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Review

A Practical Review to Support the Implementation of Smart Solutions within Neighbourhood Building Stock

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Abstract: The construction industry has witnessed the increasing use of digital tools and smart solutions, particularly, in the realm of buildings energy automation within the concept of smart cities. While to truly realize the potential benefits of smart cities, a broader scope of smart initiatives is required to support the transition from smart buildings towards smart neighbourhoods, appreciated as the critical unit of urban development. To support this interplay of smart solutions between buildings and neighbourhoods, this article aims to collect and review all smart solutions presented in existing scientific articles, technical literature, and realized European projects. These solutions are classified under two main sections of buildings and neighbourhoods, which are investigated through five domains: buildings energy-related uses, renewable energy sources, water, waste, and open space management. Showcasing the quantitative outcomes demonstrates the potential benefits of implementing smart solutions from buildings to neighbourhoods. Moreover, this research concludes that the true enhancement of energy conservation goes beyond the buildings' energy component and can be genuinely achieved by integrating intelligent elements of the neighbourhood, due to their strong interdependencies. Future research is recommended to focus on assessing the effectiveness of these solutions towards resource conservation.

Keywords: Smart building; smart energy grid; smart energy management; neighbourhood building stock; sustainable development goals

1. Introduction

The efforts to achieve sustainable energy provision have been the main priority of developing and developed countries, particularly European Union members which are among the top fossil fuel importing countries, in the world. Based on the Statista report in 2021, Europe imported roughly about 13.5 million barrels of oil per day [1]. A large amount of carbon dioxide and other harmful environmental emissions released by the construction industry has established its reputation as one of the serious contributors to global climate change. Once more, buildings' vintage and inefficient construction materials in the historic neighbourhoods of European countries have spurred a greater need for energy and made them major energy-intensive sectors [2]. These concerns have imposed pressure on European governments and energy markets to seek a cost-effective solution to strike a balance between reducing energy and decarbonizing construction activities. Subsequently, over recent years, the construction industry has discovered the application of digital technologies and smart solutions as a promising approach that paves the way toward reducing buildings' environmental repercussions as well as improving the residents' quality of life [3].

Generally, with the growing advancement of technology towards digitalization and becoming smarter, more daily activities are being affected by computer tools and intelligent devices. This evolution has caused a significant shift towards more automated and connected ways of living and increased the dependency between humans and

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technologies [4]. According to the United Nations report, smart solutions are expected to support and accelerate the successful achievement of each of the 17 sustainable development goals (SDGs) [5]. Indeed, the implementation of smart systems utilizing the information and communication technologies (ICT) can create excellent opportunities to deliver different building and urban scales services through an integrated set of smart grids and address existing challenges hindering the achievement of SDGs [6]. smart sustainability refers to the efforts of developing and implementing smart technologies to attain SDGs [6]. The interconnected nature of SDGs intensifies the needs of modern civilization to guarantee the comprehensiveness and reliability of global programs. Technically, when smart and intelligent tools are aimed at meeting sustainable objectives, they can be interpreted under the domain of smart sustainability, (also known as digital sustainability). Therefore, an inclusive program intended to introduce the application of these tools, must cover all committed goals, such as economic, environmental, social, cultural norms, and even spiritual values [7][8].

Meanwhile, deploying technologies such as smart grids, machine learning approaches, the Internet of Things (IoT), and artificial intelligence, are clear examples that have transformed daily routines and construction activities in different socio-economic and environmental contexts [9]. These emerging technologies have added more value to urban management by introducing novel methods of responding to urban needs (e.g., distributed energy generation from renewable sources, storage facilities simplifying demand response, etc.) [10]. Technically speaking, smartening and digitalization of cities can be interpreted as the integration of all urban flows by collecting data, analysing, and transmitting the desired information to the target points. Indeed, this information enables society to gradually optimize the use of physical assets, operation of businesses, and proactive management of customers. With technological advancements, every point and subject that can be read and analysed by sensors, cameras, and software can be assumed as a significant point on the IoT network. To the extent that, [11] alleged that, by the year 2030, more than 50 billion devices will be connected to the IoT network and about 52% of users use smart and digital systems to improve their activities. In this regard, connecting different nodes and elements of smart cities to the internet is an essential need that should be taken into account in every smart city [12]. Although the myriad benefits of making these data flows have not been fully realized yet, they are widely regarded as a cornerstone for a transition toward the true development of the smart and efficient city [6]. In another word, digitalization and smart systems can bring many beneficial tools, while their utilization should be examined to ensure their alignment with sustainable objectives and avoid their designation to the frivolous purposes [13].

Particularly, the integration of ICT technologies with building and urban elements has introduced new interactive features to the European energy markets, such as dynamic responses to the residents' needs, flexible adjustment of systems' operations with respect to internal and external conditions, etc. [14]. By the same token, enabling buildings to intelligently optimize their energy usage based on time-of-use electricity tariffs and residents' energy demand has become one of the leading perspectives of this sector [15]. Hence, a smart building, integrated with a smart city, can be defined as a nearly zero energy building (nZEB) able to actively contribute to energy generation, energy storage, and load shift [16]. [17] also highlighted the significance of the transition from the conventional building energy design to the deployment of smart heating, cooling, and ventilation (HVAC) systems that manage energy demand and generation according to the weather conditions, energy grid balance, and residents' needs. Such a paradigm shift in the building automation process required a detailed technical guide to define and clarify the required smart readiness levels, enabling data transfer and management in an integrated building energy system. To this end, the European Commission (EC) decided to develop the Smart Readiness Indicator (SRI), a comprehensive descriptor as a part of the Clean Energy for All Europeans packages, to define and support smart elements that can be deployed in a smart building. SRI report presented a classification of buildings' components that can be automated at different levels and bring more efficient energy operation

[18]. However, one of the main limitations of the use of SRI is that there is no practical and enlightening example to show the potential percentage of energy reduction that might be obtained by applying the list of automation. This lack of numerical evaluation in smartening buildings' energy performance may cause discouraging confusion among stakeholders who have no perspective on the final performance of the project. Moreover, alongside the building scale initiatives outlined in SRI, there are abroad spectrum of smart solutions at higher scales that can support energy conservation, integration of renewable energy and other live elements of the community, which must be taken into account. However, there is no technical benchmark, similar to the SRI, to support these smart initiatives at community scales in a practical manner.

With a specific reference to neighbourhood-scale projects that have been testified as the most important and practical scale of urban development [19], this research aims investigate multifarious smart solutions and innovative technologies that can support the attainment of global sustainable programs (e.g., SDGs) and energy optimization both at building to neighbourhood scale. One of the novelties and contributions of this purpose is to define a clear boundary to confine the domains and elements that can be smartened across neighbourhood building stock. Moreover, presenting the potential achievements that can be obtained through these smart solutions stimulates the integration of all elements through the use of ICT technologies. Clarifying the real definition of smart solutions allows us to distinguish smart solutions from common sustainability measurements that have been widely carried out in this context. To this end, a literature review is carried out, to collect all smart solutions from scientific papers, technical literature, and realized European projects that can be applied at neighbourhood. The structure of this paper is as follows: the methodology of this research is explained in section 2; Section 3 explores multifaceted aspects of utilizing collected smart solutions in six community-scale domains furtherly classified into different smart solutions; Section 4 concludes and sums up the overview and perspectives obtained from this research.

2. Methodology

According to [20], there are numerous types of literature review, namely, systematic review, cumulative review, developmental review, and narrative review. The first method is carried out when theoretical objectives and boundaries can be established, in advance, to eliminate biases and bring a more reliable set of findings. The cumulative review aims to summarize the findings obtained from the papers focused on specific topics which often help to identify research gaps in literature. The developmental review tracks the trend of evolution on a particular issue. Finally, a narrative literature review provides an overview of the studies conducted on a particular topic, without any strict restrictions on the inclusion or exclusion of the articles [21].

The methodology taken in this research is based on the combination of narrative and systematic literature reviews. As the main objective of this research is to present an elaboration on the use of smart solutions and novel technologies that can be applied across a neighbourhood building stock, the first step of methodology begins with searching through scientific articles, technical literature, and EU projects to find out different smart solutions. It is worth noting that, in this research, the definition of a smart solution is laid out based on the concept of a smart system. A smart system is a system that incorporates functions of sensing, actuation, and control based on the data collected from internal and external sources, to perform smart actions. As there is no scientific benchmark to confidently determine the smart solutions that can be implemented in a neighbourhood, a narrative literature review is conducted to initially encompass all disciplines, management of which can be bounded in this context.

In the following step, all smart solutions that can be implemented at building and neighbourhood scales are separated and thematically classified under five domains, namely, buildings energy-related uses, renewable energy sources (RES), water, waste, and open space management, widely discussed in many sustainability protocols. The collection of smart solutions in searching process has been based on answering to the following three research questions (RQs) respecting sustainability performance of each domain: i) Which smart solutions can improve each domain? ii) How smart solutions can improve each domain? and iii) To what extent these smart solutions can improve each domain?

In the next steps, some filtrations are adapted to exclude those smart solutions that are out of scope of this article. For instance, even though many sustainability protocols deal with the improvement of economic or mobility elements for a neighbourhood, these issues cannot be incorporated in this context. Besides, there are many neighbourhoods planning and regeneration initiatives that may enhance the quality of the neighbourhood's elements (e.g., the proximity of facilities, bus stations, etc.), though they cannot be considered smart, based on abovementioned definition of smartness, and should be excluded. Figure 1 schematically demonstrates the steps of methodology taken in this research.

