IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 21 May 2023, accepted 15 June 2023, date of publication 19 June 2023, date of current version 3 July 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3287641

TOPICAL REVIEW

A Systematic Review on Demand Response Role Toward Sustainable Energy in the Smart Grids-Adopted Buildings Sector

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This work was supported by Tenaga Nasional Berhad (TNB) and Universiti Tenaga Nasional (UNITEN) through the BOLD Refresh Publication Fund through the Centre of Excellence under Project J510050002-IC-6 BOLDREFRESH2025.

ABSTRACT In the so near future, climate change caused by Carbon dioxide (CO_2) emissions as a result of an increase in energy demand (ED) in the buildings sector becomes really hazard to our green environment. Both climate change and increase in ED are affected by each other. Such increase in ED would increase both climate change and global warming. Fortunately, there is, however, still plenty of time to address this issue. This increase might be significantly and effectively controlled. One of the effective solutions is to apply demand response (DR) strategies exploiting the smart grid (SG). Hence, SG contributes to help reduce both ED and CO_2 emissions. Of importance is establishing SGs-adopted buildings in which DR role could act as an operating and management system aiming to reach energy sustainability. We review researches on DR strategies and technologies applied to SGs-adopted buildings. Unlike previous literature reviews considering certain types of buildings or strategies which therefore narrow the focus of review papers, this review has analyzed numerous types of buildings and a variety of technologies to expand the review's scope. Concluded remarks, insights, challenges faced by researchers, and suggestions proposed by this review paper have been in detail discussed. Limitations, further gaps in future research on DR strategies, potential implications of DR in SG-adopted buildings have been also discussed. Towards sustainable energy in the buildings sector utilizing DR strategies, points of strength and weakness concluded from the reviewed articles have been highlighted and discussed to open trends that might potentially enhance future proposed DR strategies applied to SG-adopted buildings.

INDEX TERMS Buildings, demand response, renewable energy resources, smart grid, sustainable energy systems.

NOMENCLATURE

A. ABBREVIATIONS

AMI	Advanced metering infrastructure.
AHUs	Air-handling units.
ACL	Agent communication language.
AI	Artificial Intelligence.
API	Application program interface.
BCVTB	Building controls virtual test bed.
BEMS	Building energy management system.

The associate editor coordinating the review of this manuscript and approving it for publication was Yu-Huei Cheng.

CPLEX	An optimization software package developed by IBM used to solve the MILP problem.
DER	Distributed energy resources.
DR	Demand response.
DSM	Demand-side management.
ED	Energy demand.
EDR	Energy demand reduction.
ESS	Energy storage system.
EV	Electric vehicles.
GA	Genetic algorithm.
GAMS	The General Algebraic Modeling System.
GUI	Graphical User Interface.
IPOPT	Interior Point OPTimizer is a solver for NLP.
JDBC	Java Database Connectivity.
JSON	JavaScript Object Notation.
MILP toolbox	Mixed-Integer Linear Programming toolbox.
MINLP	Mixed-Integer Non-Linear Programming.
ML	Machine learning.
MPC	Model predictive control.
NARNET	Nonlinear Autoregressive Neural Network.
NARX	Nonlinear autoregressive exogenous model.
NLP	Nonlinear programming.
NN	Neural Network.
PAR	Peak to average ratio.
PCM	Phase change materials.
PCT	Programmable communicating thermostat.
PLS	public lighting systems.
PVs	Photovoltaics.
QP	Quadratic Programming.
RC networks	Resistance-Capacitance networks.
REG	Renewable energy generation.
RER	Renewable energy resources.
RES	Renewable energy sources.
RL	Reinforcement learning.
RMSE	Root mean square error.
RPi	Raspberry Pi.
RTP	Real-time price.
SQP	Sequential Quadratic Programming.
TCLs	Thermostatically Controlled Loads.
TCP standard	Transmission Control Protocol.
TES	Thermal Energy Storage.
TOU	Time-of-Use.
TRNSYS	Transient System Simulation Software.
T-Stat	Thermostat.
V2B	Vehicle to building.
V2V	Vehicle-to-vehicle.
VTS	Visual test shells.
WEKA	Waikato Environment for Knowledge Analysis; it is an open-source machine learning software.
XML	Extensible Markup Language.
XMPP	Extensible Messaging and Presence Protocol.

B. DEFINITIONS

BACnet	BACnet is a communication protocol for Building Automation and Control networks.
CasADi	A free and open-source symbolic framework for automatic differentiation and optimal control.
doGATE	An automation server optimized to doMOOV that is equipped with all necessary physical interfaces, which can also take over backup and remote-control functions related to rooms.
doMOOV	A building management software for building automation.
EnergyPlus	EnergyPlus™is a whole building energy simulation program that engineers, architects, and researchers use to model both energy-consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.
GridLAB-D	An open-source simulation and analysis tool that models emerging SG energy technologies.
Gurobi	The Gurobi optimizer is a commercial optimization solver for linear programming, quadratic programming, quadratically constrained programming, mixed integer linear programming, mixed-integer quadratic programming, and mixed-integer quadratically constrained programming.
IEEE 802.11	A part of the IEEE 802 set of local area network (LAN) protocols.
KNX	An open standard for commercial and domestic building automation used to manage lighting, HVAC and many other building's devices.
Laravel	A free, open-source PHP web framework, created by Taylor Otwell and intended for the development of web applications following the model–view–controller (MVC) architectural pattern and based on Symfony.
MATLAB	A proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks.
Modbus	A data communication protocol originally published by Modicon in 1979 for use with its programmable logic controllers.

MVC	Model–view–controller is a software design pattern commonly used for developing user interfaces that divides the related program logic into three interconnected elements.
OpenDSS	Open-source software Distribution System Simulator.
PHP	A general-purpose scripting language especially suited to web development.
RESTful	Representational state transfer is a de-facto standard for a software architecture for interactive applications that typically use multiple Web services.
SimApi	A cloud infrastructure used to allow such a system to remotely control the simulation of a building.
TRIANA	TRIANA three step method. "TRIANA is a control methodology capable of monitoring and adjusting the energy profiles and electricity streams.

I. INTRODUCTION

A. WHY IS DEMAND RESPONSE (DR) IMPORTANT FOR ENERGY MANAGEMENT IN THE SMART GRID (SG)?

Energy management is an issue paid attention particularly in the setting of the shift to smart grids (SG) [1], [2], [3], [4]. Demand response (DR) is one of the key solutions followed in SG [5], [6] due to the operations of effective management performed by DR to several sources such as renewable energy resources (RERs) and energy storage systems (ESSs) that can make real SG's development [7]. DR is considered as an energy saver [8] and electricity bill reductor [9], [10]. From the economic point of view, it is considered as an acceptable solution that leads to reduce costs of projects that require expansion capacity particularly in SG environment [11]. Besides, it is mentioned by [12] that DR can effectively help enhance environmental conditions towards maximizing the use of RERs and minimizing energy demand (ED) aiming to reach a connected buildings level or even a district level. At this level, buildings can act as active participants in SG [13]. DR strategies are of importance means and approaches in accommodation of renewable energy sources (RES) towards a clean and effective SG-including environment [14].

Several issues can be caused by the weakness of DR towards SGs or even the unavailability of DR-related strategies applied. High energy-consumption, high energy supply during peak hours, shortage of supply of energy for periods of time, and the need for capacity expansion projects for constructing energy generation and distribution units are examples of the issues and problems that can be caused in case DR is not considered. Contrarily, DR can help solve several problems, the above-mentioned drawbacks are inclusive, and also can efficiently improve SG environment as well as contribute to smart buildings and Energy Internet of Things (EIoT) [15], [16], [17].

One of the important aspects that has been discussed in a number of studies is that there is a need to design an efficient and sufficient automated DR scheme for energy management applied to residential and office buildings specifically when there are numerous demand occurrences that cause an imbalance of supply during peak demand [18]. Demand occurrences will obviously affect the utility in terms of load curve. Hence, it is very necessary to manage these considerations in buildings to serve better constitute SG infrastructure. In this circumstance, an automatic DR-based energy management scheme will contribute to enable occupants to shift the demand to off-peak hours by saving their unnecessary loads. Therefore, this will help the utility provide better management and can balance between demand and supply during peak times [19]. One of the solutions proposed is that the fast DR will produce an immediate and instant response to the request made by SG towards Energy demand reduction (EDR) [20].

Integration between energy generators and buildings' consumers can be efficiently built through a successful and optimal DR system taking into account the communication system for data exchange [21]. The connected systems in a network can benefit to the DR scenario by providing a balancing ability of energy flexibility specifically during peak periods in SG [22].

One of the important factors that can enhance the performance of DR towards a SG is the energy storage [23], [24] and that performance has a highly successful rate once RER has been effectively utilized [25]. One of the strategies applied to improve energy storage is by implementing an optimization algorithm between temperature and operations of charge and discharge related to the battery used [26]. When the temperature either outside or the indoor one is being reduced, there will be an opportunity for extra charging of battery operation in the hot zones. There will be a reduced level of energy demand (ED) from the utility. This can also be enhanced by utilizing the building envelope so that more periods of battery storage operations can be obtained. Thus, the better the building envelope, the less ED. Therefore, SG is being enhanced due to this factor [27].

In addition, distributed energy resources (DER) behave better than centralized energy generators and can help shape future ED to enhance supply performance [28]. DER also can promote further benefits to the environmental and economic sectors [29]. Enhancement of infrastructure of SG and networks is likely getting more opportunities of achievability once centralized energy generators have been replaced by DER [28].

B. INTEGRATION OF DR STRATEGIES WITH BUILDING AUTOMATION AND ENERGY MANAGEMENT SYSTEMS

In this review, identified DR strategies can be integrated with existing building automation systems or energy management systems to improve energy efficiency and support sustainable energy in the SG-adopted buildings sector [30], [31], [32].

This integration can be carried out thru the following procedures:

- Price-based DR: This strategy involves adjusting energy consumption in response to changes in electricity prices. Price signals can be received through advanced metering infrastructure (AMI) and integrated with building automation systems or energy management systems to automate energy usage based on price signals. For example, during peak hours when energy prices are high, non-critical building systems can be turned off to reduce energy consumption.
- Load shedding: Load shedding involves reducing energy consumption during peak periods to prevent SG instability. This strategy can be implemented through building automation systems or energy management systems that can automatically adjust energy usage during high demand periods. For example, lighting and HVAC systems can be turned off or reduced during peak hours to reduce energy consumption.
- Demand bidding: Demand bidding involves bidding for energy usage during peak periods. Building automation systems or energy management systems can be integrated with demand bidding platforms to automatically adjust energy usage based on bidding prices. For example, a building operator can bid to reduce energy consumption during peak hours in exchange for a financial incentive.
- Interruptible load programs: Interruptible load programs involve temporarily interrupting non-critical building systems during peak periods. Building automation systems or energy management systems can be integrated with interruptible load programs to automatically adjust energy usage during high demand periods. For example, non-critical lighting and HVAC systems can be turned off for short periods of time to reduce energy consumption.

C. SG

SG is an environment in which DR plays a very key role contributing to energy management towards sustainable energy applied to various types of buildings in which SG would be greener [33], loads could be controlled, more energy generation sources could be penetrated and utilized specifically RERs and ESSs [7]. It is said that DR is important for any SG to completely integrate between all SG infrastructure's elements [21], [34]. Energy grids and electricity networks should be regularly upgraded to handle the ED increase [35]. With these upgrading needs in grid infrastructure, there must be an obvious low-energy built grid day-after-day and enhanced grid's performance in terms of operations and management [36]. For these purposes, there is a need to exploit advanced technologies towards to achieve a green environment [36]. One of the key means followed to enhance grid operations is the energy reduction requests in buildings as a DR strategy applied within SG environment [5]. Besides, SG enhances the energy storage for a large-scale. This can be implemented by utilizing both RERs and energy storage best technologies [37]. Subsequently, this would enhance and contribute to the energy storage issue [37]. Effective and efficient utilizing SG should perform better for several buildings' purposes, for example, cooling, and therefore related operations, for example, ED, could be reduced accordingly. Thus, opportunities for creating sustainability would be of increase [38]. The creative SG can contribute to recurrent RERs by providing inclusive operations and solutions to help either reduce and/ or shift ED [39].

