available: https://www.todofp.es/

[132] SEPE, "Sistema de Formación para el Empleo."

[133] NRO, "About NRO."

[134] Europass, "The European Qualifications Framework (EQF) ." Accessed: Jun. 25, 2024. [Online]. Available: https://europass.europa.eu/en/europass-digital-tools/european-qualifications-framework

[135] CEDEFOP, "Statistical overviews on VET- Netherlands." Accessed: Jun. 25, 2024. [Online]. Available: https://www.cedefop.europa.eu/en/country-reports/statistical-overviews-vet-netherlands

[136] CEDEFOP, "VET in the Netherlands: a strong reputation abroad, but a poor image at home ." Accessed: Jun. 25, 2024. [Online]. Available: https://www.cedefop.europa.eu/en/press-releases/vet-netherlands-strong-reputation-abroad-poor-image-home

[137] Deutschland., "Bundesinstitut für Berufsbildung (BIBB)." Accessed: Jun. 26, 2024. [Online]. Available: https://www.bibb.de/

[138] CEDEFOP, "Spotlight on VET Germany ." Accessed: Jun. 26, 2024. [Online]. Available: https://www.cedefop.europa.eu/en/publications/8137

[139] SecurityLeaders, "Smart buildings: 38% are targets of malicious attacks in 2019." Accessed: May 14, 2024. [Online]. Available: https://securityleaders.com.br/edificios-inteligentes-38-sao-alvo-de-ataques-maliciosos-em-2019/

[140] S. Wendzel, J. Tonejc, J. Kaur, and A. Kobekova, "Cyber Security of Smart Buildings," in *Security and Privacy in Cyber-Physical Systems*, Wiley, 2017, pp. 327–351. doi: 10.1002/9781119226079.ch16.

[141] M. Mylrea and S. N. G. Gourisetti, "Cybersecurity and Optimization in Smart 'Autonomous' Buildings," in *Autonomy and Artificial Intelligence: A Threat or Savior?*, Cham: Springer International Publishing, 2017, pp. 263–294. doi: 10.1007/978-3-319-59719-5_12.

[142] Europa, "Europa GREECE." Accessed: Jun. 04, 2024. [Online]. Available: https://www.europarl.europa.eu/doceo/document/TA-9-2022-0383_EL.html

[143] Home, "Nationaal Cyber Security Centrum. ." Accessed: Jun. 25, 2024. [Online]. Available: https://www.ncsc.nl/

[144] BMI, "Cyber Security Strategy for Germany." Accessed: Jun. 26, 2024. [Online]. Available: https://www.bmi.bund.de/EN/topics/it-internet-policy/cyber-security-strategy/cyber-security-strategy-node.html

[145] ConnectWise, "Cybersecurity Laws and Legislation." Accessed: May 14, 2024. [Online]. Available: https://www.connectwise.com/blog/cybersecurity/cybersecurity-laws-and-legislation

[146] GDPR.EU, "What is GDPR, the EU's new data protection law?" Accessed: May 14, 2024. [Online]. Available: https://gdpr.eu/what-is-gdpr/

[147] European Commission, "EU Cyber Resilience Act." Accessed: May 14, 2024. [Online]. Available: https://digital-strategy.ec.europa.eu/en/policies/cyber-resilience-act

[148] European Insurance and Occupational Pensions Authority, "Digital Operational Resilience Act (DORA)." Accessed: May 14, 2024. [Online]. Available: https://www.eiopa.europa.eu/digital-operational-resilience-act-dora_en

[149] America's Cyber Defense Agency, "Cyber Incident Reporting for Critical Infrastructure Act of 2022 (CIRCIA)." Accessed: May 14, 2024. [Online]. Available: https://www.cisa.gov/topics/cyber-threats-and-advisories/information-sharing/cyber-incident-reporting-critical-infrastructure-act-2022-circia

[150] N. Leesakul and C. Morisset, “Position Paper: The role of law in achieving privacy and security measures in smart buildings from the GDPR context,” in *2023 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW)*, IEEE, Jul. 2023, pp. 619–626. doi: 10.1109/EuroSPW59978.2023.00073.

[151] GDPR, “GDPR - Legal Text.” Accessed: Jun. 26, 2024. [Online]. Available: https://gdpr-info.eu/

[152] M. Ahmed and P. Haskell-Dowland, Eds., *Cybersecurity for Smart Cities*. Cham: Springer International Publishing, 2023. doi: 10.1007/978-3-031-24946-4.

[153] ZVEI, “Germany’s Electro and Digital Industry. .” Accessed: Jun. 26, 2024. [Online]. Available: https://www.zvei.org/en/

[154] Procuradoria-Geral Distrital de Lisboa, “Decree n^{o} 46/2019, 08th of July.” Accessed: May 14, 2024. [Online]. Available: https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?artigo_id=3104A0002&nid=3104&tabela=leis&ficha=1&nversao=

[155] INCIBE, “Plan Estratégico Plurianual 2023-2025.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.incibe.es/sites/default/files/paginas/que-hacemos/plan-estrategico-plurianual-23-25-incibe.pdf

[156] BSI, “Federal Office for Information Security.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.bsi.bund.de/EN/Home/home_node.html

[157] M. H. Dadashi-Rad, A. Ghasemi-Marzbali, and R. A. Ahangar, “Modeling and planning of smart buildings energy in power system considering demand response,” *Energy*, vol. 213, p. 118770, Dec. 2020, doi: 10.1016/j.energy.2020.118770.