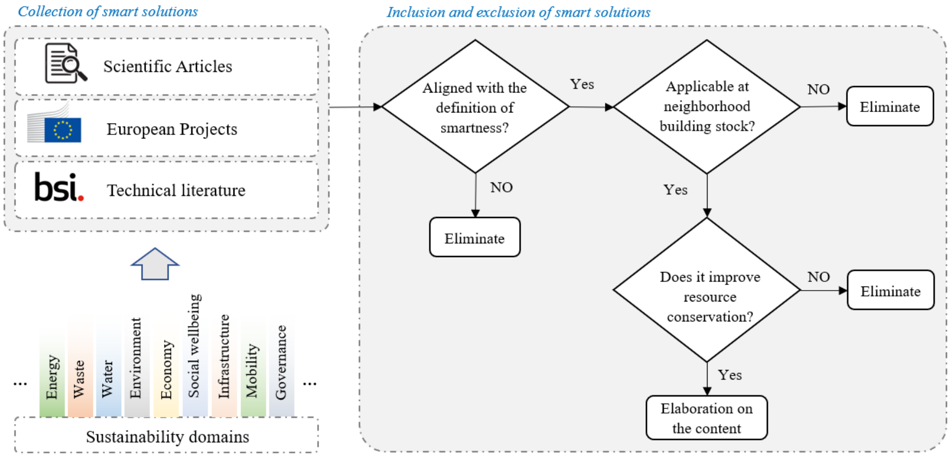

Figure 1. Schematic steps of inclusion and exclusion in considering smart solutions

By the same token, it should be clarified that the smart solutions collected in this research are aimed to deliver a series of smart services that not only enhance human intervention to make decisions more smartly but also improve energy conservation (e.g., smart parking systems that steer drivers toward the empty slots reducing the time of use of cars, a smart irrigation system that controls sprinklers operation based on plants' needs, reducing energy consumption related to water use, etc.).

Finally, smart solutions are organized in a thematic order to highlight the constituent elements of each domain which are also emphasized in different references. Although the availability and advancement of existing smart solutions are not consistently addressed within different domains, the comprehensive review of collected documents demonstrated a relative consensus among researchers and urban developers on the importance of certain classifications. Moreover, the description given on each smart solution may cover eighter digital ICT technologies (e.g., optimization algorithms in design, communication protocol, and mobile applications), physical devices (e.g., sensors, digital screens), or integration thereof (e.g., smart thermostats).

3. Results and discussion

This section presents those smart solutions that have been applied in buildings and neighbourhood contexts, to boost energy conservation in smart manners. The findings collected from the literature review are organized within two main sections of building energy related use and neighbourhood scales which are furtherly classified to different domains and smart solutions. As it is shown in Figure 2 each domain is investigated through one or more smart solutions.

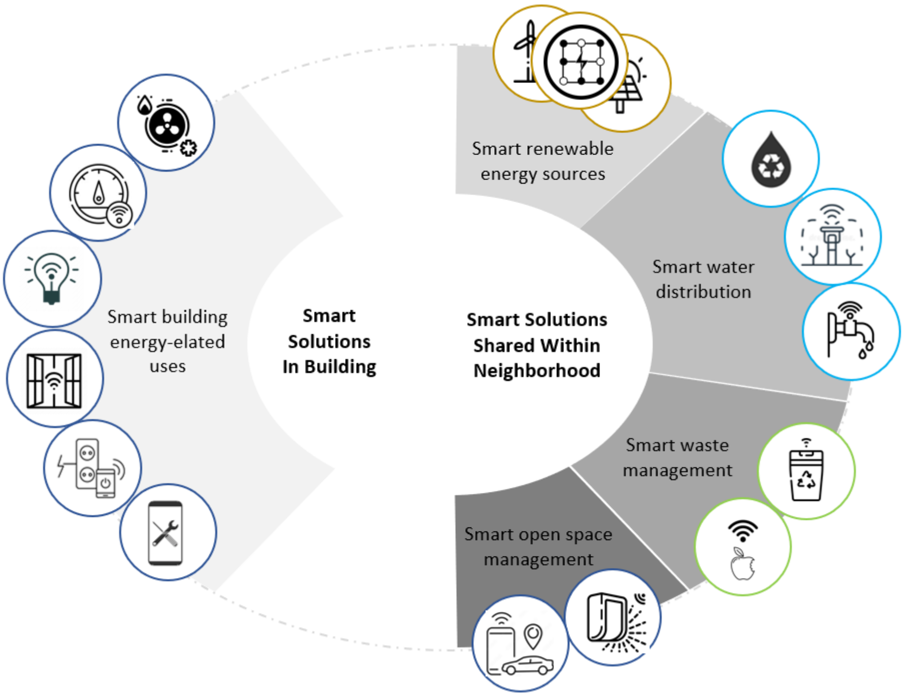

Figure 2. The classification of applicable smart solutions in neighborhood building stock

The content of each domain is presented in a narrative form so that each domain is started by raising the needs that have prompted the development of smart solutions. As outlined in the methodology, to better structure the content of collected information describing the smartness of the domain, they are thematically broken down into one or more sets of smart solutions that can be applied, description of which includes the ultimate goal of smartening, the procedures to establish smart solutions, as well as the quantitative result of the improvement, which has been obtained from previous articles and reports. Due to the interrelationships between different domains, the outcome of smart solutions may cover direct or indirect impacts on energy conservation (e.g., reducing water consumption, and simultaneously reducing the energy required for delivering water); while to avoid any conflictions, smart solutions are strictly divided based on the primary subject that they address. In the following sections, the description of smart solutions collected to answer to the RQs, are first presented for the buildings and then investigated for the shared area of the neighbourhood which will five domains in total.

3.1. Smart solutions for buildings energy-related uses

With the rapid growth of the urban population, it is estimated that the amount of energy consumption in the building sector can increase by about 65% by 2050. The [22] demonstrated that about 50% of total energy consumption in public buildings is related to the HVAC system. [23] also alleged that the average energy consumption in residential buildings for heating, domestic hot water (DHW), cooling, and lighting utilities are respectively, 27.3%, 13.1%, 11.8%, and 7.2%. The lack of reliability in conventional energy management plans and manual collection of data related to energy consumption is among critical obstacles in upgrading the building energy systems. In addition to the residents' misbehaviour in the use of energy systems, low thermal performance and poor quality of buildings' envelopes have often brought overheating risks or caused high energy consumption for overcooling. From another perspective, there are possible factors such as installation of faulty elements, inappropriate adjustment of energy systems, and poor maintenance of equipment, that also may impose a large amount of energy wastage to the buildings [24]. In this regard, different control systems and strategies have been proposed to mitigate operating time, energy consumption, and cost across all elements.

Smart HVAC system

The ultimate goal of smartening the HVAC system is to maintain a comfortable indoor environment in terms of temperature and air quality, with minimum energy consumption [25]. Long ago, utilities that had been used to create a comfortable indoor ambience had been limited to the heating and cooling functions. Indeed, it was an incorporation of the thermostat and control system that allowed HVAC systems to operate in a more efficient way. Since then, the introduction of communication technologies to the circuit board of heating and cooling equipment enables the whole board to operate more intelligently. In this case, instead of relying on manual control or rigid settings of heating and cooling operations, which often led to overheating or overcooling in the indoor spaces, smart HVAC systems can intelligently adjust its operation, based on data collected from the surrounding environment such as indoor temperature, outdoor temperature, number of occupants, etc. [26].

Particularly for smart ventilation systems, the concept of Demand Controlled Ventilation (DCV) has been introduced to specify the way of response to the temporal or spatial needs for the ventilation [27]. There are various types of DCV strategies that can be classified based on type of sensors, control algorithms, and buildings regulations [28]. By the same token, [29] proposed a classification on different ventilation control strategies including variables such as outdoor temperature, zone occupancy, predicted or measured exposure to the contaminants, zonal control (single or multi zone) dynamic or fixed direction or rate of airflow (exhaust, supply, balance), etc. For instance, [30] developed a control system to monitor local occupancy, grid signal, and outdoor temperature. This smart ventilation system that was designed for residential buildings in California, achieved 20% energy reduction and delivered demand response benefits. Comparing different types of DCV strategies that includes the occupancy and contaminant trackers, [31] shows that smart ventilation scenario developed based on zonal control and unzone control (i.e., supplying the whole dwelling) can averagely reduce energy consumption, respectively by about 20% and 7%. [32] developed an outdoor temperature-based smart ventilation control strategy to maintain the equivalent indoor air quality aligned with ASHRAE 62.2-2013; an implementation of this DCV on a two-story residential building delivered up to 6% of reduction on annual energy use. [33] developed smart ventilation strategies for humidity control and applied it on nearly zero energy buildings. This research, which evaluated 10 smart control strategies across six types of climatic conditions revealed that smart control system can averagely reduce the fraction of annual hours of relative humidity (RH) from above to below 60% (in worst climatic condition it was about 16%). [34] developed different smart ventilation strategies based on occupancy detection and auxiliary fans; this research demonstrated that energy saving obtained from occupancy control is not significant, due to the intensified recovery period required when residents come back home (i.e., up to double the rate of air flow). Concerning this intensified operation of ventilation system after re-occupancy, [35] stated that the energy performance of occupancy-based ventilation control can be improved if the control strategy automatically turn on the ventilation system with normal level, a period before the arrival time of residents.