When talking about a huge SG that considers a huge number of smart buildings (i.e., units and appliances), there is a highly required integration level amongst these connected units involved in SG. Then, SG requires the availability of an integration infrastructure with smart buildings to achieve a "smartness" level [40]. At this level, operations performed by smart buildings need to be included in the way to save energy and reduce energy-consumption not on the level of individual buildings but also on the level of a larger collection of connected buildings e.g., campuses and cities. This integration is aimed to be enabled thru a regional domain that considers RERs. To enhance this integration, data exchange and controlled systems thru networks could contribute in this direction bringing other enhanced and smart services such as monitoring functions, predicting data, information about energy prices, and production and generation of renewable energy perform well. Information exchange and communication services between, for example, smart buildings and the grid are performed thru DR [41], [42].

1) SG IMPACT ON DR

DR enhancement is mainly dependent on SG's development level. DR relates to the outcomes obtained from energy-use variations by, for example, buildings' occupants from their normal consumption patterns. One of the supportive tools helping reduce energy-use is the use of smart home appliances to significantly interact with and respond well to ED. Smart home appliances are very required with a SG system [43]. DR has been one of the smart tasks associated with SG due to several factors. One of these factors is the emergence of deregulated markets and dynamic pricing schemes [44]. Utilizing new technologies related to energy systems e.g., photovoltaics (PVs), EV, smart meters and few others is likely of importance to enhance DR performance once the grids have initialized a suitable environment [45].

D. SG CONNECTION WITH SMART ENERGY COMPONENTS

In this sub-section, SG diagram connection with smart energy components is graphically shown in Figure 1. This is followed by a discussion related to the working and connection of every component.

In this diagram (Figure 1), SG is an advanced electrical power system that uses digital communications technology to manage and monitor energy flow between energy generators, energy consumers, and the electric grid. SG can allow for real-time monitoring and control of the electrical grid, which enables greater energy efficiency and reliability.

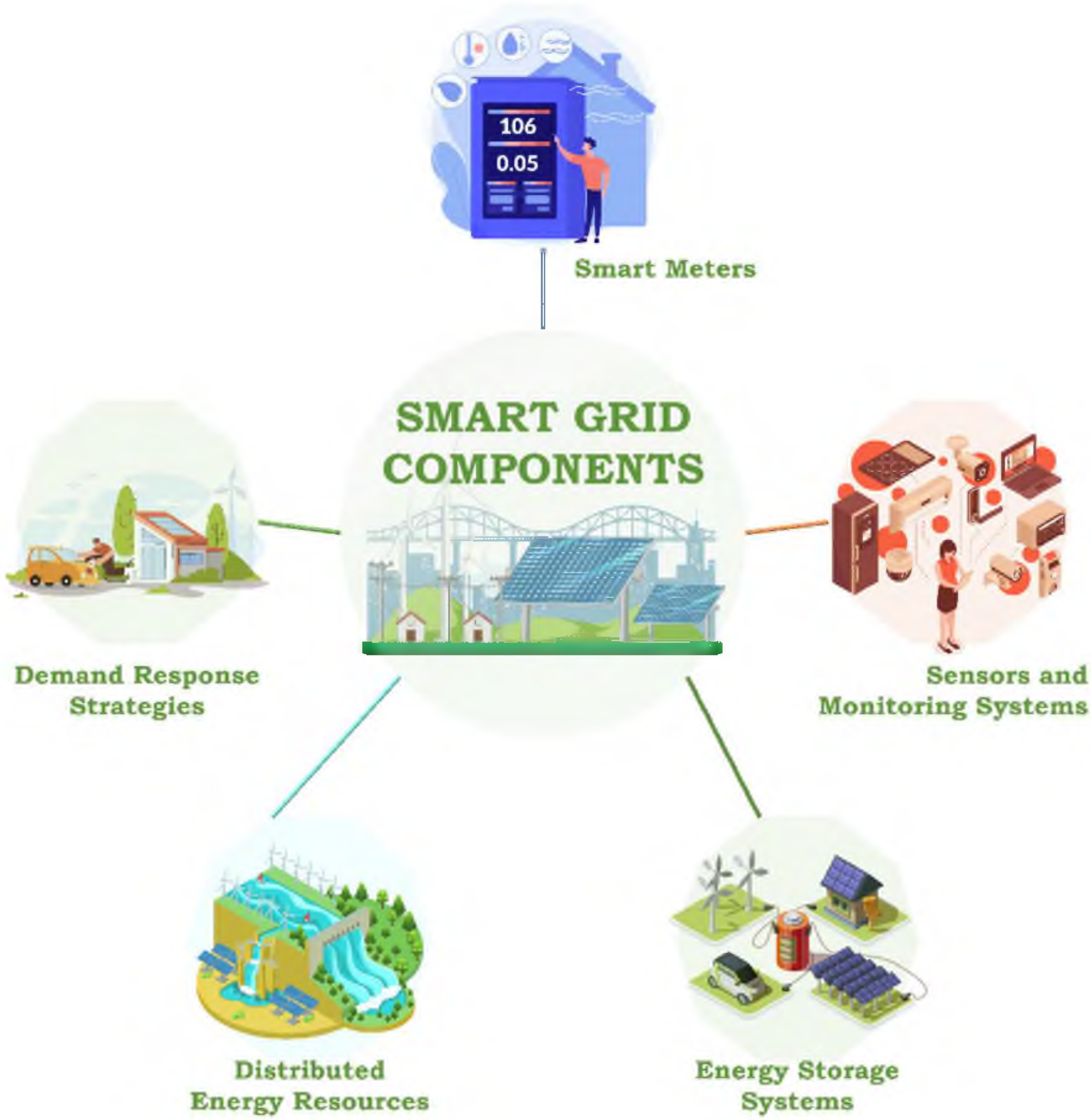

FIGURE 1. SG connection with smart energy components - A graphical representation. Images are licensed. Design is made by authors.

In Figure 1, SG consists of a number of components, including:

- Smart Meters: These are digital meters that are installed at buildings to measure energy use and send data back to the utility company in real-time.
- Sensors and Monitoring Systems: These devices are placed throughout the electrical grid to monitor energy flow, identify outages, and detect other issues.
- Energy Storage Systems (ESSs): These systems are used to store excess energy generated by RES like wind and solar power. They can be used to provide backup energy during outages or peak periods.
- Distributed Energy Resources (DERs): DERs include RES like solar panels and wind turbines, as well as ESSs and other devices that generate or store energy.
- Demand Response (DR) Strategies: They allow utilities to adjust energy use in response to changes in demand. For example, during peak periods, the utility may send a signal to smart appliances and other devices to reduce their energy use temporarily.

SG is designed to be more efficient, reliable, and sustainable than traditional electrical grids. By integrating digital communications technology and advanced energy systems, smart energy components could be produced and thus SG should have the potential to transform the way we produce, distribute, and consume energy [46], [47], [48].

E. A LIST OF EXISTING INDUSTRY PROJECTS RELATED TO DR PROGRAMS

This list is a comprehensive compilation of ongoing projects in various industries that are specifically focused on DR programs. DR programs involve actively managing energy consumption during peak demand periods, with the aim of balancing energy supply and demand, reducing strain on the grid, and promoting energy efficiency.

This list provides insights into the wide range of DR initiatives implemented by industries across different sectors. It offers valuable information about real-world projects that demonstrate the practical application and benefits of DR programs. The list encompasses projects from diverse industries such as manufacturing, commercial buildings, residential communities, and more, highlighting the widespread adoption and significance of DR in today's energy landscape.

1) PACIFIC GAS AND ELECTRIC's SmartAC PROGRAM

This project aims to reduce peak energy demand by remotely controlling air conditioning units during high-demand periods. Pacific Gas and Electric's SmartAC Program is an initiative that was launched by Pacific Gas and Electric Company (PG&E), a major utility company based in California, United States. The program was designed to address the challenges posed by peak energy demand and improve energy efficiency.

The SmartAC Program by PG&E is a DR solution that manages energy usage during high-demand periods, especially in hot summer months when air conditioning units consume substantial power. Through advanced technology and smart thermostats, the program remotely controls and optimizes AC unit operation. It was introduced in the early 2000s as a response to the need for balancing energy supply and demand, particularly during peak periods. PG&E aimed to reduce energy demand without compromising customer comfort amidst increasing AC adoption and grid strain.

In 2008, PG&E launched the SmartAC Initiative as a pilot program to test the use of smart thermostats in managing air conditioning loads. The successful pilot led to the expansion and official launch of the SmartAC Program. Participants received free smart thermostats and allowed remote control of their units during peak demand events. The program provided benefits to both PG&E and customers by reducing energy consumption, saving on energy bills, and promoting grid reliability and sustainability. PG&E has since enhanced and expanded the program, offering personalized insights, remote control options, and improved coordination with grid operators. For further details regarding this project, it can be found here.[1]

2) ENEL X's DEMAND RESPONSE PROGRAMS

Enel X offers various DR programs globally, including initiatives in the United States, Europe, and Australia. These DR programs enable customers to reduce energy consumption during peak periods and receive incentives in return.[2]

Enel X's Demand Response Programs promote energy efficiency and grid reliability by engaging consumers and businesses in managing energy consumption during peak demand periods. These programs reduce strain on the grid and optimize energy usage. Over time, Enel X has expanded its portfolio, offering tailored programs and incentives for adjusting usage patterns. Leveraging advanced technologies, participants can remotely control and monitor energy consumption, ensuring real-time responsiveness and customer satisfaction.

3) NEW YORK INDEPENDENT SYSTEM OPERATOR's (NYISO) DEMAND RESPONSE PROGRAMS

NYISO has several DR programs, such as the Day-Ahead DR Program and the Emergency DR Program, which engage consumers in reducing energy usage during critical periods.[3]

NYISO's DR Programs were established to ensure grid reliability in New York by engaging consumers and businesses in reducing energy usage during critical periods. These programs incentivize participants to adjust consumption and have expanded over time to include tailored initiatives for different customer segments. By collaborating with participants, NYISO promotes grid stability, cost savings, and efficient energy usage in the state.

4) NEST THERMOSTAT's RUSH HOUR REWARDS

Nest, a subsidiary of Google, has a DR program called Rush Hour Rewards. It allows homeowners with Nest thermostats to receive incentives for adjusting their thermostat settings during peak energy demand hours.[4]

Nest Thermostat's Rush Hour Rewards is a program that originated with Nest, a subsidiary of Google, to encourage energy conservation during peak demand periods. The program was developed as an innovative solution to reduce strain on the energy grid and promote energy efficiency.

The history of Nest Thermostat's Rush Hour Rewards dates back to the introduction of the Nest Learning Thermostat in 2011. The program incentivizes users to adjust their thermostat settings during peak energy demand by offering financial incentives or credits. By making minor adjustments to temperature and activating energy-saving features, participants contribute to energy conservation and grid stability. The Rush Hour Rewards program has been successful in promoting sustainability and empowering users to play an active role in managing energy consumption.

5) SOUTHERN CALIFORNIA EDISON's DEMAND RESPONSE PROGRAMS

Southern California Edison offers various DR programs, such as the Summer Discount Plan and the Critical Peak Pricing

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[1] https://www.pge.com/en_US/residential/save-energy-money/savings-solutions-and-rebates/smart-ac/smart-ac.page?WT.mc_id= Vanity_smartac

[2] https://www.enelx.com/n-a/en/businesses/distributed-energy/demand-response

[3] https://www.nyiso.com/demand-response

[4] https://farmerselectric.coop/google-nest-rush-hour-rewards/ or https://support.google.com/googlenest/answer/9244031?hl=en&co=GENIE.Platform%3DAndroid

Program, to encourage customers to reduce energy consumption during peak times.[5]

Southern California Edison's DR Programs have a history that dates back to the early recognition of the need to address peak energy demand in the region. As a major utility company serving Southern California, Southern California Edison has implemented these programs to engage customers in actively managing their energy usage during high-demand periods.

Southern California Edison's DR Programs have evolved since the early 2000s with initiatives like the Summer Discount Plan and Critical Peak Pricing Program. The Summer Discount Plan offers discounts or credits to customers who voluntarily reduce energy consumption during specific times, while the Critical Peak Pricing Program encourages usage reduction or shifting through time-sensitive pricing. Over time, these programs have improved grid reliability, empowered customers to conserve energy, and reduced energy bills. Through ongoing innovation and customer participation, Southern California Edison's DR Programs contribute to a more efficient and sustainable energy future in the region.