[158] T. Samad, E. Koch, and P. Stluka, “Automated Demand Response for Smart Buildings and Microgrids: The State of the Practice and Research Challenges,” *Proceedings of the IEEE*, vol. 104, no. 4, pp. 726–744, Apr. 2016, doi: 10.1109/JPROC.2016.2520639.

[159] J. Qi, Y. Kim, C. Chen, X. Lu, and J. Wang, “Demand Response and Smart Buildings,” *ACM Transactions on Cyber-Physical Systems*, vol. 1, no. 4, pp. 1–25, Oct. 2017, doi: 10.1145/3009972.

[160] C. Shao, Y. Ding, P. Siano, and Z. Lin, “A Framework for Incorporating Demand Response of Smart Buildings Into the Integrated Heat and Electricity Energy System,” *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2, pp. 1465–1475, Feb. 2019, doi: 10.1109/TIE.2017.2784393.

[161] L. Ma *et al.*, “Multi-party energy management for smart building cluster with PV systems using automatic demand response,” *Energy Build*, vol. 121, pp. 11–21, Jun. 2016, doi: 10.1016/j.enbuild.2016.03.072.

[162] TenneT, “Lighting the way ahead together.”

[163] M. Gibescu, “Economic potential of Demand Response for office buildings in the Netherlands,” 2023. Accessed: Jun. 25, 2024. [Online]. Available: Economic potential of Demand Response for office buildings in the Netherlands

[164] Fraunhofer IAIS., “Homepage.” Accessed: Jun. 26, 2024. [Online]. Available: https://www.iais.fraunhofer.de/en.html

[165] P. Du, N. Lu, and H. Zhong, *Demand Response in Smart Grids*. Cham: Springer International Publishing, 2019. doi: 10.1007/978-3-030-19769-8.

[166] J. Al Dakheel, C. Del Pero, N. Aste, and F. Leonforte, “Smart buildings features and key performance indicators: A review,” *Sustain Cities Soc*, vol. 61, p. 102328, Oct. 2020, doi: 10.1016/j.scs.2020.102328.

[167] W. Han and L. Ang, “German Smart Meter Development and inspiration,” *IOP Conf Ser Mater Sci Eng*, vol. 439, p. 052040, Nov. 2018, doi: 10.1088/1757-899X/439/5/052040.

[168] INESCTEC, “Portugal contribuiu para a digitalização da rede elétrica europeia com soluções interoperáveis que ligam casas e edifícios à rede.” Accessed: May 14, 2024. [Online]. Available: https://www.inesctec.pt/index.php/pt/press-releases/portugal-contribuiu-para-a-digitalizacao-da-rede-eletrica-europeia-com-solucoes-interoperaveis-que-ligam-casas-e-edificios-a-rede#intro

[169] ENDESA, “Smart Grids.” Accessed: Jun. 04, 2024. [Online]. Available: https://www.endesa.com/en/our-commitment/innovation/smart-grids

[170] International Energy Agency, “The Netherlands 2020.” Accessed: Jun. 25, 2024. [Online]. Available: https://www.iea.org/reports/the-netherlands-2020

[171] T. Rösch, P. Treffinger, and B. Koch, “Regional Flexibility Markets—Solutions to the European Energy Distribution Grid—A Systematic Review and Research Agenda,” *Energies (Basel)*, vol. 14, no. 9, p. 2403, Apr. 2021, doi: 10.3390/en14092403.

[172] Euronews, “Varandas solares estão a crescer na Alemanha. Eis o que precisa de saber sobre esta popular tecnologia doméstica .” Accessed: Jun. 26, 2024. [Online]. Available: https://pt.euronews.com/green/2024/04/21/varandas-solares-estao-a-crescer-na-alemanha-eis-o-que-precisa-de-saber-sobre-esta-popular

GERMANY

LDI

GREECE

HELLENIC MEDITERRANEAN UNIVERSITY

ECTE EUROPEAN CENTER IN TRAINING FOR EMPLOYMENT

EBEX Chania Chamber of Commerce & Industry

TÜV AUSTRIA HELLAS

ITALY

ENAIP NET

como nExt INNOVATION HUB

BuildTech

NETHERLANDS

ATERMON EDUCATIONAL PLAY

NORTH MACEDONIA

ЦЕНТАР ЗА РАЗВОЈ НА ЈУГОИСТОЧЕН РЕГИОН

СОЈУЗ НА СТОПАНСКИ КОМОРИ НА МАКЕДОНИЈА

EMKICE www.emkice.mk

PORTUGAL

P.PORTO

25 DIGITALMENTE

SPAIN

Alecop Knowledge & Technology

instagi

ZubiGune fundazioa

conaif

Infodef INSTITUTO PARA EL FOMENTO DEL DESARROLLO Y LA FORMACIÓN

Co-funded by
the European Union

101144027 — SEBCoVE — ERASMUS-EDU-2023-PEX-COVE

SEBCoVE.eu
LinkedIn
Facebook