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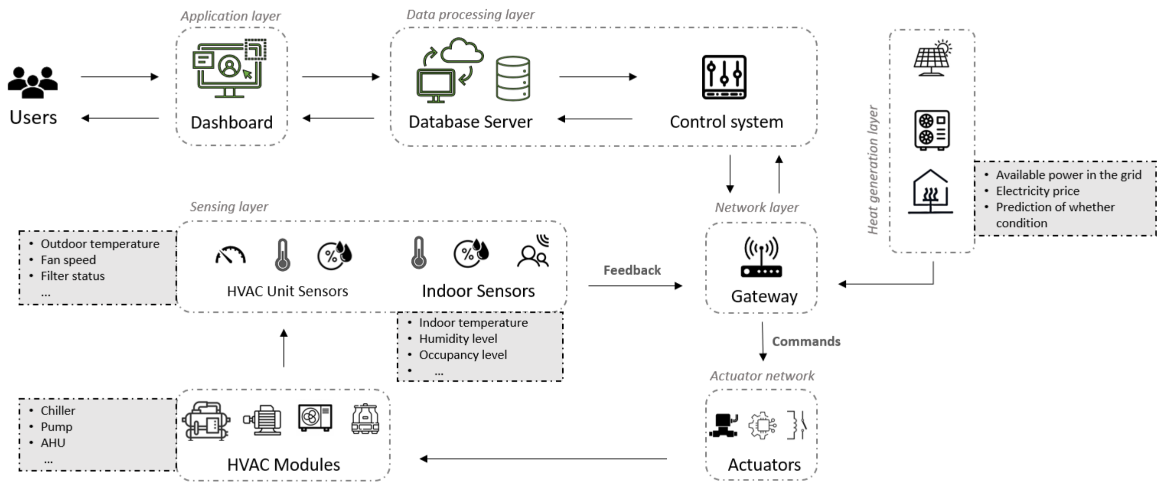

Figure 3. Schematic architecture of data flow in smart HVAC systems

Although, the results that can obtained from these strategies can be varied between different climate conditions [36] alleged that smart ventilation systems often give a significant energy saving in all situations except from climate that have less seasonal temperature variations.

In light of this trend, based on the specific goal of the control system, the following parameters can be obtained from sensors installed indoors and outdoors, and signals in energy grids: i) occupancy, ii) air quality conditions (e.g., parameters such as humidity, temperature); iii) electricity grid status; iv) contaminants; v) operation of HVAC systems (e.g., fans, flow rates, velocity, etc.) [36]. For modelling the smart ventilation systems, the recommended values and ranges of the following contextual parameters can be obtained based on the daily events and activities of households and extracted from cited standards and guidelines: occupancy; CO_2 [37]; moisture [38]; particles [39]; Generic Contaminants [40]; weather conditions [41]. Table 1 illustrates some examples of smartening components of HVAC systems:

Table 1. Some examples of offering smart solutions for smart HVAC system

Reference	Smart solutions	Results
[31]	Zone- based in occupancy detection (dwelling)	o Saving for smart HVAC systems 0-19% o Saving for ventilation energy 0-41% o CO_2 reduction between 9 to 19%
[42]	Changing temperature set points and defining two types of real-time tariff (Two Medium/Large Households)	o Energy cost saving 10.8% o 12.8%- 24.7% saving for peak load o 4.3% saving for HVAC systems
[43]	Changing temperature set point by predicting demand response potential (Single residential unit)	One-degree setpoint adjustment which resulted in 2.5% energy saving
[44]	Changing temperature set points, using humidity-controlled ventilation system (16 apartments)	o Up to 35% reduction in airflow o No condensation, No RH higher than 43%
[45]	Relative humidity control, occupancy sensors (31 new apartment)	About 37% of the time: o 35% reduction on electricity consumption o 23% on heating need

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[46]	Control strategies on air handling (Multifamily dwellings)	20-30% electricity reduction
[35]	Occupancy based control (1-2 story buildings)	Up to 15% energy reduction
[47]	Using the smart cooling system to customize thermal comfort temperature based on body mass index (BMI) of the residents	35% energy reduction in average
[48]	Forecasting indoor temperature, and scheduling different set points using IoT based solutions to improve the contribution of users (a lab building)	○ 8.1-10.9% Energy reduction ○ 11.3 cost reduction

Smart water management in buildings

The ultimate goal of smartening water system in buildings is to measure water flow characteristics and optimize it based on users' needs and behaviour. Generally, water consumption can be curbed in large scales (i.e., infrastructural actions and regulatory) and individual conservation (i.e., building and community efforts). At building scale, this can be achieved through the use of advanced meters working based on ultrasonic or electromagnetic readings that provide more accurate data (e.g., potential leakages, amount of water consumption, etc.) compared to conventional meters [49][50]. [51][52] underlined three following initiatives that can be obtained by deploying smart water meters: i) increasing community awareness on water value; ii) billing and alternative pricing scheme; iii) forecasting water consumption, resulting in water and energy preservation. [53] suggested the use of in- home display (IHD) to give real time feedback to the users, which resulted in reducing water consumption by 16%. [54] also used IHDs to notify users when the consumption go beyond the predefined limitations and consequently lead to 23% reduction in water use.

In addition to the precise measurements, smart water systems designed for buildings incorporate intelligent control systems; they automatically adjust the desired temperature and required volume of water based on consumption patterns, ensuring that water is used efficiently while minimizing energy consumption. By dynamically adapting to users' needs, these systems optimize water usage without compromising comfort or convenience [55]. Indeed, besides the adaptation of already well established measures such as insulation of pipelines, careful planning of draw-off points, using renewable energies, etc., there are smart solution to improve the energy efficiency in DHW systems [56][57][58]. [59] reported that among the type of energy consumed in European building stock, energy required for heating and DHW, respectively account for 64% and 15% of the total energy. According to this study, residents' behaviour and lifestyle have more significant impacts on energy consumption compared to the type of heat source. To address this issue, [56] raised an application of submeters known also as individual metering and charging (IMC) of hot water as a potential solution on a multi-family case study in Poland and achieved 20% reduction in the use of DHW. To measure the accurate amount of water, it is necessary to install different sensors and auxiliary devices enable to collect and transfer data with high accuracy in a short time period, particularly when renewable energy sources are used to supply heating required for DHW [56]. An example of smart solution in this field is [60] that measured the impact of data collection interval on energy consumption and found that by reducing the interval from 1 minute to 6 seconds, the energy required for peak demand could be reduced by 40%. DHW meters usually quantify and demonstrate the total amount of household's consumption which is suitable to calculate bills. While, using individual smart sub-meters gives the possibility of transmitting interpretable real- time information to the residents, which can significantly affect and reduce residents' consumption [61][62]. According to [56], the most critical value that can be obtained by DHW smart meter is the calorific value required for supplying hot water, which necessitates typical equipment such as temperature sensors, flow meters, computing core, and communication sector. This study also introduced some other important data that can be collected from servers such as water temperature, time synchronization which can be analysed to deliver valuable information such as endpoint, discarded energy, flow, accumulated and instantaneous energy, etc. Moreover, [51][52] underlined three following initiatives that can be obtained by deploying smart water meters: i) increasing community awareness on water value; ii) billing and alternative pricing scheme; iii) forecasting water consumption. In more detail, smart water metering can pave the way toward a more flexible water pricing method and resource management.

[63] claimed that the smart control on boilers equipped with related smart sensors, and remote controls, help to find out consumption pattern in advance (i.e., desired temperature, required volume of water, and time of use) which results in saving water and energy. According to [64] that highlighted 50% heat loss in conventional DHW system with storage tank, an efficient effort has been 4th Generation District Heating which circulate hot water with lower temperature and subsequently lower use of energy. However, one of the main challenges of low temperature district heating (LTDH) is increasing the possible risk of Legionella growth [65]. To solve this problem [66] suggested the use of a dual function residential thermal stations (RTS) in which standby loss is eliminated and energy provided for heating system also used for DHW. In all these systems, control methods of electric tracing can have a significant impact on the final performance of the system.

Table 2 presents several examples of applying novel ideas and smart solutions to smarten and enhance the water management system, along with the corresponding benefits that are claimed to be achievable through this approach.

Table 2. Some examples of using smart solutions in water management system

References	Smart solutions	Results
[66]	Developing a control system to manage electric tracing in residential thermal station (RTS) (One or two-family dwellings)	31% energy improvement compared to the DHW storage
[65]	Improving the conventional DHW system supplied by medium temperature district heating (i.e., base run scenario: S1) within two scenarios: - Decentralized substation systems with LDTH (S2) -Innovative decentralized substation system with LDTH (S3)	Reducing annual distribution loss compared to S1: ○ S2: 30% ○ S3: 39% OPEX cost reduction ○ S3: 36% operating cost reduction
[67]	Developing an electric heat tracing system on DHW (A Multi-residential building)	○ Reduced power use by 10% ○ Heat loss by 18%. ○ Loss reduction by 34 to 67%
[68]	Smart heat pump for heating water	○ Reduction in energy consumption by 60% ○ Energy cost reduction by 30%
[69]	Using smart water meters with daily report	○ 13 % reduction in water consumption
[56]	Sub-meter for accurate reading of energy and flow in discarded hot water (i. e., interval of 1 min) (918 household project)	○ Increase the accuracy of measuring DHW demand by 38% ○ Saving 3.3% energy demand ○ Saving 5.2% flow demand

[70]	Showerhead prototypes equipped with light and IHD to show duration of shower and water consumption (Residential district)	Reducing DHW consumption by about 9.6%
[71]	Compare different types of interventions in translating data to useful information such as education, giving feedback, etc. (221 households)	Intervened group consumed 7.9% less water compared to the control group
[72]	Giving feedback to the consumers through online portal and a comparison with normal consumption	6.6% drop in water consumption compared to the control group
[73]	Detailed feedback via an online portal both on electricity and water consumption (Dormitories)	○ 3% average reduction in water use (max 11% reduction in one building) ○ 32% reduction in electricity
[53]	Provide IHDs devices to give real-time consumption data, shifting consumption to the time with the low-price tariff (10000 households)	○ 16% increase in water consumption ○ Significant reduce in water bills
[54]	Provide IHDs device, alarm to announce consumption more than predefined limitations (44 households)	27% reduction in water consumption
[55]	Giving feedback on water consumption and subordinate promoting strategies for on water saving	Average 19.6% reduction in water consumption in all related studies.
[74]	Wireless data transmission of water consumption to the users	30 % reduction in water consumption and their bills
[75]	An application of SCADA system and smart water metering	Reduce water loss from 40% to 15%