6) ONTARIO's INDUSTRIAL CONSERVATION INITIATIVE (ICI)

ICI is a DR program in Ontario, Canada, that provides incentives for large industrial consumers to reduce their energy usage during peak periods.[6]

Ontario's Industrial Conservation Initiative (ICI) was created to encourage energy conservation and decrease peak energy demand among large industrial consumers. The program was established to address the growing importance of grid reliability and sustainability in the province.

Ontario's Industrial Conservation Initiative (ICI) was introduced in 2011 to incentivize large industrial consumers to actively manage and reduce energy usage during peak periods, easing strain on the grid and fostering energy efficiency. Over time, the ICI program has adapted to evolving energy demands, refining eligibility criteria, incentives, and measurement approaches to align with the province's energy objectives. It has successfully promoted energy conservation among industrial consumers, advancing Ontario's sustainable energy future.

7) UK POWER NETWORKS' FLEXIBLE POWER

Flexible Power is a DR platform in the UK that enables businesses to offer flexibility in their energy usage, helping to balance the SG and reduce peak demand.[7]

UK Power Networks' Flexible Power program was launched in 2016 to leverage flexible energy resources and meet changing customer needs. It enables the participation of distributed energy resources in grid services, fostering innovation and empowering customers. The program enhances grid reliability, integrates renewables, and advances the UK's sustainable energy future.

F. RENEWABLE ENERGY RESOURCES (RER)

DR contributes to several SGs-associated units such as RERs [49], [50]. DR and load control strategies are used to support the integration of RERs and SG [21]. Besides, DR is considered a high potential facilitator of RERs dedicated to SGs as well as energy markets [51].

DR solutions along together with RESs can contribute much to enhancing energy supply in terms of fluctuations occurrences [52] and ED's requirements meeting [53]. Thus, DR can affect SG performance in case the demand-side is not effectively managed.

In addition, renewable energy technologies are used to face urban climate change [54]. The fact the increased demand for energy for cooling purposes in, for example, hot areas, is a big hazard to our environment. The increased demand for energy has affected global warming and increased CO_2 emissions. Thus, attempts to propose techniques and apply strategies aiming towards zero-carbon technologies to find an optimal solution that accommodates future increased ED for cooling purposes are growing. Therefore, less demand(s) from the demand-side will lower supply-side requests to buildings and SG to reduce energy-consumption, so that DR will be enhanced. At this point, DR interaction with SG-adopted buildings utilizing RERs for supply will reduce the pressure on generation units to supply additional energy and therefore less CO_2 emissions will be achieved [55]. This is one factor towards global warming solutions when using RERs as an alternative or a supportive source for SG infrastructure. Another factor is that, DR is being interactively enhanced specifically when, for example, PVs are utilized by SG-adopted buildings.

G. POTENTIAL NEGATIVE ENVIRONMENTAL OR SOCIAL IMPACTS OF SG AND HOW THEY COULD BE ADDRESSED

1) SGs' POTENTIAL NEGATIVE ENVIRONMENTAL AND SOCIAL IMPACTS

While SGs have the potential to reduce ED and CO_2 emissions, there are also potential negative environmental and social impacts associated with their implementation. Some potential negative impacts of SGs can be listed as follows:

Electronic waste increment: SGs deployment can lead to an increase in electronic waste due to the replacement of existing meters and infrastructure. The disposal of electronic waste can have significant environmental and health impacts.

Energy consumption increment: While SGs can help reduce ED, the increased use of electronic devices and communication networks required for SGs could increase energy consumption.

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[5] https://www.sce.com/residential/demand-response

[6] https://news.ontario.ca/en/backgrounder/41819/ontarios-industrial-conservation-initiative-ici or https://www.hydroone.com/business-services/commercial-industrial-generators-and-ldcs/commercial-industrial-customers/industrial-conservation-initiative

[7] https://www.ukpowernetworks.co.uk/electricity/distribution-energy-resources/flexible-connections

Cybersecurity risks: The use of digital technology in SGs increases the risk of cybersecurity breaches, which could have significant social and economic impacts on a number of related devices to SG such as electric vehicles (EV) [56], [57].

Privacy concerns: SGs may collect and transmit sensitive information about energy consumption and user behavior, which could raise privacy concerns [58], [59], [60], [61], [62].

Cost implications: SGs implementation can be expensive, and the costs may be passed on to consumers, which could have social and economic impacts.

2) HOW TO ADDRESS SGs' NEGATIVE ENVIRONMENTAL AND SOCIAL IMPACTS?

To address such potential negative impacts, it is considerable to have the following measures:

The first one is to implement responsible e-waste management practices to minimize the environmental and health impacts of electronic waste.

The second one is to ensure that energy efficiency measures are in place to offset any potential increase in energy consumption resulting from the deployment of SGs.

The third measure is to implement a strong cybersecurity scheme to protect against potential cyber-attacks and ensure occupants' privacy.

The fourth one can be done by establishing clear guidelines and policies to address privacy concerns related to SG.

The last one is to ensure that SG implementation is cost-effective and benefits all occupants.

H. THIRTY DR DEFINITIONS DERIVED FROM 201 REVIEWED ARTICLES

From the reviewed articles, definitions and features related to DR have been derived and listed in Table 1.

I. QUALITY AND RELIABILITY ASSESSMENT RELATED TO THE STUDIES

The quality and reliability of the studies included in this systematic review have been assessed by applying the following criteria:

- Inclusion and exclusion criteria have been set and defined before the collection procedure has been applied for this systematic review to make sure that the quality and reliability are met. Besides, the criteria have included papers published within the period between 2008 and 2020 only written in English focusing on DR in SG-adopted buildings, papers published in peer-reviewed journals with a percentage exceeds 50% of the total reviewed papers.
- Specific digital libraries have been chosen in this systematic literature review including IEEE Xplore, ScienceDirect, and Taylor & Francis.
- Very certain databases have been considered by which the journals are indexed. This procedure has only identified two databases which are Web of Science and Scopus.
- A comprehensive search conduction has performed a comprehensive search of the identified databases using appropriate keywords and search terms to identify all the studies that meet the suggested inclusion criteria.
- A screen procedure for papers' inclusion has been applied to verify papers' titles, abstracts, and full texts in order to determine whether a paper can be able for potential inclusion.
- The selected paper's quality's assessment has been evaluated in terms of suitability of the obtained results according to this paper's title and keyword.
- Findings' synthesis process has been done after assessing the quality and reliability of the studies. Findings have been synthesized in order to draw conclusions about DR role in the SGs-adopted buildings sector towards achieving sustainable energy.

J. MOTIVATION AND OBJECTIVES

1) MOTIVATION

The motivation of this review is to provide a comprehensive overview of the current state of research on DR in the context of SG-adopted buildings.

DR could refer to the practice of adjusting energy use in response to changes in electricity prices or grid conditions. SG-adopted buildings are equipped with advanced energy management systems allowing for more energy-efficient use.

2) OBJECTIVES

This article aims to address the increasing interest in DR as a potential solution to the challenges facing the energy sector, including the need for sustainable energy sources and the integration of intermittent RES into SG. It seeks to explore the role that DR can play in achieving sustainable energy goals in the context of SG-adopted buildings.

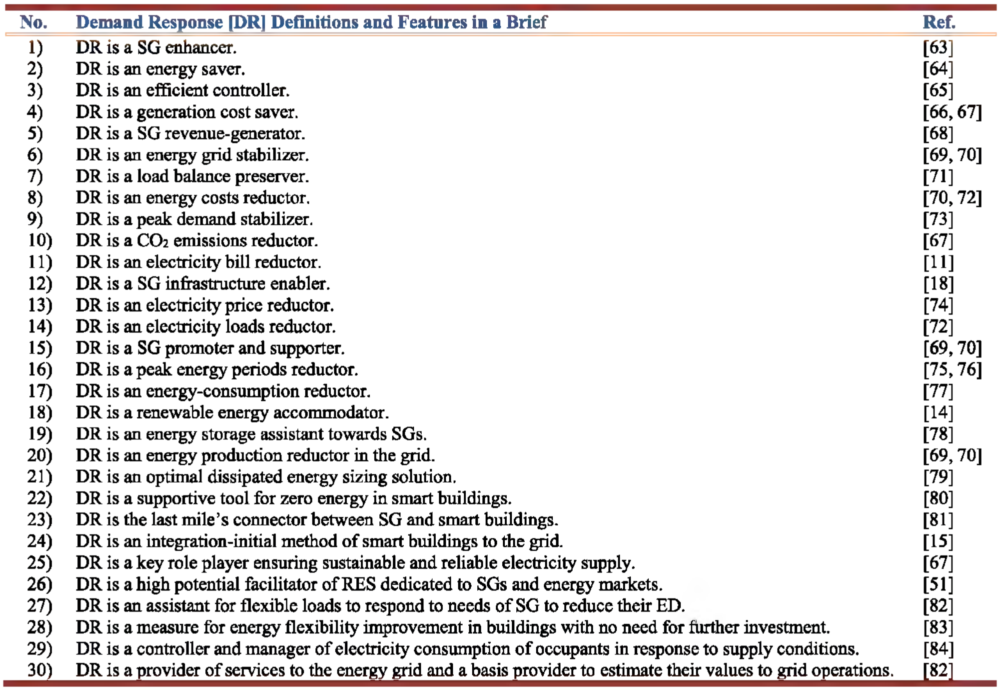
This systematic review aims to identify the existing literature on DR in SG-adopted buildings, synthesize the findings, and identify research gaps and areas for further investigation. The paper's ultimate goal is to contribute to a better understanding of the potential of DR to promote sustainable energy in the SG-adopted buildings sector.

K. CONTRIBUTIONS

In this section, listed are a number of contributions of this review article:

1. A comprehensive overview: This review article has provided a comprehensive overview of the current state of research on DR in SG-adopted buildings. It has also analyzed existing literature to identify the potential of DR to promote sustainable energy in the SG-adopted buildings sector.
2. An identification of research gaps: It has identified research gaps in the existing literature, highlighting areas where further research is needed. This can help guide future research efforts and inform policy decisions related to sustainable energy and DR in SG-adopted buildings.
3. Implications for practice: Its findings have implications for practice, as they can inform the design and implementation of DR programs and policies in the

TABLE 1. Thirty definitions for DR.



No.	Demand Response [DR] Definitions and Features in a Brief	Ref.
1)	DR is a SG enhancer.	[63]
2)	DR is an energy saver.	[64]
3)	DR is an efficient controller.	[65]
4)	DR is a generation cost saver.	[66, 67]
5)	DR is a SG revenue-generator.	[68]
6)	DR is an energy grid stabilizer.	[69, 70]
7)	DR is a load balance preserver.	[71]
8)	DR is an energy costs reductor.	[70, 72]
9)	DR is a peak demand stabilizer.	[73]
10)	DR is a CO_2 emissions reductor.	[67]
11)	DR is an electricity bill reductor.	[11]
12)	DR is a SG infrastructure enabler.	[18]
13)	DR is an electricity price reductor.	[74]
14)	DR is an electricity loads reductor.	[72]
15)	DR is a SG promoter and supporter.	[69, 70]
16)	DR is a peak energy periods reductor.	[75, 76]
17)	DR is an energy-consumption reductor.	[77]
18)	DR is a renewable energy accommodator.	[14]
19)	DR is an energy storage assistant towards SGs.	[78]
20)	DR is an energy production reductor in the grid.	[69, 70]
21)	DR is an optimal dissipated energy sizing solution.	[79]
22)	DR is a supportive tool for zero energy in smart buildings.	[80]
23)	DR is the last mile's connector between SG and smart buildings.	[81]
24)	DR is an integration-initial method of smart buildings to the grid.	[15]
25)	DR is a key role player ensuring sustainable and reliable electricity supply.	[67]
26)	DR is a high potential facilitator of RES dedicated to SGs and energy markets.	[51]
27)	DR is an assistant for flexible loads to respond to needs of SG to reduce their ED.	[82]
28)	DR is a measure for energy flexibility improvement in buildings with no need for further investment.	[83]
29)	DR is a controller and manager of electricity consumption of occupants in response to supply conditions.	[84]
30)	DR is a provider of services to the energy grid and a basis provider to estimate their values to grid operations.	[82]

SG-adopted buildings sector. This article has highlighted best practices and challenges associated with implementing DR programs and identified potential solutions.

4. Contribution to knowledge: It has contributed to the knowledge base on sustainable energy and DR in SG-adopted buildings, providing insights that can inform future research and policy decisions.

L. ARTICLE's ORGANIZATION

This review is organized as follows: In Section II, the reason why DR is needed is mentioned in a graphical and mathematical representation way. In section III, how this review research has been designed is explained. Section IV, the method applied to extract reviewed papers is in-detail explained according to PRISMA 2020. Section V reviews relevant literature in a brief. Results reported in reviewed papers are discussed in Section VI. Statistics-based analysis is in detail will be discussed in Section VII. In Section VIII, Research Questions-based analysis and evaluation will be provided. Finally, concluded remarks, insights, summary, challenges, our suggestions, future directions, limitations, further gaps in future research on DR strategies, potential implications of DR in SG-adopted buildings are presented in Section IX.

II. WHEN AND WHY DO WE NEED LESS DR?

A. OVERVIEW

When automation of a building is effectively performed, energy-consumption will be less, energy-savings will be increasingly achieved, and the most important feature is that DR will be decreased [85]. Thus, the automation and control operation applied to a building will efficiently contribute to achieve a high level of smartness conception to the related building. Therefore, the more smartness the building has, the less ED from the building will be. Besides, the less ED is the less demand from the grid is. Finally, the less SG's demand is, the less DR is. This is the most important feature of smart building(s) and SG.

B. WHEN DOES DR IDEALLY STOP?

DR could stop and mathematically equals to zero when the demand of the generation unit has stopped and mathematically equals to zero.

C. WHEN AND WHY DOES THE DEMAND FROM THE GENERATION UNIT OCCUR?

Simply, it occurs when: 1) a lot of ED(s) made by buildings occur, 2) buildings' demands mathematically are greater than maximum energy supply. At this time, the generation unit will send demand(s) to buildings asking to reduce their initial ED(s) by reducing energy-consumption.

DR at these periods will be necessary as a responsive building will contribute to the generation unit's demand by responding and that DR will be represented by less energy-consumption, energy share, and ED. These DRs made by many buildings will let the generation not supply additional energy; and therefore, this is the main purpose generation unit aims to achieve. A graphical representation of demand and supply curve and role of DR in enhancing that curve utilizing SG is shown in Figure 2.

As shown in Figure 2, there are three scenarios of demand made by buildings (highlighted in Figure 2 (a), (b), and (c)),

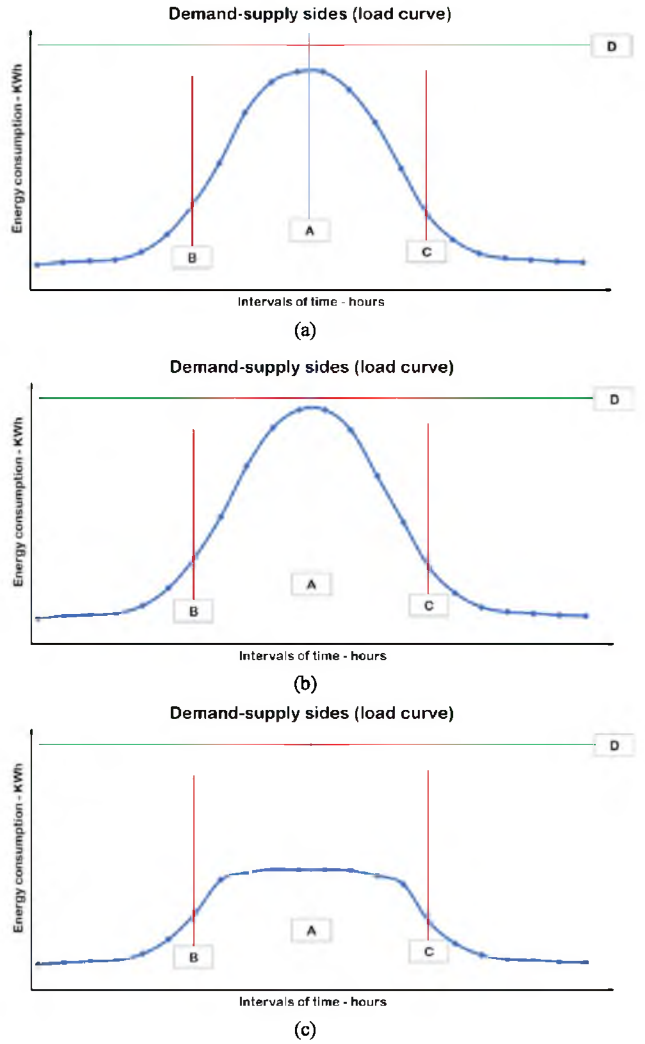


FIGURE 2. **DR role in energy demand reduction (EDR). Figure 2 contains four labels mentioned in alphabetic letters namely A, B, C, and D. Labels 'A', 'B', and 'C' are exactly intersections of those labels with the curve (in a blue-colored font) and the label 'D' is the intersection of line 'D' with y-axis. The label 'A' points out the highest value of energy-consumption located on the load curve, the label 'B' points out the first interval-of-time on x-axis at which its corresponding y-axis's value will be increased in terms of energy-consumption, the label 'C' points out the second interval-of-time on x-axis at which its corresponding y-axis's value will be reduced in terms of energy-consumption, and the label 'D' points out the maximum limit of energy supply, denoted by $\mathbf{ML_{ES}}$. The distance between labels B and C is the period during which the load curve of energy supply is at its highest values in terms of energy-consumption (on y-axis) and that is marked by a red-colored sign shown on the label D. The green-colored mark on the 'D' label indicates that energy-consumption is being reduced and has low values on the load curve. The distance between $\mathbf{ML_{ES}}$ and peak of load curve has reverse proportional relationships with both load curve and energy-consumption.**

respectively. In the first scenario, the demand is increasingly growing and the supply-side is supplying energy to meet the needs of buildings with energy-consumption as shown in Figure 2 (a). In the second scenario, energy is highly consumed by demand-sides caused by the huge demand (as a result of energy-consumption) as that appears in the increment of load curve at the label 'A', where energy demanded (load curve) almost reaches or approximately equals to ML_{ES}. Also, within the second scenario, the load curve starts to tend to go from peak to valley (as can be seen in Figure 2 (b) between labels 'A' and 'C'). In the third scenario, the load curve at label 'A', as shown in Figure 2 (c), has been obviously reduced from its previous peak (during the second scenario shown in Figure 2 (b)) to a lower value compared to its values in Figure 2 (a) and (b). The reason this lowering value occurs is that, the generation unit (supply-side) has sent a message asking (i.e., demanding) the building (demand-side) to reduce energy-consumption rate and therefore the building has replied to that message (a response) with agreement. That is, in the first two scenarios there is no DR scheme or strategy applied yet but in the third scenario.

D. AN INTERACTIVE SCENARIO BETWEEN A BUILDING DEMAND AND GENERATION DEMAND

The conversation between a building and the generation unit (demand- and supply-sides) will create the conception of DR applied for SG-adopted buildings. This conversation is graphically and interactively shown in a simple scenario as shown in Figure 3.

As shown in Figure 3, there are three scenarios each of which is labeled by an Arabic number marked in a circle. Each number-labeled scenario corresponds to only one of those three scenarios highlighted in Figure 2. The three scenarios in Figure 3 represent scenarios shown in Figure 2(a), (b), and (c), respectively. These three scenarios summarize the way both a building and the grid interact. In the first scenario, the building, denoted by "B1", performs ED and the generation utility supplies to B1. In the second scenario, this situation (i.e., ED by B1) will be remaining and therefore energy-consumption will be active and load curve will increase and thus the supply will be increased as a result. This might be continuously and gradually increased until the peak value related to load curve equals to ML_{ES}. This situation should be handled because if the ED made by B1 is continuously in an unlimited interval of times, the generation unit might fail to effectively supply. Thus, the solution proposed for this issue is to ask B1 to reduce ED and consumption. in the third scenario, B1 will respond to the demand and made an answer to the grid's request. Then, B1 starts to perform an ED within a DR circumstance. DR aims to help the building perform the ED optimally.

In the first scenario the building (i.e., B1) is performing ED without utilizing a DR strategy nor thru SG; therefore, B1 can be considered as a non-SG-adopted building. But, in the second and third scenarios, B1 has utilized DR and has been involved in SG environment.

With connecting scenarios in Figure 3 with their corresponding ones in Figure 2, the following can be noticeable. Firstly, the first conversation illustrated in Figure 3, labeled by 1, represents the action of ED made by building B1, and since there is no DR strategy or scheme applied yet, the generation unit will supply without such a limitation or a criterion. This is represented in a graphical mathematical

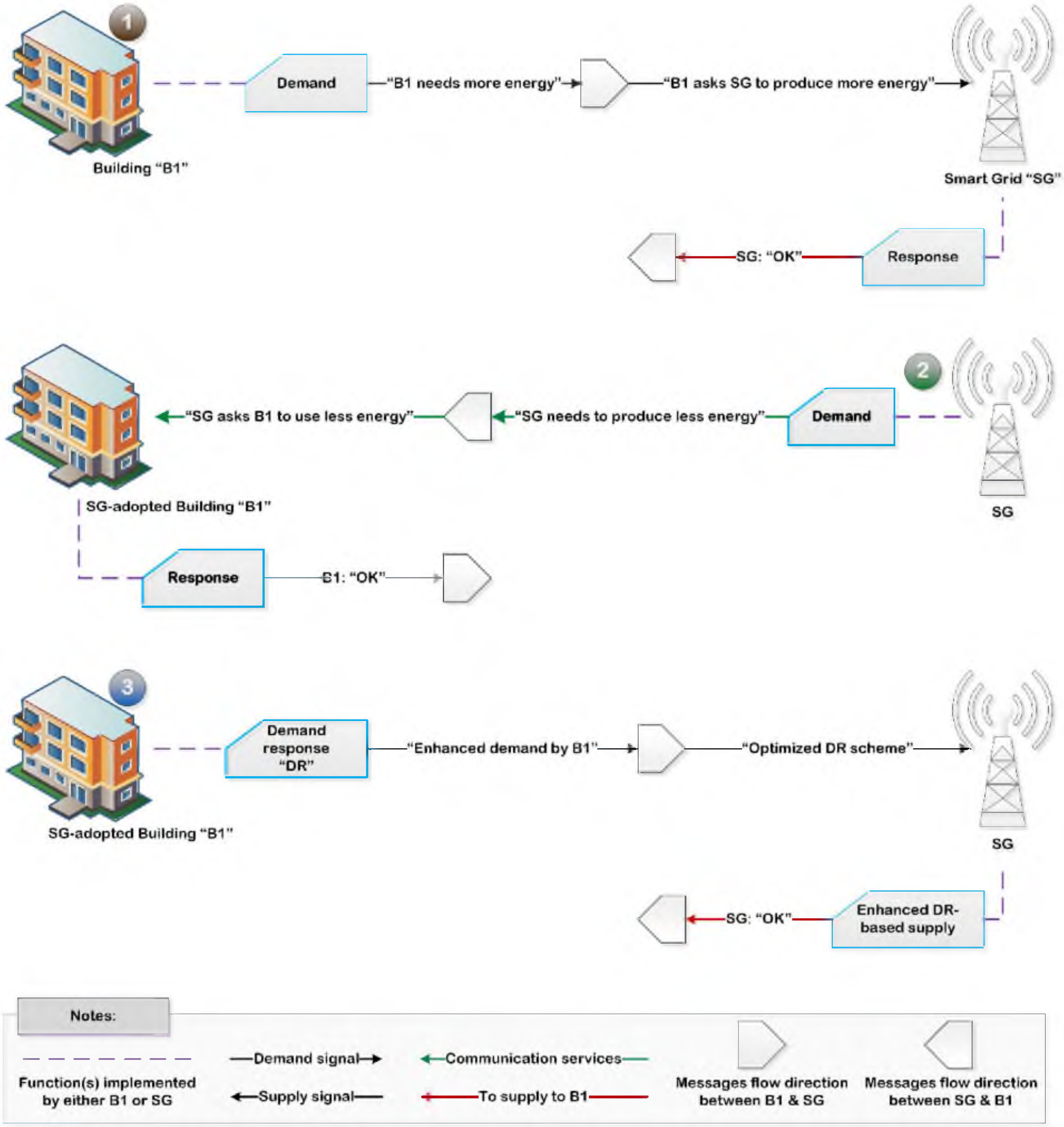


FIGURE 3. A conversation between demand- and supply-sides producing a DR conception in SG-adopted buildings. Shown are three scenarios labeled in Arabic numerals. The first scenario starts when a building performs an ED to the grid. The second scenario starts when SG asks the building to reduce the highly energy consumed. The third scenario is when the SG-adopted building starts to respond to the demand of grid to reduce energy-consumption.

formula shown in Figure 2 (a). Secondly, the other scenario illustrated in Figure 3, labeled by 2, represents the continuously energy-supplied scenario. The continued ED case will be represented by a gradual increment in the load curve shown in Figure 2 (b). Since, there is a DR scheme applied in this case, B1 will receive a message from the grid asking it to reduce energy-consumption (probably, for specific period(s) of time) specifically, during peak periods. Thirdly, in the third scenario illustrated in Figure 3, labeled by 3, B1 will respond to the grid's demand by reducing energy-consumption and that will be translated to a noticeable reduction in ED; this has been previously shown in Figure 2 (c). In this case, the grid's role has enhanced ED made by B1 utilizing DR.