Smart lighting systems

The ultimate goal of smartening the lighting system is to provide comfortable and healthy light based on specific usages of the environment and occupants' demands. A smart lighting system (SLS) may be comprised of different elements, namely, efficient light sources (i.e., light emitting diodes (LEDs)) as a prerequisite and smart control system that may include a wireless communication network, software, sensors, and a remote control system that realizes specific innovative solutions [76]. In light of this trend, [77][78] concluded that the application of SLS in office buildings can save energy up to 95% which is a function of activity pattern and types of control system. For example, the control system equipped with occupancy detection sensors adopted in [79] saved energy up to 60%. Having highlighted the impact of building and windows characteristics (e.g., direction, latitude, etc.) on the efficiency of SLSs, [80] adopted the daylight-integrated lighting control system (i.e., enable to dim down or completely turn off the lamps by detecting an adequate amount of natural light) to save energy up to 47% compare to the conventional system. This paper calculated the energy savings of 35% and 20% through the separate use of occupancy detection and daylighting harvesting sensors, respectively. [81] analysed the application of time-base lighting control system, which depends on the clarity of commuting pattern, to save energy from 10% to 40% in office buildings. Although most projects on SLS have focused on issues related to energy conservation, recently, the examination of residents' well-being has become more significant, so that improving features such as aesthetic aspects of the environment, visual comfort, and light effects beyond vision are heatedly discussed [82][83]. Table 3 shows the energy efficiency and cost reduction that can be achieved by the SLSs deployment.

Table 3. Some examples of offering smart solutions for smart lighting systems

References	Smart solutions	Results
[79]	Occupancy detection based on users' behavior and activity pattern (Sixty office buildings)	Energy saving for different spaces: o 29% for break rooms o 58% for classrooms o 47% for conference room o 38% private office o 59% for restrooms
[84]	Daylight harvesting, light quality control, remote control	o 54.7% energy saving o Maintaining the desired lighting colour
[80]	Control system equipped with occupancy detection, daylight harvesting, and dimming control (Deep-plan office building)	o Occupancy sensors: 35% energy saving o Daylight harvesting: 20% energy saving o Dimming: 11% energy saving o All together: 42-47% energy saving
[66]	Occupancy detection, daylight harvesting, and smart bulbs[1] (Single family home)	23% energy saving
[85]	The combination of control (occupancy detection), fault diagnosis, and Prognosis module diagnosis	50% energy saving and increase the reliability of system

[1] Light bulb connected to the Wi-Fi without any external hardware.

Smart buildings openings

The ultimate goal of smartening building openings is to adjust solar radiation by transmitting, reflecting, and absorbing the sun light through windows which allows building to conserve energy and maintain a comfortable environment [86], using movable shading devices or adopting dimmable glass (also known as smart glass, switchable glass). Despite many sustainable design solutions that can be applied to design and form of the facade to improve the energy performance of the buildings (e.g., Double layer air corridor, external and internal insulation layers, windows with low U-values, etc.) [87], a building envelope can be considered intelligent and smart, only when it can automatically adapt itself to weather conditions, occupant behaviour and needs, and conflictions [88]. As it is not possible to predict 100% of the environmental and climate condition, the intelligent envelope system must be able to manage the strategy required to deal with these variables [88]. Indeed, the control system used for the intelligentization of the envelope should be designed for self-powered sensing, controlling, and actuation. According to the EU commission projects, smart windows can also be aimed at providing better natural ventilation [89]. To this end, it requires managing the volume of air that leaves and enters the room, which subsequently mitigates the need for mechanical ventilation. From an architectural perspective, an additional smart solution involves the application of AI technologies to strike a balance between comfortable environment and energy efficiency by taking account of buildings' orientation and openings dimension for an optimal lighting, heating, cooling, and ventilation [90].

Along with trend, [91] proposed two new models of smart windows, thermochromic and electrochromic windows, utilizing crystal droplets and suspended particles to change glass transparency. [92] designed a solar smart window system in which flexible photovoltaic cells are installed on one side of the blind and cooling coats on the other side, which leads to a 4% to 9% reduction in temperature during the passive cooling performance. Some examples of using smart windows are tabulated in Table 4:

Table 4. Examples of using novelties and smart implementations in buildings envelope

References	Smart solutions	Results
[90]	Using feature selection method and game- theoretic method (Office building) to find energy-efficient configuration of envelopes	Proposing two types of envelopes that save 10.6% and 21.2% of energy
[89]	Smart shadings to control sunlight	25% energy reduction
[91]	Smart thermochromic windows to automatically switch between heat/ light transition state to the blocking state, and vice versa.	8 % reduction in energy consumption compared to the double-glazed windows
[93]	Smart thermochromic windows to automatically switch between heat/ light transition state to the blocking state, and vice versa	35% reduction in energy consumption compared to the double-glazed windows

Smart electric devices management systems

The ultimate goal of smartening electricity management in the building is to automatically manage the time and mode of operation in electric devices, aimed at shifting loads and reducing electric bills. Although there are several systems that allow residents to remotely control electric devices through installed actuators (e.g., switching on/off washing machines or ovens through mobile phones), they are merely intended to enhance residents' comfort and are different from interfaces that provide an intelligent reduction of energy consumption [94]. In November 2016, the European Commission has updated the application of smart technologies in the Energy Performance of Building Directive (EPBD) that had been introduced in 2002 for the first time to actively optimize energy use in buildings [95][96]. A corollary of this update was to reveal the potential benefits of smart buildings in creating an intelligent environment integrated with home automation to secure comfort, safety, and energy efficiency enhancement [97]. A great capability in this area is the collection of data from devices and processing them through heterogeneous and dynamic sources. An advanced IoT- based system can consider variables such as building data, current and predicted amount of available renewable energy (in a case connected to the smart grid), energy prices, weather data, and end-users behavior to optimize the time and mode of the electrical devices' operation [48]. These optimizations can be designed through a set of rules incorporated in intelligent electricity management [98].

By the same token, [99] showed that demand-side load management, which refers to the shifting of residents' consumption towards the period of off-peak demand, can effectively improve the overall energy efficiency. [100] developed an electricity management tool, able to provide a personalized plan with awareness services that lead to users' behavioural change. There are many tools to support end- users energy management. For instance, Siemens Synco designed for mixed-use small to medium size buildings, in which the control system manages energy plants by monitoring and adjusting HVAC electric equipment [101]. Honeywell Attune Advisory Services is another monitoring and optimization tool supported by Software as a Service (SaaS) and cloud-based technologies, which help facilities to determine the best way of saving resources [102]. These sorts of tools are more helpful for energy service companies, specialists, and facility managers willing to use collected data and processed information to make decisions and set rules [103]. Some well-known tools and companies working in this field, are as follows: Loop Energy Saver and Origami Energy in the United Kingdom [104][103]; NUUKA and OPT-WATTI in Finland [105][106]; Bidgely, Enetics, and PlotWatt in USA [107][108][109]; Plugwise in Netherland [110]; SMARAKIA in Spain [111]. Indeed, these tools utilize IoT- based system to collect and analyse input data and to provide monitoring and controlling services such as data visualization and notification that assist users to find out potential ways for reducing electricity consumption [48].

Another important function that has shown great potential for being smart and intelligent is the metering methods and subsequently reporting system. As smart meters like gas and electricity meters are often installed in out-of-sight places, the installation of an IHD, a small monitor that displays valuable and understandable information from smart meters, has been recommended [112]. [113] alleged that a control system that manage smart meters can analyse and provide valuable information as a virtual assistant for residents showing defectiveness of consumption patterns and discover energy guzzlers in the homes. [114][115] helped to improve users' lifestyle insight by listening to the unique energy signature of homes and subsequently proposing different series of recommendations, enabling remote control and automatically turn off the electricity. [116] showed that giving feedback about consumption pattern to the consumers can reduce it by about 5% to 15% compared to the baseline. In addition, about 64% of people who have smart meters in their homes think twice about the energy consumption of their devices. Table 5 represents outcomes can be obtained by particular tasks in the system.

Table 5. Some examples of using smart technologies in smart electricity management

References	Smart solutions	Results
[117]	Demand response scheduling model: ○ Time of use ○ Critical peak pricing ○ Real time pricing (Single Family Homes)	Reducing peak-valley difference in energy-term: ○ 9.04% ○ 9.04% ○ 7.56% Total Energy reduction: ○ 0.29% ○ 1.07% ○ 1.52%
[73]	Detailed feedback via an online portal both on electricity and water consumption (Dormitories)	About 32% and 3% reduction respectively, in electricity and water use
[118]	Smart appliances and different tariff of use on electricity prices to shift load (Community of 1-2 story residential buildings)	Saving 10% of energy, with greatest individual savings up to 20%
[119]	Putting real time pricing by tariff based on estimating consumption pattern (A city)	About 10.4 -17.4% load reduction in peak demand
[120]	Individual metering and charging (Multifamily buildings)	20% energy saving
[121]	Individual metering (2400 Danish dwellings)	15-30% heat energy saving
[122]	Balance between electricity tariffs and CO_2 intensity (30 Smart buildings in UK (electricity/ thermal storage, boiler, CHP, wind turbines, conventional grid))	○ 7% bill reduction 13% CO_2 reduction
[123]	Direct feedback on energy consumption (A case study region)	○ About 5 to15% energy reduction
[123]	Direct feedback on energy consumption (Twenty households)	○ 8.1% energy reduction

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Smart maintenance and commissioning

The ultimate goal of smartening maintenance and commissioning is to enhance the efficiency of maintenance and monitoring process on buildings services at the right time and in a most cost-effective manner [124]. In light of technological evolution in different sectors of the building industry, it's vital to also progress through the concept of utilities' services and commissioning to realize the smart maintenance concept. To this end, an integration of two well-known terms of lean and smart maintenance has formed a dynamic, intelligent, and value-added management model that will embrace all buildings' components [125]. The highest step of maintenance hierarchy refers to smart maintenance and commissioning which goes beyond the fixed commissioning plan, by embracing the measurements conducted by diagnostic tools integrated into the control system [125]. Indeed, apart from the specialist's contractors, it needs an integrated network of IoT devices actively patched to the firmware to provide and transfer updates about the operation status of systems, within a reasonable timescale to keep the network secure [126]. Therefore, smart maintenance can provide services based on the intelligent system, operated by technologies eighter equipment embedded in various urban or buildings elements [127]. To develop a smart management plan, it is necessary to consider the following disciplines:

- Data management: Using data generated by cyber-physical system for predictive maintenance.
- Knowledge management: externalization of existing technical knowledge to the new labors
- Learning orientation: Integration of fundamental steps into the control cycle of maintenance
- Weak point elimination: Using big data analytics and IT systems for elimination of weak points.
- Employee qualification: Precise qualification of specialists working in maintenance sections.
- Optimization of maintenance strategy: Optimal decision between reactive, preventive, predictive, and proactive measurements

As it is still hard to explore the benefits that can be obtained by the recent smart maintenance and commissioning programs, no quantitative elaborations have been found.