E. DR AIM

DRs made by many buildings reduce the load curve to be less than ML_{ES} (i.e., supply capacity).

III. REVIEW RESEARCH DESIGN

This section is dedicated to give detailed description(s) on how this review research is designed and why. There are four elements are covered, which are: review research problem design, current review researches' focus and strategies, objectives, and research questions.

A. REVIEW RESEARCH PROBLEM

According to the previously discussed conception of smartness related to buildings and the grid, it is important to increase functions, operations, strategies that help buildings reduce ED from the generation/ production source [86]. In this case, the demand associated with the production/ distribution unit will be less. This is a big aim needs to be achieved. Currently, strategies applied to buildings that aim to reduce the ED of such a building are still facing challenges where the building keeps demanding energy due to several issues those strategies lack. DR strategies are attempting to reach a high level of performance at which the building's demand and generation unit's demand need to be as low as possible.

Several reviewed literature articles have been published. Previous articles have focused on a single topic or aim, for example, optimization algorithms for energy flexibility for residential buildings have been the main aim of the review research presented in [22]. Several review articles have considered incentive and price-based programs [67], [83], [87]. Apart from the aim a review research article focuses on, types of buildings covered in previously published review articles are mostly limited to one [22], two [85], or three types of buildings [88]. However, including unlimited CSs buildings types is recommended and of importance to cover a larger band of scenarios so that methods, proposed by researchers, reviewed in such a review article should have enhanced the state-of-the-art and added a value to designers and researchers to be aware of limitations, conditions, applied methods, advancement in the related field, and future directions. For example, the future directions are expanded according to case studies being reviewed. Besides, to include a varied type of methods, that could help read the analyzed results from such a review research article in a more clarified way and it could also help researchers on what best of suitability of methods to a certain scenario.

B. CURRENT REVIEW RESEARCHES' FOCUS AND APPLIED STRATEGIES

A Comparative overview between several previous review papers and this review research paper is provided in Table 2.

C. OBJECTIVES-BASED SCOPE OF THIS REVIEW RESEARCH

In this review, the scope has been expanded to increase a wider range of related strategies and methods applied for DR operating with SG toward the buildings sector. A wide range of buildings has been covered in this review to include several types of buildings and scenarios for which different strategies have been used. At this point, this review has covered this wide variety of buildings, methods and strategies, the number of reviewed papers, and an expanded period of the date of publishing to find out several solutions and ideas that would probably be useful for other similar scenarios and situations. Meaning, when a group of criteria and conditions for such scenarios are likely identical to other scenarios with a high percentage of similarity, the successfully implemented strategies may be supportive, that is on the one-hand. On the other hand, many open problems and challenges will rise enabling for researchers to propose solutions and strategies. Besides, gaps in the research of this paper's topic are to be discovered by researchers and it is of necessity to contribute.

Furthermore, this review attempts to include a number of research questions that help study further elements and factors. For example, one of the considerable elements is what encourages buildings to be adopted with SG or network via utilizing DR. In other words, such a question, "What do buildings need from the involvement in SG?", is to fulfill certain purposes. Meaning, the question: "what do buildings need from SG and DR?", is to be answered. Also, what factors are supporting the fulfillment of such purposes/needs will be an objective of this review. A further discussion is to be provided in the next sub-section.

D. RESEARCH QUESTIONS

This review research attempts to answer four research questions. The philosophy behind these questions is discussed in this section. The most important and key question relates to the reasons and or needs for which the reviewed article has selected/adopted DR to be involved in the proposed system. Meaning, why the reviewed article has aimed to exploit DR for SG-adopted buildings is the main and primary question this review paper attempts to answer. Therefore, the research question can be formulated as:

RQ1: "What are the reasons/needs for which such a reviewed article has designed the proposed system?"

However, there are also factors or means that can contribute to fulfilling the needs mentioned in RQ1. That is, for reviewed articles to fulfill their aimed needs, there should be at least one or more supportive factors. Thus, the second research question can be written as follows:

RQ2: "What are factors which contribute to/ support the reviewed articles' systems meet the needs/fulfill the purposes?"

For these purposes, methods and strategies usually vary therefore a further research question will be rising.

RQ3: "What are the most frequently implemented methods and strategies that apply DR in SG-adopted buildings?"

Amongst these methods, levels of performance in terms of efficiency differ. Therefore, the fourth research question is provided as:

RQ4: "What are the most effective methods and techniques applied to utilize DR in the SG-adopted buildings sector?"

TABLE 2. DR strategies for SGs adopted buildings.

Ref.	Paper's focus	Types of buildings	Methods and strategies	Other considerations
[22]	DR-related optimization algorithms	Residential	Optimization algorithms	- Energy flexibility
[85]	DR-related energy prediction	Residential and commercial	Optimal control for DR	- Energy modeling
[89]	DR-related ML algorithms	Residential and commercial	Reinforcement learning (RL)	- Energy prices as demand-dependent variables
[67]	DR-related incentive and price programs	Residential and commercial	Incentive- and price-based programs	- DR role in energy generation cost reduction
[83]	Demand-responsive buildings and ED flexibility strategies	Residential and commercial	Price and incentive-based strategies	- ED flexibility
[90]	DR and energy flexibility	Residential	Fluctuation of renewable energy generators, energy flexibility, HVAC, TES inertia	- Role of flexible load patterns due to the inertia of a thermal storage in DR in residential buildings
[91]	DR and HVAC systems in providing ancillary services to non-residential buildings	Non-residential	HVAC systems-related applications and methods	- Role of HVAC systems in enhancing SG-adopted buildings utilizing DR - Incentive and price-based DR programs
[92]	DR and HVAC providing ancillary services to smart buildings	Residential and smart	PEV, smart loads	- Communication technologies, control algorithms, potential security issues related to DR and smart buildings
[88]	Time and incentive DR programs	Residential, commercial, and industrial	Occupants-given incentives-based DR	- Role of occupants in change their energy usage behaviors - The need to solve grid's peak load and energy imbalance issues
[87]	DR-related demand-side control methods	Commercial and residential	incentive- and price-based DR mechanisms	- Grid imbalance problems
This review paper	Various DR strategies applied to SG for the buildings' sector	Residential, commercial, distributed, industrial, offices, universities and many others	Related methods to the following: energy price-based, incentive-based, loads control, programmable methods, AI applied methods, forecasting, thermal ESSs, and few others.	- Reasons behind a certain DR method is applied - Contributing and supportive factors to DR leading to reach successful sustainability as through reduction of energy-use, ED, CO_2, and electricity bill cost - Methods applied to achieve goals of DR implementation to SGs adopted buildings - Most effective methods applied to improving both DR services and SG infrastructure to reach environmentally friendly smart buildings and contribute to sustainability in energy systems

IV. METHOD

The search strategy applied is based on PRISMA 2020 [93]. The method applied for extracting related articles from selected digital libraries is in detail explained. Steps applied to include, exclude, remove, and check duplicates, and/or apply further criteria to extracted articles are also presented. This is supported by further figures and logical and mathematical formulas to add a more explanation on how steps are implemented. Steps applied are explained in the way they can be applied again. For this purpose, two additional criteria are drawn out. First of which is that the criteria for extracting related articles are applied to each digital library individually and one-by-one. Second of which, the date the criterion was applied to each digital library is mentioned. In this section,

A. MAIN KEYWORDS-APPLIED SEARCH STRATEGY

There have been several keywords the general searching phrases and words. They are: "smart grid", "demand response", and "buildings". However, a modification to this list might happen according to the type of publisher's digital library. These modifications will be highlighted and clarified. Publishers to which digital libraries belong are mentioned one by one according to the date the search method has been applied.

1) IEEE (IEEE XPLORE)

There are two criteria applied for keywords search. The first one denoted by c_1 has the following general phrase:

Title = "demand response" and ("smart grid" in Abstract OR in Title). This textual phrase is simplified as follows:

[(Title) AND (Title OR Abstract)]. This logical phrase is mathematically expressed in Eq. (1):

$$c_1 = \text{A AND (B OR C)} \tag{1}$$

where,

- A is DR in Title; where DR is demand response
- B is SG in Title; where SG is smart grid
- C is SG in Abstract.


Find articles with these terms: demand response

Title, abstract or author-specified keywords: "demand response" "smart grid"

FIGURE 4. **Keyword-searching method applied to advanced search in the ScienceDirect digital library.**

Obtained results from this search were 504 articles.

The second criterion is denoted by c_2. Removal of articles that are irrelevant to "building" or "buildings" was applied. This is shown as:

[(Title) AND (Title OR Abstract) AND (Title OR Abstract)]. This logical phrase is mathematically expressed as in Eq. (2):

$$c_2 = [\text{A AND (B OR C) AND ((D OR E) OR (F AND G))}] \tag{2}$$

where,

- A is DR in Title
- B is SG in Title
- C is SG in Abstract
- D is "building" in Title
- E is "building" in Abstract
- F is "buildings" in Title
- G is "buildings" in Abstract.

Obtained results from this search were 55 articles.

2) ELSEVIER (ScienceDirect)

There were three phases with three criteria applied in a sequence. The keywords-searching method is briefly explained as follows:

The first phase used one keyword in which criterion 1 is expressed as: (Title = "demand response"); extracted articles = 2563 searching results.

In the second phase, a new word was added to criterion 2, and also, new fields had been considered. In this phase, more conditions were added to minimize searching results and more focus-related articles resulted. Criterion 2 is expressed as follows: (title = "demand response" AND (title = "smart grid" OR abstract = "smart grid" OR keywords = "smart grid"))

In this phase, keywords such as "demand response" and "smart grid" were used as exact words using the quotation marks "" in the search box; as shown in Figure 4:

The extracted articles = 502 searching results.

The third phase had applied a further keyword to increase the focus on SG-adopted buildings and to exclude results that their main aims or scope are not within the "building" and/or "buildings" terms. This phase had applied the following criterion: criterion 1 AND criterion 2 AND ("building" OR "buildings"); extracted articles = 99 searching results. Two exclusion filters had been applied, one of which considered titles' duplication, other of which excluded non-research articles such as a survey. Obtained results were 97 articles.

3) ACM (ACM DL)

This phase contains four phases mentioned as follows:

In phase 1, this criterion, c_1 = [Publication Title: demand response] AND [Abstract: smart grid], has been applied. Obtained results were 223 results.

In phase 2, this criterion, $c_2 = c_1$ AND [Abstract: building], has been applied. Topics-general results that do not include "building" are to be filtered and excluded. Obtained results were 44 results.

In phase 3, an exclusion rule was set. This rule considered only contents' type. A filter to exclude non-research articles such as tutorials, posters, extended abstracts, and demonstrations were applied. Obtained results were 27 articles.

In phase 4, an exclusion rule was also added and applied. Removal of "buildings"-irrelevant results and/ or "demand response"-irrelevant results was used. Obtained results were 16 articles.

4) SPRINGER NATURE (NATURE)

Applied criterion contain the following expressions: ((title = "demand response") OR (title = "demand-side response")) article contain terms: ("building" OR "household" OR "home"). Obtained results were 23 articles.

5) WILEY (WILEY ONLINE LIBRARY)

Applied criterion had the following expression:

c_{Wiley} is ((title = "demand response") AND (title = "smart grid") AND ((title = "building") OR (title = "home") OR (abstract = "building") OR (abstract = "home"))).

Eq. (3) was applied to extract research articles from Wiley Online Library, EP_{Wiley}.

$$EP_{Wiley} = \begin{cases} 1, & c_{Wiley} = True \\ 0, & Otherwise \end{cases} \tag{3}$$

where,

- c_{Wiley} represents the condition for which its expression is being logically fulfilled
- EP_{Wiley} represents the status of an article to which the condition, i.e., c_{Wiley} is applied.

Extracted papers from the Wiley Online Library are only obtained results at which $EP_{Wiley} = 1$. Obtained results were 4 articles.

6) TAYLOR & FRANCIS (TAYLOR & FRANCIS ONLINE)

The applied criterion used in this search is denoted by $c_{t\&f}$. Its expression can be provided as: $c_{t\&f}$ is ([Title: smart grid] AND [Title: demand response]). Obtained results were 165 articles some of which are irrelevant to "building" or "buildings". Thus, another criterion was applied to remove irrelevant to "buildings".

$c_{t\&f}$ is ([Title: smart grid] AND [Title: demand response] AND [Title: building]). For extraction procedure of articles Eq. (4) was used:

$$EP_{t\&f} = \begin{cases} 1, & c_{t\&f} = True \\ 0, & Otherwise \end{cases} \tag{4}$$

where,

- $c_{t\&f}$ represents a condition for which the expression is being logically fulfilled
- $EP_{t\&f}$ represents the status of an article to which the condition, i.e., $c_{t\&f}$ is applied.

For those articles which fulfill the condition $EP_{t\&f} = 1$, the relevant article would be selected, after Eq. (1) was applied to the above-mentioned criterion, obtained results were 5 articles.

Other obtained records (specifically MDPI) contained 1 result.

Statistics and criteria applied for the searching method dedicated to extract reviewed articles according to PRISMA 2020 flow-diagram template for systematic reviews are shown in Figure 5.

B. INCLUSION AND EXCLUSION CRITERIA

This review article has selected a number of indexing services. Furthermore, four publishers have been considered which are IEEE, Elsevier, ACM, Springer Nature, Wiley, Taylor & Francis, and MDPI. Additional criteria which have been considered are described as follows:

- Indexing service: WOS and/or Scopus
- Publisher: IEEE, Elsevier, ACM, Springer Nature, Wiley, Taylor & Francis, and MDPI
- Database names: IEEE Xplore, ScienceDirect, ACM DL, Nature, Wiley Online Library, Taylor & Francis Online, and MDPI
- Article date: 2008 to 2020
- Type of papers collected: Conference proceedings & Journals
- Conferences papers to journals articles: 26.3:72.6%
- Scope of a candidate article: buildings, demand response, renewable energy resources, smart grid, sustainable energy systems
- Types of buildings related keywords: residential, smart, commercial, industrial, distributed, offices, historical, universities, and many others
- Paper selection: NOT a newspaper, demonstration, poster, and extended abstract.

C. CLASSIFICATION OF RETRIEVED PUBLICATION TYPE-BASED ARTICLES

As mentioned earlier, the total of 201 results of retrieved articles (papers from conferences are inclusive) from digital libraries has been classified based on the type of publication. This is shown in Figure 6.

Reviewed literature and retrieved papers have been collected from seven digital libraries with which related publishers are associated. A publisher-based collected papers classification is shown in Figure 7.

A total of 201 results (including journal articles, conferences papers, and books sections) are analyzed according to the year. Obtained results show a distribution of articles per year in Figure 8.

Following is another analysis dedicated to journal names per total extracted articles. This analysis highlighted statistics of journals-retrieved articles. The analysis is performed and related information is shown in Figure 9.

In the analysis shown in Figure 9, only 72.64% of the total collected and reviewed papers (previously mentioned in Figure 6) have been used.

V. LITERATURE REVIEW

A. MULTI-OBJECTIVE OPTIMIZATION: ENHANCING DR PROGRAMS THROUGH A HOLISTIC PERSPECTIVE

Multi-objective optimization offers a valuable perspective for understanding and improving demand response (DR) programs.

Multi-objective optimization plays a crucial role in understanding DR methods [94], [95]. DR programs aim to modify energy consumption patterns in response to changes in energy supply or market conditions. The objective is to balance SG, reduce peak demand, improve energy efficiency, and enhance overall system reliability. In the context of multi-objective optimization, the goal is to find optimal solutions that simultaneously satisfy multiple conflicting objectives [96]. In the case of DR programs, these objectives may include minimizing energy costs [97], [98], reducing peak demand [99], minimizing GHG emissions [100], maximizing customer comfort [101], [102], and enhancing SG stability [103], [105], [106].

To achieve these objectives, various techniques can be employed in the field of multi-objective optimization for DR programs. These techniques typically involve modeling and optimizing the behavior of individual consumers or aggregations of consumers. Here are some commonly used methods:

1) PARETO-BASED APPROACHES

These methods aim to find a set of solutions that represent trade-offs between different objectives [107]. The solutions lie on the Pareto front, which represents the optimal compromise between conflicting objectives [108], [109]. Decision-makers can then choose a solution from the Pareto front based on their preferences [110].

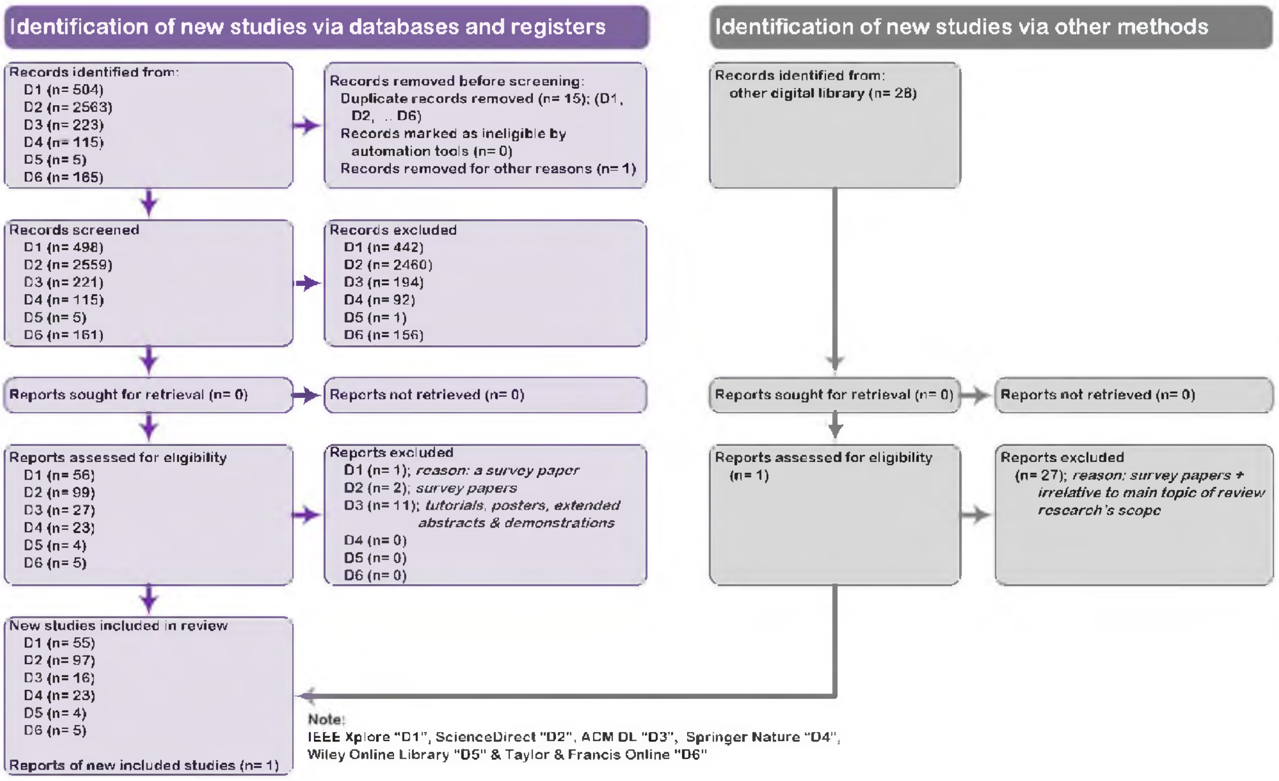


FIGURE 5. 3 Search strategy applied for extracting and collecting articles according to PRISMA 2020 Statement for systematic reviews. The far left-bottom box in Figure 5 shows the total articles extracted and used for this systematic review with 201 articles.

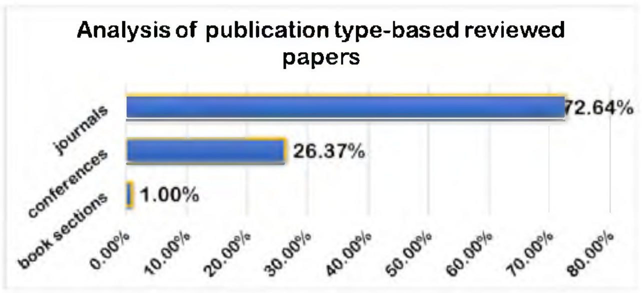


FIGURE 6. Distribution of papers according to publication's type.

2) EVOLUTIONARY ALGORITHMS

Evolutionary algorithms, such as genetic algorithms and particle swarm optimization, can be employed to find optimal or near-optimal solutions in multi-objective optimization problems [111], [112], [113]. These algorithms use principles inspired by natural evolution to explore the search space and converge towards Pareto-optimal solutions [114].

3) FUZZY-BASED APPROACHES

Fuzzy logic can be used to handle uncertainty and vagueness in DR programs [115], [116]. Fuzzy optimization models can capture the imprecise nature of decision-making and provide robust solutions considering multiple objectives [117], [118].

4) CONSTRAINT HANDLING TECHNIQUES

Multi-objective optimization for DR programs often involves dealing with various constraints, such as load balancing constraints [119], [120], [121], equipment limitations [122], [123], [124], or customer comfort constraints [125], [126], [127], [128]. Constraint handling techniques [129], like penalty methods [130], [131] or constraint satisfaction algorithms [132], can be applied to ensure the solutions adhere to these constraints while optimizing multiple objectives [119], [133], [134], [135].

5) MACHINE LEARNING AND DATA-DRIVEN APPROACHES

With the availability of large-scale data from SGs and advanced metering infrastructure, machine learning techniques [96], [136] can be utilized to analyze historical data [137], forecast load profiles [138], and optimize DR programs [139]. Data-driven approaches can provide insights into consumer behavior [140], identify patterns [141], [142], [143], and develop predictive models for optimizing multiple objectives [144], [145], [146].

B. OCCUPANTS' COOPERATION-CENTRIC INCENTIVE FOR DR

It is mentioned by a number of studies [71], [74], [147], [149], [178] that the cooperative behavior of customers and managers in regard to response to demand [150] specifically

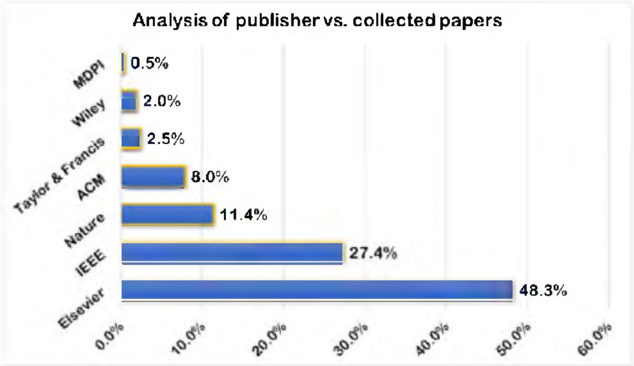


FIGURE 7. Distribution of papers according to publishers.

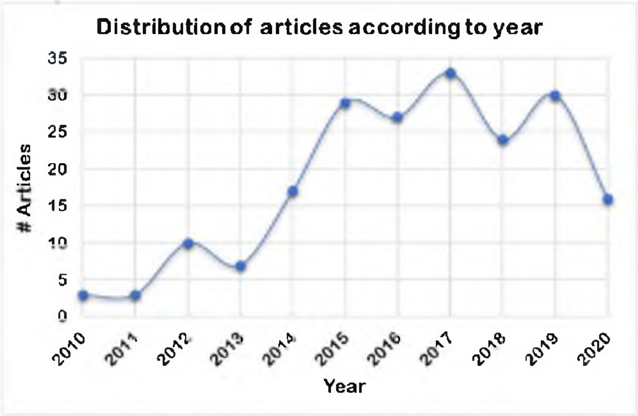


FIGURE 8. Distribution of papers according to year.