3.2. Smart solutions shared within a neighbourhood

3.2.1. Smart solutions to improve energy provision

High energy demand and environmental repercussions caused by the depletion of fossil fuels have stimulated the development of renewable energy technologies for many years. Depending on the environmental and contextual features, available technologies, and urban management system, the community may discern whether to deploy different types of RES (i.e., solar, geothermal, wind, biomass, and even hydraulic energy) to generate energy [128][129] [128]. However, uncertainty in the efficiency of the energy generation process makes it hard to calculate the return of investment (RoI), which has somehow discouraged investment in this area. Another challenge in this field is the low value of capacity factor (i.e., realized output to the maximum possible output) in renewable power plants. Due to the intermittent nature of renewable sources (e.g., lack of strong wind, cloudy weather, etc.) that make these energy resources not always available, the capacity factor is often lower than fossil fuel-based plants [130]. This periodic availability of all RES exacerbates mismatch between supplied energy and demand which can make blackouts and low voltage, a regular occurrence [131][132]. On the other hand, enlarging the plants and designing them based on peak demands can impose additional financial pressure. In this regard, deciding between under-production or over-production plants had remained a big question, for several years [128]. However, there are some smart solutions and innovative ideas that can resolve these obstacles.

Smart renewable energy grid

The ultimate goal of smartening renewable energy grid is to secure energy supply, improve widespread access to energy without dependency on fossil fuel. Smart management of renewable power plants relies on the integration of all components in energy generation systems with smart infrastructure considering different objectives (e.g., energy efficiency improvement, emission control, etc.), in real-time. As energy management in a smart energy network, can be automated by a technical control centre that allows immediate real-time data transmission and analysis, [133][134] highlighted the significance of identifying and executing corrective actions to diagnose and prevent errors in time. Although existing renewable energy grid systems may already cover some smart functionalities such as balancing supply and demands, [135] testified that achieving a real smart grid system requires an incorporation of ICT into all aspects of electricity supply, delivery, and consumption. In this regard, [136] classified the application of ICT in developing renewable energy plants into two imperative disciplines of optimal power flow (OPF) and configuration strategies (CS); the CS deals with the placement of RESs or generators in the power distribution system and OPF refers to the load flow problems and operating conditions. Indeed, due to the uncertain availability of RESs, different ICT technologies and forecasting algorithms have been employed to boost CS and OPF [137]. [138] claimed that an incorporation of a multitude RESs in a microgrid has potential benefits such as more effectiveness of the local implementation of computational intelligent models, facilitating configuration and fault control, elimination of deep charge problems, and increasing the quality and reliability of power. [135] demonstrated that depending on the types of renewable energies and geographical demand profiles, the highest ratio of renewable energy supply to the peak load (i.e., defined as renewable penetration level) in an electricity system can be classified into three levels. The lowest level can be implemented without any smart technology by capacity penetration of less than 15%. The medium level of renewables' penetration is between 15 to 30%, which necessitates considering smart components throughout the grid. [139] also alleged that the incorporation of digital tools and innovative design within a renewable smart grid can secure a capacity penetration of higher than 30%.

Moreover, given the high potential of intelligentization in energy storage, it has become one of the themes that stimulate heated discussions. [128] proposed energy storage has been as a logical solution for saving energy in the system allowing variable renewable energy systems to be more desirable and doable in existing electrical grid systems among communities. Although electricity can be stored in different storage media such as batteries, fuel cells [140], flywheels [141][142], compressed air energy storage (CAES) [141][143], etc, only batteries and fuel cells are appropriate for a neighbourhood scale projects, due to the characteristics such charge/discharge time, energy density, etc. Even though all these systems are equipped with sophisticated pieces of technology, without smart self-control over their performance, they are dumb machines that can only store and discharge energy. While smart energy storage system can be defined based on having following features:

- Self- optimization, and justification of charging and discharging processes based on electricity prices.
- Control the time and source of obtaining energy, to achieve a longer cycle life
- Coordinate the operations with other storage systems, the capacity of power plants, and load demands.
- Predict and prevent failure and unusual catastrophes that may degrade the performance of batteries (e.g., thermal runaway, imbalance energy among cells in a battery pack)

The subject of energy storage can benefit from smart solutions by using precise and well-structured data to empower AI systems. By the same token, [144] clarified that the automation and optimization of energy storage systems require sufficient knowledge and real-time communication regarding power plant production and consumer load demands. This crucial information enables decentralized decision-making for regulating microgrid components. These microgrid's operations can be executed by a central control whose main task is to maintain power quality and reliability by regulating the frequency and voltage in the grid [145]. Figure 4 demonstrates an example of general components in community scale microgrid.

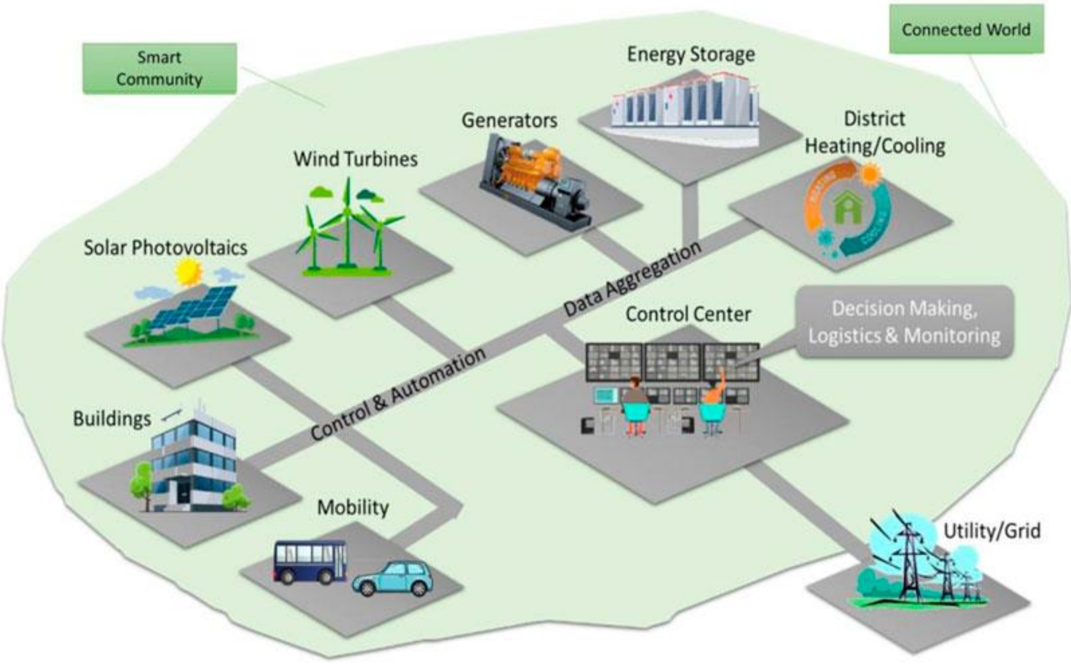

Figure 4. General architecture of smart energy grid [146]

In addition to the abovementioned smart solutions, International Renewable Energy Agency (IRENA) also released a guidance for effective deployment of smart grids and renewable energies, in which technologies that can be utilized were investigated [135]. Accordingly, IRENA summarized related smart technologies of smart grids under nine groups, including advanced metering infrastructure (AMI), advanced electricity pricing, demand response (DR), distribution automation (DA), renewable source forecasting, smart inverters, virtual power plants (VPPs), and microgrids. This report, elaborated on these technologies throughout different disciplines such as maturity levels, availability in market, capital and operational costs, time scales, etc. Table 6 represents the quantitative impacts of different smart methods that have been introduced in existing literature respecting electricity generation from renewable sources:

Table 6. Some examples of using smart solutions in deploying a smart energy grid

Reference	Smart solutions	Results
[147]	Small scale microgrid including responsive load demand, energy storage, and two energy sources such as PV panels and wind turbines, (Home scale)	21% cost reduction on bills
[148]	Using game theory and genetic algorithm to optimize the switching sequence and reinforcement among multiple microgrid	60% total cost reduction 90% reduction in losses

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	(supplied by distributed RES)	
[149]	Using the combinations of a genetic algorithm and a mixed integer linear programming to optimize renewable power plants; formulating grid's constraints to host more renewable sources with lower CO_2 emission and cost. (A couple buildings considered as energy hubs)	○ 45% CO_2 reduction ○ Potential for Adding extra 45% renewable energy ○ 18% cost reduction
[150]	ntegration of windmill and PV panels; launching different tariff of use on electricity consumptions; shift the peak demands. (Smart building connected to the smart grid	○ 48% cost reduction
[151]	Introducing the concept of energy hub to integrate distributed renewable energy plants at district level, by using linear programming	○ 81-95% CO_2 reduction
[152]	Shifting daytime cooling load to the night-time cooling storage (meteroplex)	○ 12.2 % reducing fuel consumption
[153]	Optimize discharge power and period of the storage system (Office building)	○ 28-48% cost reduction
[154]	The effect charging/discharging schedules of battery installation on changing people's behaviour (mid-sized UK family home)	○ 10% reduction of energy bill by PV panels ○ 38% reduction of energy bill by energy storage system
[144]	Application of Adoptive Intelligence Technique (AIT) in systems with variable energy regulations; using multiple renewable power plants including wind turbines, PV panels (Community micro-grid)	40% overall improvement of energy usage
[155]	Using genetic algorithm approach to optimize the size of energy storage system and daily operation to increase RoI and minimize the energy consumption; optimize charging/discharging profile; different tariff of use on electricity consumption. (A single-family home)	No quantitative result
[156]	Cost-optimal control and rule-based control for PV self-consumption maximization (Residential low-energy detached house including PV panels, Li-ion battery, thermal and DHW storage))	13-25% reduction in electricity bills

3.2.2. Smart solutions to improve water distribution network

According to the World Bank data, the amount of non-recover water loss, due to leakage and breakage, in developing countries, is about 35% to 50% of water consumption [157] and related auxiliary energy (water treatment, distribution, etc.) [158]. The intricate system of pipes that are buried in the ground and have different profiles is one of the major obstacles to better water management. The long-term exposure of the iron casts to the moisty soil may speed up the corrosion process and reduce their expected useful life. On the other hand, a complete replacement of all system's cast iron pipes, which are in some cases more than 120 years old, impose a huge financial pressure on municipalities; so that an inability to diagnose the problem or predict system deterioration require expensive crisis intervention. Apart from financial and physical barriers, the global water crisis needs a practically efficient method to deal with these challenges [159].

By the same token, several smart solutions and ideas have been developed so far. Indeed, different advanced technologies can be employed to collect required data and simulate the performance of water systems. Even though retrofitting activities often are managed at district or city scale, there are a few smart measurements and technologies that must be considered and applied at neighbourhood scale. In the following parts, all smart solutions related to the water delivery in the neighbourhoods are summarized.

Smart water distribution system

The ultimate goal of smartening water distribution systems is to continuously monitor and control the water supply network and its performance to carry potable water with effective pressure. According to the [129][160], smart water distribution system deals with the two aspects: i) smart leakage detection; ii) smart water quality preservation. Smart water distribution system deploys high-tech equipment and systems to monitor different characteristics of water flows and abnormalities in the distribution network pipelines. For this purpose, technologies such as sensors, integrated communication modules, software, and suggestively open-source platform for cloud access are required [160]. From the perspective of pressure management, which affect related energy consumptions, sensors can also be utilized in different methods to detect abnormal waterflow, such as bursts and leakages. To this end, hydraulic-based solutions and acoustic sensing have been often used to analyse the variations in the flow and pressure of water in different nodes of the network. For instance, [161] used wavelet analysis and Cumulative Sum (CUSUM) (i.e., a widely used statistical control method) to identify potential burst events across pipelines by revealing the accurate time of abnormalities in pressure and flows. Due to the high cost of installation of sensors, the number of sensors in these models must be optimized and allocated to the strategic nodes in the network [162]. Therefore, finally, the smart water grid refers to the smart design and placement of all physical components of the system so that realizes the operational efficiency of smart water management as it is expected and foreseen with smart devices. Figure 5 demonstrates the general perspective of smart water distribution systems for a neighbourhood. As can be seen, different critical components of the water distribution system (e.g., pumps, valves, tanks, end-use water taps, etc.) can be monitored through a network of sensors where each one is connected to a microcontroller that has the ability to store and interpret the data and send the information through wireless to desired points (e.g., users or technician team) [160][163].

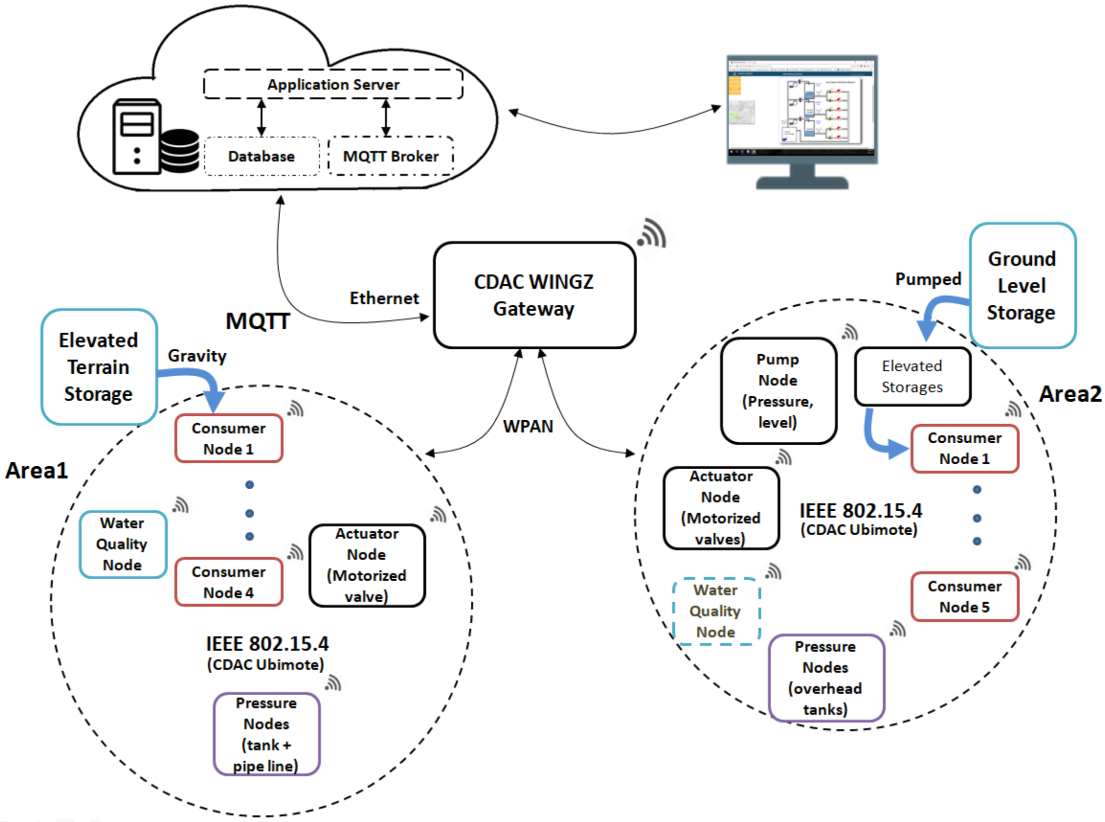

Figure 5. An example of using smart solutions in water distribution systems [163]

A practical application of abovementioned smart solutions can be the optimization of maintenance plans. [70] identified high-risk pipes based on the likelihood of failure (calculated based on age, material, pressure of the pipes and the type of soil around) and consequence of failure (calculated based on sensitivity of customers to the water loss) to optimize the maintenance models. To sum up, [70] also listed the following benefits of a smart water grid:

- Real-time monitoring of the condition across the pipelines which enable technicians to apply preventive maintenance at the right time
- Real-time measurement of water quality and pressure for early identification of potential contamination and leakages
- Automatic control of valves to prevent flooding, damages, water loss, and spreading of pollution
- Real-time feedback on technical measurement to calibrate pumps, and subordinate utilities.

According to the [164], deploying a smart supply system in Lisbon has reduced non-recovered water losses by about 40%. In a comprehensive review article, [165] investigated the application of Supervisory Control And Data Acquisition (SCADA) on water distribution system and revealed that the deployment of real time alarms and automatic operation plant, can bring 30% energy savings and 20% decrease in water loss. Besides, [70] leveraged joint time-frequency analysis (JTFA) to analyse the pressure signals collected throughout the sensors for burst event identification within the range of 3 to 7 1/s (Burst event is often treated as discrete occurrences; so the more rate shows the more accuracy of system.). [166][167] highlighted the financial benefits of the using smart water technology, which is able to decrease the initial investment required for water utilities by 12.5%. Table 7 tabulates some examples of using smart technologies in neighbourhood scale water distribution systems:

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Table 7. Some examples of performance improvement in smart water distribution system

References	Smart solutions	Results
[168]	- Use Kalman filtering to detect abnormalities - Multi-parameter water quality monitoring system - Accurate flow metering	o Online detection of abnormalities in water consumption, o Enhance the efficiency of water pipe operation
[160]	Monitoring model to collect data by sensors in the network managed by powerful microcontroller	o More accuracy of data o Presenting prototype system capable of measuring water flow o Minimal errors
[169]	Using inverse transient for controlling bursts detected by analysing pressure sensors	Identifying pipeline burst event of 7.7 1/s
[70]	Using Joint time-frequency (JTFA) approach for burst detection analysed by pressure sensors	Efficiently identify the burst even varies from 3 to 7 1/s
[170]	Using CUSUM and Haar wavelet analysis to measure pressure signals	Identify burst event causing leakage in 3 to 8.33 1/s
[171]	Commercial leak-detection devices	o Reducing 30% of water consumption o 25-35% saving energy used to push water
[172]	Design a smart water network	o 20% reduction of average cost o 7.4% reduction in leakages
[173]	SCADA method: Real time alarm, automatic control of network operations	o 30% saving energy use o 20% reduction water loss o 20% reduction in disruption
[174]	IoT- base water monitoring	6.66% less water consumption

Smart irrigation controllers

The ultimate goal of smartening water irrigation systems is to automatically adjust the watering volume and time based on environment conditions (e.g., soil moisture, humidity, etc.) and plant's needs. It is about two decades that the so-called term of "smart irrigation controllers" have been widely developed to implement advanced methods of irrigation to the residential and commercial landscapes [175]. The smart irrigation systems, based on it is real objective, can be comprised of different sensors feedback, and devices to monitor site conditions and subsequently collect required data such as wind, soil moisture, slope, plant type, etc. Communication protocols transmit these data, as input to the control system for making decision upon the precise irrigation schedule based on the real needs of the plants and current and future site conditions [166]. This system can also include mobile application for remote intervention in irrigating management [176]. The trace of using machine learning techniques, have been also observed to manage and operate decision support systems of smart irrigation at a higher level of advancement and require expert knowledge to train the algorithms [177][178]. Figure 6 illustrates the general components of smart irrigation systems.