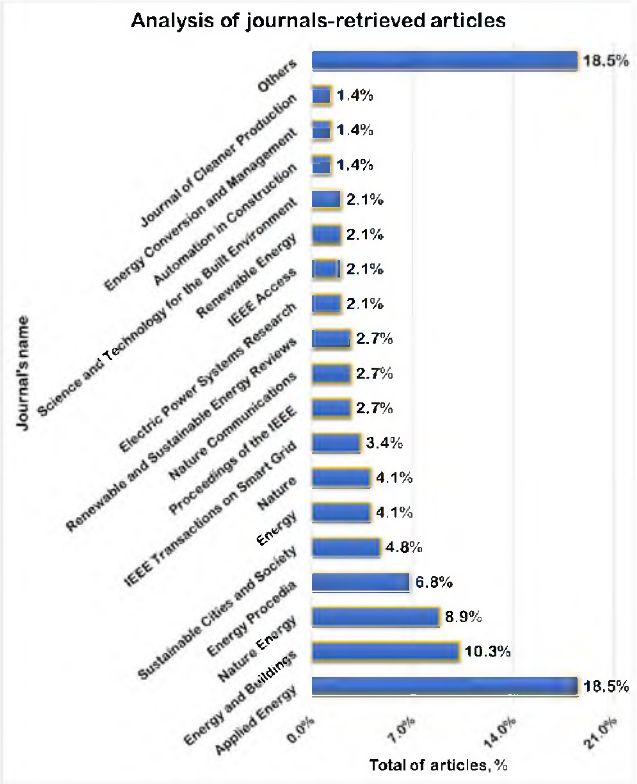


FIGURE 9. Distribution of articles according to journals type.

during peak hours will lead to many features which are: 1) maintain load balance [71], 2) postpone capacity expansion projects [71], 3) reduce the electricity cost [72], 4) reduce electricity price [74], 5) reduce electricity bill [11], 6) reduce energy-consumption [77], and 7) enhance and improve SG-connected smart buildings [63] and many others. Besides, occupants have been involved in a study to control appliances in the commercial buildings sector to manage the demand-side [151].

In literature, many reviewed papers have considered incentive-based DR [148], [149], [152], [153], [154]. Several methods have been utilized to build up an incentive DR program directed towards residential customers to respond to prices that usually and over time vary [153].

Incentive-based DR strategies are centric for occupants or buildings' owners [155], [156], [157]. In some cases, financial incentives can be offered. Financial incentives-related DR strategies have been considered by several studies [74], [158] where these incentives are provided for buildings' owners to achieve more energy reduction, more stability, and more loads-smoothing curve of energy supply during peak hours.

Besides, incentive-based offers can be used to 1) encourage occupants to reduce energy consumption, 2) make them aware of high energy-use, 3) exploit energy storage sources for EDR and energy supply, or 4) concern energy flexibility. Reviewed are a number of examples. The system proposed in [152] has aimed to reduce ED made by buildings and their occupants. The role of occupants in energy demand reduction is effective and can quickly work to enhance DR in the path of SG applications. Occupants have a key role in energy reduction and improving DR programs. For example, a proposed method has encouraged occupants to participation in energy patterns' changing to improve DR performance applied to SG-adopted buildings [159] where the aim is to achieve loads scheduling.

In [160], the paper has mentioned that incentive-based energy management and occupants-participated awareness have contributed to energy-saving by responding to demand events to reduce peak-demand.

Incentive-based DR strategies can be a useful tool that encourages occupants to reduce energy-consumption where thermal energy storage (TES) systems can be utilized and used as a supportive source for energy-dispatched building [161]. Besides, the proposed cooling system in [54] has adopted a smart renewable installation strategy at SG-adopted buildings to reduce ED, CO_2 emissions, and global warming. Incentive has been utilized as a means to enhance preheating as a control strategy prior to DR periods [162].

The study reviewed in [163] concerns the energy flexibility in buildings. Case studies (CSs) of different buildings discussed in [163] provide proof to be active players of energy flexibility towards energy market contributing to energy storage, DR, energy sources-related usage shifts. The energy share and energy flexibility in buildings require, for example, developing flexible energy tariffs and supporting incentives. Another proposed algorithm reviewed in [164] seeks possibility to provide a flexible service by energy system operators through incentives in regard to energy signals.

C. PRICE-CONSIDERED DR

In [165], it is mentioned that: when demand is high and generation is low, then the price is going to be increased so that the SG participants will be encouraged to reduce energy-consumption. And vice versa, when demand is low and generation is higher, then the prices are low to allow SG participants to benefit from the low rates in electricity.

Dynamic pricing-based strategy has been considered by several studies [144], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176]. Dynamic price signals-based DR control and management method for optimal SG-adopted buildings has been proposed in [177]. The proposed method aims to minimize the cost made by commercial building's operations exploiting compatible DR facilities responding to dynamic and real price signals such as solar power plants and EVs.

Reviewed papers have concerned management operations related to, for example, heating and cooling, monitoring operations, battery charging and discharging operations, EVs-related operations, flexibility operations, bi-directional information, and Real-time price (RTP) optimization during peak hours. A number of reviewed papers are summarized as follows:

Heating and cooling-related operations are still of considerable attempts to be very well managed and controlled in a SG environment taking into account RERs [178]. The proposed controller aims to manage and control heating and cooling systems for SG-adopted buildings taking into account the RER utilizing the price-based DR. The proposed controller is able to minimize the cost of energy consumed among SG participants.

Monitoring for RTP improvement has been considered. The air conditioners in residential buildings have been monitored and controlled to allow SG participants to implement DR for less energy-consumption [179]. Both IoT utilizing room temperature and cloud servers with the help of RTP have been used for monitoring and control thermostats. The system proposed in [180] has controlled the inlet water temperature as a DR strategy. It monitors three elements which are inlet water temperature, occupants' comfort, and thermal comfort.

The proposed optimized framework in [26] has aimed to reduce operation cost. It responds to market dynamic prices. It optimizes building temperature and battery charging and discharging operations in a real-time implementation scenario.

EVs are used as a means to supply energy to the building during the peaks of energy prices [181]. During the normal price, and when there is no much ED, the EVs are used as an energy load. Therefore, DR scheme is managed to have the minimum cost in terms of energy-consumption.

In [182], the OpenADR was tested for possibility of transferring energy price signals inside SG between grid utility and loads.

A proposed system has aimed to maximize efficiency of operations related to flexibility of home energy management system and reduce the cost of operations related to SG [183]. The system has incorporated DR and energy RTP.

The proposed method for dynamic pricing-based DR in [184] has utilized a genetic algorithm (GA). This method indirectly enhances DR by enhancing bi-directional information exchange that accordingly helps reduce daily energy cost, reduce ED made by buildings, and reduce energy imbalance.

Finding an optimization-based solution for the best responsively cooperative social participation related to DR scheme for buildings to anticipate prices is a very challenge due to many reasons and considerations. Cooperative and efficient response by occupants to the demand-side during peak hours are examples of these considerable issues [74]. An incentive method was used so that loads can be delayed or shifted from peak to off-peak hours [11].

D. CONTROL-BASED DR

The main element in this type of strategy is smart appliances' availability to ease the control of these appliances. Besides, one important element is the quality of communication services to ease the data gathering and measurement for analysis and then to ease the real-time control of smart appliances inside SG-adopted buildings [41], [42]. In addition, there are several strategies applied for loads control to ease DR performance. For example, load control, demand shifting, demand reduction are strategies applied to integrate between quality of energy and SG. For these types of integrated strategies, sometimes, scheduling operations for the building's loads are performed to optimally provide the minimum cost of energy supplied and minimum cost of energy dispatched. Scheduling operations consider two sides the utility or REG and the building's controllable loads [164].

1) PEAK TO AVERAGE RATIO (PAR)

There are numerous researches concerning the peak-to-average ratio due to it affects the overall energy-consumption inside SG. Due to the important role peak to average ratio (PAR) plays in enhancing the reduction level related to energy-consumption and balancing both demand and supply in the energy system, PAR has been considered by several proposed systems [77], [185], [186].

Energy efficiency and energy management are considered by the proposed framework reviewed in [185] to reduce energy-use in residential buildings. The proposed method aims to increase ratio of peak-to-average with a balancing strategy between energy-use (electricity bill as little as possible) and occupants' comfort. An artificial neural network-based prediction method has been proposed. The proposed method monitors DR-based on the price as well as the patterns of energy-consumption. In this circumstance, those smart appliances under the predicted or forecasted pricing signal and patterns of energy-consumption are being monitored and recorded to enhance energy management.

The curtailment of peak to average ratio contributes to energy-consumption and helps in balancing the supply and demand for SG infrastructure [77]. The paper has proposed a control method for PAR curtailment by controlling energy adjustable appliances in a residential building. The proposed PAR curtailed control method balances the supply and demand by controlling the energy adjustable appliances.

2) LOADS CONTROL-BASED DR

Loads control has been considered by many DR strategies in SGs-adopted buildings [21], [52], [75], [187], [188], [189], [190], [191], [192], [193] focusing on, for example, smart appliances control [194], [195], [196] and plugs loads control [197]. EVs have also been considered by several studies to apply DR strategies with the best performance to enhance SG infrastructure [198]. The system has considered how to efficiently reduce energy-consumption caused by domestic loads e.g., lighting load [199]. The main aim is to control small domestic loads such as lighting loads. It controls the load for best electrical prices utilizing AMI. The research work has proposed a method to control domestic loads by electrical market RTPs. The related price signals will be sent to the building's EMS via AMI. Illumination level of desired lighting loads will be calculated. A suggested illumination value will be highlighted. Smart appliances can be controlled utilizing Information and Communication Technology (ICT) so that the control system can be easily implemented [42]. The study in [42] has focused on the assessment side of applying DR scheme in real life.

Lighting loads control has been considered by [64]. The paper has considered energy-consumption caused by lights in the building in which loads will require additional demand. This method has focused on such a way to reduce the total energy-consumption utilizing DR. The reduction in lighting loads will be distributed over other controllers. Meaning, the facilities inside the building such as corridors reception will be utilized where some facilities allow for illuminance reduction by 50% and some other facilities allow for 20%. In total, an amount of energy-saving level will be gained. This as a result will contribute to reduce the demand. DR has been utilized to reduce energy-consumption in SG-adopted buildings.

A DR management system is used to control loads of a number of appliances e.g., EVs and air-conditioners [200]. It can reduce energy-consumption to reach a certain limit by utilizing building energy management system (BEMS) and DR scheme inside an office building. Several studies related to energy storage have been proposed [201], [202]. The study presented in [201] has analyzed the reuse possibility of EV batteries for a second life. The study attempts to discover if a lifespan of an EV battery is suitable for an alternative source of energy supply in smart buildings utilizing DR.

DR functionalities were included in SG in a real-time simulation scenario. A real-time simulation for load controlling to mimic DR functionality for a SG-adopted building has been proposed [203]. The dynamical behavior of large-scale appliances is aimed to be simulated with their loads in the SG-adopted buildings with regard to DR strategy [204].

The aim of energy cost reduction, ED shift, and peak loads reduction has been considered through controllable loads such as lighting systems, air conditioning, and PV energy systems [63], [68], [205]. The method proposed in [68] has monitored and controlled public lighting systems and it could reduce ED cost, shift ED, and increase revenue. These benefits together help enhance DR towards better SG management. Peak loads reduction has been considered by [63] and [205]. In [63], it has considered indoor temperature and heavy loads controllable such as air conditioners. It also considered the operations of units of rooftop in the residential and commercial buildings to reduce energy-consumption and peak demand to comply with DR events. The method proposed in [205] has aimed to control loads to integrate PV, ice storage systems, and DR aiming to reach peak load reduction.

3) HVAC CONTROL

A number of DR strategies have concentrated on Heating, Ventilation, and Air Conditioning (HVAC), [69], [206], [207], [208], [209], [210], [211], [212], [213], [214], [215], [216], [217], TES [218], [219], [220], [221], [222], [223], active chillers for direct control [224], and Thermostatically Controlled Loads (TCLs) [225].

HVAC is considered one of the biggest energy consumers in residential buildings where this affected by external environmental conditions such as air temperature outside buildings [76]. Thus, a lot of energy-consumption is caused. Therefore, HVAC is important to be effectively controlled to enhance DR service and largely reduce energy-consumption. In [226], DR is aimed to be enhanced in residential buildings by analyzing two DR strategies active and transactive control.