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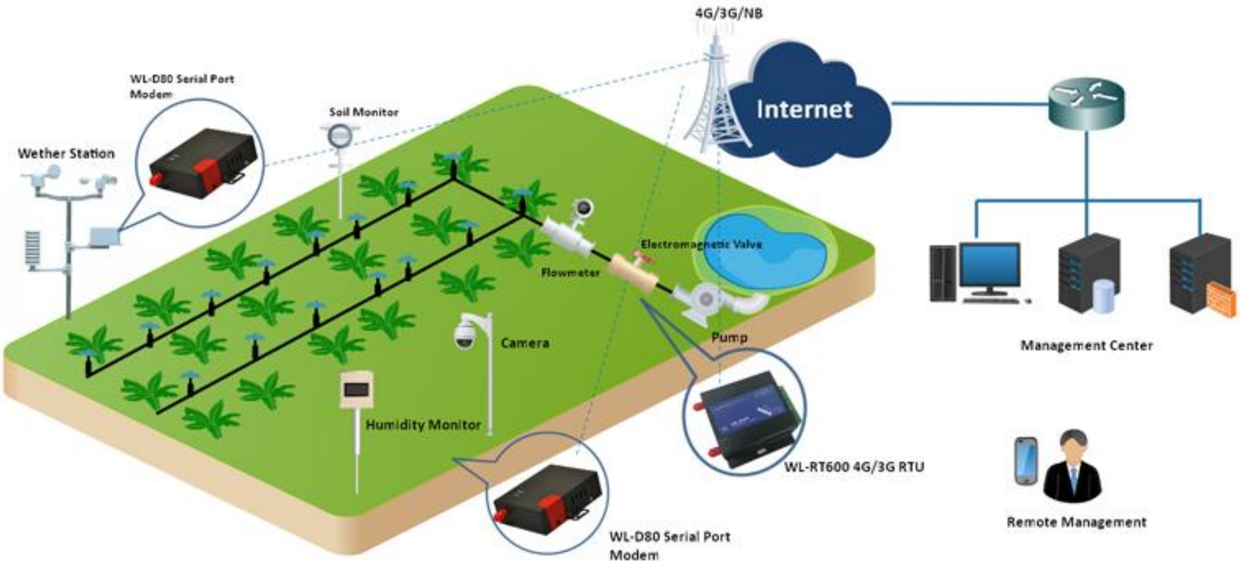

Figure 6. General components of smart irrigation systems [179]

Generally, the architecture of systems that are often proposed to monitor and control of irrigation system is a dynamic multi- agent system. The multi agent architecture is capable of merging information from multifarious data sources and enable stakeholders to include or exclude new sensors based on the landscape requirement [180]. A lot of research projects have been defined in this area, some of which even have been financed by European Community [181][182]. Table 8 represents some examples of using smart irrigation control and their subsequent impacts in saving water.

Table 8. Some examples of smart solutions in irrigation control system

References	Smart solutions	Results
[183]	Smart farming covering weather forecasting, moisture, nutrient content of the soil, watering, and fertilization scheduling.	20% reduction in water use
[182]	Wireless communication and environmental sensors to actuate irrigation at accurate time and place. (farmlands)	21% reduction in water use
[181]	Developing autonomous sprinklers operating based on in field data (Sprinklers positions, water pressure, land characteristics, etc.)	About 20-30% reduction in water use

Smart grey water reclamations

The ultimate goal of smartening grey water reclamation system is to establish and secure reliable treatment systems that would be able to detect abnormal materials in sewage flow, potential risks, and errors. In light of digitalization and smartness in grey water reclamation, [184] mentioned the types of component and volume of sewage flow in the short and long term which can be changed due to the multifarious steps required for the treatment process. Accordingly, [185][186] highlighted the use of real time control on treatment process in which, anomalies in the components of the grey water can be immediately detected and transferred data to the expert technicians or control system for taking further urgent measures. To this end, different intelligent technologies such as big data, sensors, IoT, and artificial intelligence methods might be used, with the focus on monitoring and controlling patterns, identifying, and diagnosing plant's anomalous behavior and errors, and predicting wastewater inlet flow and required workloads. For example, sensors allow the acquisition of physical and chemical parameters such as Ph, nitrates, temperature, ammonium, etc. These parameters can be collected within short specific intervals (e.g., 1 min) in a cloud environment and then processed in a higher layer of modules [184].

Apart from using sensors and smart control systems, there are some novelties in using ICT-based methods. For instance, artificial intelligence technologies have been also widely used to reduce the energy and costs of these processes. [187] employed the data mining (DM) method to optimize aeration process and reduce required energy by 31.4%. [188] also used DM method to optimize activated sludge process (i.e., ASP classified as an aerobic biological process), by controlling dissolved oxygen in wastewater, which resulted in 15% reduction in required air flow. Using an Expert System (ES) method in Oxic reactor (i.e., a treatment process with high biogas production and low energy consumption), [189] could reduce total treatment costs and energy by 40%. [190] also used an advance control in the Flemish plants, which result in 10% to 20% reduction in energy needed for aeration process, and 30% saving on chemical doses. Data collected from wastewater flow can also be used to calculate the optimal tank water level, which reduces the high pressure behind the pipes in the network and subsequently reduce leakage risks [191].

3.2.3. Smart solution to waste management

The recycling and reusing materials has been one the main priorities of the municipalities during last decades and perceived as the concept of a circular economy [192][193]. However, limited knowledge of formal or informal sectors who are responsible for such activities and lack of advance facilities and infrastructures to efficiently collect and sort waste are two main challenges which have caused inefficiencies in solid waste management, particularly in developing countries [194]. Another nuance but critical issue is openly dumping and burning organic waste in low-income districts and cities; while they can be used either as a source of waste-to-energy or composting plants [6][195]. Using current methodologies to control composting or sorting and recycling processes is a time consuming and high energy demand task which require high- skill workers [196].

To secure an achievement of such sustainability objectives, it is crucial to adopt intelligent measures that would be able to effectively control waste management processes either at the building or neighbourhood scales. Although, an application of smart waste management is a city-scale vision that requires sufficiently advanced infrastructure and components (e.g., smart waste collectors equipped with GPS and connected to the smart bins' sensors), there are some elements that should be handled at neighbourhood scale. The following part presents two smart solutions that can be adopted in this field.

Smart waste bins

The ultimate goal of smartening the waste bins is to automate some initial steps in the waste management chain such as minimization, collection, and separation in an intelligent manner which culminates in energy and cost reduction. According to [197] the potential for reducing the amount of unrecycled material is between 30 to 130 kg/year, person. Hence, numerous digital tools have been developed to support the gradual transformation of "design, use, disposal" model to circular model in which discarded waste can be recycled and reused [197]. For instance, smart bins deployment can make a direct contribution to waste minimization by digital tracking of waste where residents would be charged based on the content and weight of their trashes through the new system of "pay-as-you-throw" (PAYT) [198][199]. This system sends some feedback based on historical

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data of individuals and introduces different procedures for decreasing their costs. Berlin is one of the cities that introduced the application of Radio Frequency Identification (RFID) for PAYT systems in communities[199]. [200][201] also highlighted smart bins equipped with other sorts of technologies such as a sorting feature that works based on image recognition technology (e.g., using sensors to identify the content of waste or the color of plastics) and a conveyor belt that separates wastes. [202] also introduced a model of smart bin in which, a solar-powered compacting lever is also added, to compress the volume of waste by about 700% and reduce collection frequency by 85%. To realize these solutions, required sensors and devices should be mounted on smart bins. Figure 7 demonstrates a sample of smart bins equipped with fill-level sensors and solar-powered compactors. In another step of smart waste management that should be supported by higher administrative level of urban management, data related to the districts' waste containers can be collected through cloud computing; once processed, the control system can navigate waste trucks toward full containers in an efficient route via mobile application [203].

Figure 7. Smart waste bins [204][205]

[206] presented an application of autonomous sweeping vehicles that are designed to clean streets and public spaces. These compact-size smart sweepers are often equipped with odometer and high-precision positioning system (e.g., Global Navigation Satellite System (GNSS)) that enable control system to adjust time, position, speed, and attitude of the machine. These smart machines are currently employed in some more advanced campus and parks, in Beijing of China [207]. Table 9 lists the potential performance of related technologies in different research project:

Table 9. Some examples of using smart waste collection system (e.g., smart bins)

References	Smart solutions	Results

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[208]	Development of "pay-as-you-throw" system and "radio frequency identification (RFID) for waste collection	Reduce time required for waste collection by about 35%.
[202]	Smart bins equipped with solar power compactors	85% reduction for waste collection
[209]	Smart bins with fill-level sensors to optimized routs of trucks	80% less manpower, emission, fuel used for waste collection
[197]	Using neural network and robotic arm to separate waste, using driverless trucks	o Reduce unrecycled waste by about 20% o Reduce 30% of demand for land-fill capacity o 75% reduction of costs due to transition of materials
[210]	Installation of Smart bins (urban scale)	50% improvement in waste collection efficiency
[211]	Analyzing 17 interventions on increasing the level of awareness (Awareness campaign)	28% food waste reduction

Smart organic waste composter

The ultimate goal of smart organic waste composter is to monitor and control composting operations by automatically adding the precise amount of required water and air and reduce human interventions. Generally, the provision of small-scale composting plants in the neighbourhood effectively eliminate the gap between where the organic waste is generated and the place where it is processed to produce fertilizers [212]. This system reduces CO_2 emissions, cost, and energy that would have been consumed for collecting and transmitting organic waste. Respecting smartness and digitalization in this area, intelligent composting has been developed to monitor and control the moisture and temperature of the process which are the indispensable factors to obtain a high- quality products [196]. [213][196] introduced different types of sensors used in the intelligent composting machine to control air circulation and to measure moisture and temperature of the composting material in different nodes of piles and subsequently transfer data to the control system through wireless sensors network (WSN), in real time. The same procedure has been taken to build composting plants at different scales so that nowadays, there are even some small machines for households, buildings, and neighbourhoods [212][214]. Although these smart systems can make a great contribution to waste reduction and energy conservation, no quantitative result has been found regarding the benefits that be obtained from these smart solutions.

3.2.4. Smart solutions to the outdoor spaces

Smart solutions categorized in this domain are those that cannot be included either in any specific subjective domain (e.g., buildings, waste, etc.) or in building energy related uses.

Smart outdoor lights

The ultimate goal of smartening outdoor lights is to provide a safe and comfortable environment for residents in public shared areas, while reducing energy consumption and light pollution. Smart outdoor lighting fixtures employ special technologies such as cameras, optical sensor photocells, and other sensors to perform monitoring functions and intended tasks in real-time [215]. Smart outdoor lighting systems by providing adequate brightness at the appropriate time, not only foster a sense of satisfaction and safety among residents but also reduce the amount of energy consumption. The technology used behind smart outdoor lighting systems can be similar to the general smart lighting technologies such as motion detection, lighting, and dimming control; on a smarter level, the infrastructure of this system can also be used as the backbone of other activities such as monitoring of weather, air pollution, and traffic [216][217][218]. Table 10 demonstrates results obtained from previous related research project concerning the effect of using smart outdoor light on energy and cost reduction.

Table 10. Some examples of using Smart technologies in outdoor lighting systems

References	Smart solutions	Results
[216]	Not simultaneously turning on of all lampposts	6.7% cost reduction
[219]	Switching to the LED streetlights Adding smart remote management Connected street lighting system	○ 50% reduction in energy consumption ○ 21% reduction in street crime ○ 30% reduction in personal injury
[218]	Using LED and different lighting sensor consist on occupancy detection and adaptive illumination level	84.7% reduction in energy consumption
[217]	Using LED, adaptive control of illumination level, occupancy detection, and rain sensor	48% reduction in energy consumption
[220]	Using LED, control of illumination level, occupancy detection,	43% reduction in energy consumption
[221]	Using LED, control of illumination level, occupancy detection,	35 to 55% reduction in energy consumption
[222]	Examples of street light refurbishment (non- smart)	30 to 50% energy reduction

Smart parking system

The ultimate goal of smartening parking system is to provide real-time data about the availability of parking lots for different types of vehicles such as cars, EVs, and bicycles in the neighbourhood and surrounding areas to save time, and energy, and also stimulate the use of more efficient vehicles. [223] alleged that the smart parking system (SPS) is one of the fundamental elements of smart mobility, particularly in densely populated neighbourhoods and districts that suffer from a scarcity of parking spaces. SPS is a good solution to remediate traffic congestion, which also reduces air pollution and is concomitant health risks [224]. In this regard, [225] used a multi-agent system (MAS) to empower drivers to negotiate the parking fees with SPS based on predefined criteria. [226] employed IoT and RFID tags to develop a car parking framework to provide payment facilities, parking lot retrieval, and security. [227] used Global System for Mobile (GSM) to develop a system in which the driver can securely reserve a parking spot by a simple short message (SMS) through a layout animation of parking space occupancy status.[228] presented a visual vehicle parking space aimed at real-time occupancy detection via a deep convolutional neural network (CNN). These services may be proposed on different user interfaces such as smartphone applications, web applications, and vehicle information and communication (VICS). Figure 8 schematically depicts the architecture of smart parking systems in which all parking slots are monitored through sensors which are connected to a control system.

Figure 8. Smart parking systems [229]

Although these platforms are usually developed for the large-scale area, the facilities and technologies that the parking lots are equipped with can be analysed individually for a single parking area in a neighbourhood. Hence, [224] reviewed different types of services that can be proposed by SPS:

- Parking guidance and information system (PGIS): it proposes the real-time number of parking spaces, by using sensors at the entrance and exits of parking. In some cases, it can also guide drivers to the designated parking spot [230].

- Transit-based smart: In addition to the public transportation schedules, it presents real-time occupancy of parking lots and its arrival routes [231].

- E- parking system: A single platform that integrates different feathers of the smart parking facilities such as vehicle guidance to the nearest parking area, occupancy status of parking lots, different payment methods, lot retrieval announcements, and reservation facilities [229].

- Automated parking system (APS): A mechanical system that automatically moves the vehicle to the available space, without any human intervention [232].

- EV charging station: An allocation of some lots in the parking area to the EV charging stations. There are different specific applications through which EV owners can check the status of their car's charge and be notified when it gets completed [233].

Another sustainability concern in this field, that can be improved through digital solutions, is bike parking stations. [234] also mentioned that the availability of safe bike parking stations in the neighbourhood can encourage more people to choose bicycle commuting as a viable transportation option. Bike storage rack can be equipped with smart entrance so that enables access for users through different digital gadgets (e.g., mobile application, cards, RFID tags). [235] highlighted more advanced bike stations in which there is a possibility to charge e-bikes similar to the ones in EV parking lots.

Table 11. Some examples of using smart technologies in smart parking systems

References	Smart solutions	Results

[236][237]	Smart parking system	Reducing the need for parking slots by about 90%, reduction of CO_2 emission by about 50%, reduce mortality
[238]	Smart parking system	Reduce the time taken to find parking space by up to 43%, miles travelled 30%,
[239]	Smart parking system	4.5 to 18% increase in economic profits
[240]	Real-time parking information (University campus)	15% reduction in parking time
[241]	Adding pop-up bike lanes (a City in Germany)	48% increase in cycling

4. Conclusion

The research is intended to propose a collection of smart solutions and novel ideas that can be applied in a neighbourhood building stock for energy conservation purposes. To this end, numerous scientific articles, technical literature, and European projects pertaining to the application of smart approach and ICT technologies in different domains are collected and scrutinized. Since most guidelines presented in this context have focused on the smart homes or smart cities, boundaries of which are more clearly determined, the first contribution of this research can lie in presenting a complete set of smart solutions that are particularly applicable in neighbourhood building stock. The key difference between neighbourhood building stock from urban planning strategies and single home renovation is the set of activities that are more socioeconomically feasible on this scale. In this regard, clarifying a clear boundary among all smart solutions and selecting those that can be deployed in a neighbourhood building stock can play a crucial role in assessing its opportunities for intelligentization. This research also makes a great contribution in clarifying the direct and indirect impacts of smart solutions on reducing energy consumption.

In this research all smart solutions are investigated in two main sections of building and neighbourhood, furtherly classified under five domains, namely building energy-related uses, renewable energy sources, water, waste, and open space management, in total. The smart solutions collected in the building energy-related domain, are almost laid on SRI report [18]; however, comparing the levels of functionalities presented in the SRI report and collected smart solutions in the first domain illustrated that only the last two levels of each indicator can be considered smart. The literature review in this domain showed that one of the main obstacles that may prevent the realization of expected improvement is a lack of skill among building users to adapt their energy usage profile to an appropriate behavioural pattern. In the field of energy generation, there was a naively general overview that supplying sustainable energy from renewable energy sources can be interpreted as a smart solution at any level; while this research strived to make a clear distinction between sustainable and smart measures by summarizing the elements that should be deployed in the renewable energy grid to solve their major challenges. Moreover, in the fields of waste management and water distribution networks, which are inseparable subjects of all sustainability protocols, all smart solutions that should be applied at the neighbourhood scale and to be supported from higher levels of urban management were elaborated. Reviewing the potential impacts of smart solutions proved that, energy enhancement is not only limited to the intelligentization of buildings' component but also it can be achieved through other elements of the neighbourhood in direct and indirect way. For instance, due to the strong interrelationships among all these elements, increasing community awareness in different fields through the use of smart water meters, smart energy meters, smart parking systems, etc. can boost effective conservation of the energy and other resources.

Although potential missed articles and projects could have made additional contributions to this review, covering various indispensable aspects of the neighbourhood

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revealed the uneven distribution of workload in developing smart tools across different disciplines. This uneven distribution has resulted in certain areas, such as smartening water reclamation, smart composing plans, etc., being hardly investigated in this context. Besides, it is observed that most smart-oriented studies merely focus on the design and development of new tools and methods without examining their final effectiveness. Although this trend led to the rapid advancement of smart and digital tools, it can be an obstacle for the stakeholders who are seeking more observable outcomes for the investments.

With all these taken into account, having a comprehensive framework not only as a guideline but also to measure and compare the level of smartness and potential achievements in energy conservation can play a significant role in structuring the content of this field. For this purpose, this research highly recommends future studies focusing on developing a comprehensive reporting framework (similar to Level(s) that is specified for building sustainability [242]) with specific reference to the smart solutions for energy conservation in the neighbourhood building stock.

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