A system proposed in [69] has considered HVAC control. It used a programming model like Nonlinear Autoregressive Neural Network (NARNET) and Mixed-Integer Non-Linear Programming (MINLP) to optimally determine the minimum energy cost caused by the building's HVAC as a DR scheme.

In [78], energy storage has been considered as one of the important factors towards SG infrastructure. To store the energy in residential buildings, it has proposed a thermal mass medium by utilizing the air conditioners.

Energy reduction in buildings is usually a key mean followed for DR requests [5]. The proposed strategy aims to reduce ED in a building so that the supply is reduced due to the energy-saving happens as a result.

The paper presented in [227] has considered ancillary services related to DR by utilizing thermodynamics and HVAC systems in the building. The system aims to increase the thermal consumption flexibility in buildings.

A system proposed in [228] has experimentally tested the performance of variable-speed pumps in terms of response time. The aim of using variable speed pumps in HVAC systems is to regulate the frequency for fast response to frequency change. Fast DR strategies are effective to respond to SGs' requests to reduce ED [20], [91], [229]. In [213], a heat-pump is used to decrease energy exchange with SG and lower peak load. The system proposed in [230] can efficiently and flexibly control air conditioners. This strategy can contribute to load shifting and electricity patterns changing.

4) AUTOMATED CONTROL DR

Several strategies have been proposed to deal with automated DR control e.g., [18], [73], and [231]. It is necessary to reduce the peak demand in the building where the energy management systems efficiently contribute towards this direction [73]. DR systems and applications help enhance the performance of those energy management systems and SG is getting improved in terms of energy-consumption and energy efficiency. RES-based generation is considered better than traditional fossil energy sources-based for a more efficient and optimization option in SGs. The paper [73] has focused on how to enhance the supply-side to reduce demand needs. Also, it aims to enhance the automated control of building's appliances. Besides, the proposed system has aimed to enhance the energy efficiency inside the building by utilizing more smart appliances e.g., water heating, air cooling and Electric Vehicles (EVs). The paper [73] aims to enhance both supply-side by utilizing more RESs such as solar PV and wind turbines for generation and distribution to buildings as well as response by utilizing automated control of smart appliances inside the buildings such as EVs. An analysis-based system is designed to simulate BEMS controller using a load shifting technique-based iterative algorithm and MATLAB.

In [18], the demand-side is managed to reduce the sudden supply needs. An automated DR management to reduce the peak demand in a time the supply might be critical due to shortage in coal or other considerations. This can contribute to economic benefits and can avoid critical supply due to the buildings' demand. In case this is solved, a SG infrastructure is being enhanced for a green environment.

5) COMMUNICATION SERVICES-BASED CONTROL DR

Communication-related services-based DR strategies have considered energy-consumption reduction [71], control [232], interacted between DR and SGs [233], used as a gateway protocol for DR [84], [234], communications services for binary information exchange [235], [236]. There is a need to reduce energy-consumption or shift it to off-peak hours. A study proposed in [71] has highlighted communication services and data models needed for efficient DR performance in residential and commercial buildings. The paper has attempted to propose a platform by which DR is being enhanced and actively and efficiently responsive through a physical smart home network to respond to the demand specifically during peak demand to contribute much to preserve the load balance.

In [232], the proposed system has aimed to manage and control energy-consumption to best respond to the supply condition. Programmable method for building automation and control system (BACS) thru communication network for monitoring and receiving messages. A communication network-based method for automation and control has been designed in which ZigBee has been used to support DR management and control of loads. DR was used to control actions to reduce energy-use in SG-adopted buildings.

Aggregated units need to be controlled in terms of energy cost reduction utilizing DR in a SG-adopted buildings environment [237]. Delays in communication services was considered in a fast-automated DR by considering the wide-area communication.

E. PROGRAMMABLE DR STRATEGIES

In this subsection, programming-oriented DR strategies such as On-Off control method and mixed-integer linear programming (MILP) are briefly reviewed [39], [65], [238], [239]. The proposed system explained in [239] has addressed the problem of how to increase BEMSs performance utilizing DR in smart buildings towards improving SG. The proposed system aims to exploit DR in enhancing both SG and BEMS to reduce electricity bill prices. BEMS can utilize smart appliances such as energy storage devices (ESD), EVs, and PV. The paper has proposed a BEMS using a MILP framework-based modeling in which dynamic thermal characteristics inside the building have been considered.

In [65], a method has focused on lighting control. It has mainly used a programmable On-Off control method for lighting. It proposed a lighting control-based DR module for the best performance for SG. Unlike [65], the proposed system in [39] has aimed to enhance bidirectional communications between RERs and buildings controllers.

A linear programming-based verification scheme [240] to evaluate occupants' response to energy reduction demands [241] specifically in peak periods was proposed. A programmable controlling method (using Grid LAB-D) for loads utilizing devices like wind turbines and PV panels was modelled [242]. The proposed model has simulated several controlled loads in which thousands of devices were considered.

Sometimes, programmable DR strategies can be used to deal with the peak load periods [72]. It aims to reduce and shift the peak load utilizing the real-time energy prices thru proposing a control strategy dedicated to HVACs.

F. ARTIFICIAL INTELLIGENCE (AI)-BASED DR

Reinforcement learning (RL) has extensively been considered by many DR strategies applied for SG-adopted buildings, for example [243] and [244]. The problem of automatic control of several lighting systems was considered [244]. Also, illuminance comfort inside the internal environment for occupants was considered. RL has been utilized to implement a learning procedure to include both DR and occupants' requirements.

Machine learning (ML) has been used to utilize DR prediction to enhance demand-side management (DSM) [245], to reduce energy-consumption [246], or to predict energy prices [247]. Energy reduction aiming to achieve conditions of SGs by exploiting DR specifically during peak hours or in response to electricity price was the main considerable issue by [246]. Its purpose was to control appliances remotely during peak hours. It proposed a pricing policy mechanism utilizing information from the provider's prices announcement. ML has been also used for energy prices prediction purposes [247].

Genetics Algorithm (GA) was used to reduce electricity bills. GA-based optimal sizing of RERs was proposed [79]. A DR control is proposed while load prediction is uncertain [248].

Neural Network (NN) was used in [249] where it is stated that the distributed loads inside a building with stochastic disorders will highly cause a huge energy demand. Distributed loads can be managed in an office building to reduce ED made by those loads. A NN-based automated DR model has been proposed to mimic and manage the behavior of air-conditioning appliances in ED in real-time considering stochastic disorders caused by these appliances.

DR strategies at SG-adopted buildings have utilized NN for load prediction [70], [250]. The model proposed in [251] provides a good prediction's percentage related to energy reduction made by SG-implemented DR utilizing the air-conditioners. In [252], a NN-based forecasting method has been proposed to forecast load demand of smart buildings. Both aggregated and disaggregated loads have been considered.

G. OTHER TECHNOLOGIES AND SYSTEMS APPLIED FOR DR IN SG

1) OPTIMIZATION-BASED DR

Optimization for fast DR is one of main strategies considered by many studies in which simulation and real tests have been implemented [26], [253], [254], [256], [257], [258], [259], [260] where different methods have been utilized e.g., game theory [261]. In [43], the proposed system's aim was to find relationship between DR and SG by comparing two DR algorithms optimal and heuristic algorithms thru computational experimental studies. In [262], DR was used to make sure a fair thermal distribution to a district of buildings in terms of cooling and heating distribution for thermal grid participants.

Another research [165] has attempted to investigate possibility of achieving relationship between real-time optimization and enhancement of prediction policy regarding SG upgrade. It attempted to investigate how DR mechanism changes the policy or has an impact on the policy of SG implementation's cost. It investigates the possibility of changing this policy depending on the physical equipment type used for SG upgrade. This could enhance the prediction policy either in a real-time optimization manner or to form an economic perspective. The proposed optimization-based DR has used refinery process to shift loads caused ED to off-peak hours [257]. In [81], an automation technology such as OpenADR was implemented to optimize energy-consumption.

2) PREDICTION-BASED DR

Strategies proposed in this category have focused on prediction of demand reduction [263], [264], prediction of reduction of energy-consumption [265], energy pricing [44], or prediction of load scheduling [266] utilizing, for example, NN [267] or real-time pricing [266]. In [263], the main problem has focused on proposing a method of measurement and verification for the purpose of quantifying the amount of demand reduction. Its objective is to monitor the smart meter and estimate the load pattern to attempt to create a behavioral framework that shows a load pattern of the potential DR reduction as a response to SGs. The paper describes SG elements formally. It estimates the customer baseline load for DR in SG by proposing a framework so that the amount of demand reduction will be quantified by measurement and verification procedures. It has applied a learning technique to cluster dimensions of input and output to a single clustered load pattern that might potentially resemble the load pattern of DR behavior.

But in [44], the main focus was to extract useful information from residential buildings regarding prediction of energy pricing at a certain time. Its aim was to collect and process data to estimate loads at a given time. Data from a domestic appliance was collected to monitor and analyze variations of energy-consumption and to predict energy-consumption for such loads at a specific time.

The interaction and cooperation between DR representatives (i.e., occupants) and SG management (i.e., energy generation and supply) is achieved with a very highly efficient means [41]. The paper aims to enhance the interaction between demand occupants and SG management and participants for a better DR mechanism. It studies the impact of load changes of assessable prediction in enhancing DR quality towards an efficient SG management.

3) SCHEDULING-BASED DR

Scheduling of PV batteries for charging and discharging is one of the active strategies utilized by DR to achieve energy share [268], energy storage [269], control for smart appliances [270], or scheduling EVs for energy storage and RES market [271], or to reduce energy consumed in intelligent buildings [272]. The system proposed in [273] considers how to solve the problem of charging scheduling of smart appliances e.g., EV by utilizing SG. Its objective was to model a DR system (charging schedule) for a smart appliance (e.g., EV) associated with a smart building by utilizing SG. It has proposed a framework describing SG elements and their related interactions; to upgrade grid components independently.

Some other scheduling DR strategies in SG-adopted buildings have concerned the scheduling of ordinary [164] or smart loads [274], where it has proposed an algorithm that schedules loads in buildings based on the time variation to help occupants with the minimum cost of electricity bill. The proposed algorithm presented in [164] has scheduled the loads until the minimum cost level for both energy dispatched and sources-supplied energy has been reached.

VI. REPORTED RESULTS IN THE REVIEWED PAPERS

A. OCCUPANTS' COOPERATION-CENTRIC INCENTIVE FOR DR

A *foresee*-application has reduced large amounts of energy-consumption and contributed to load shifting enhancing DR in which both controllable loads and batteries in the building can be utilized [147]. The study presented in [148] mentioned that TV-based communication was more effective than the phones' messages case.

Results from the simulation work [152] have reported that the percentage of EDR has been recorded between 32 and 66.5% while the indoor thermal comfort had not been affected. Using fuzzy logic with the help of programmable communicating thermostat (PCT) has contributed much to PAR, EDR, and shift demands caused by appliances specifically during peak hours [153]. Results mentioned that occupants' awareness leads to behavioral energy efficiency in low-income neighborhoods [160]. Results showed that TES capacity enhances load shifting. Thus, energy flexibility is getting affected by TES capacity. Besides, flexibility is affected by generator's sizing [161].

B. PRICE-CONSIDERED DR

According to [180], results showed that price-based DR contributes to occupants' and thermal comforts. Results of the simulation model contributed to cost reduction of several operational devices [177]. Results in [178] showed a good optimization process in energy reduction. Obtained results in [74] demonstrated that cooperative DR scheme can reduce electricity costs, electricity price, and energy-consumption. Price-based DR was used to reduce imbalance [184] related to grid energy supply by 59% and 81% for conventional thermal energy plants and RERs, respectively.

The optimized algorithm [26] contributed to an office building used for an experimental scenario by reducing peak demand by 26% monthly and electricity price reduction by 11%. Obtained results from numerical simulations [181] showed that EVs are an effective tool for energy supply to a building specifically during energy's prices-high periods. In [144], demand fluctuation was reduced by ~40% and the energy-saving has been recorded to be between 2.5 and 8.3%. Model predictive control (MPC) and price-based incentives for DR participants have been effective in terms of prediction of real-time energy prices where the method contributed to energy reduction during peak demand and made optimally a preheating operation for the tested room in a residential building [170].

C. CONTROL-BASED DR

1) PEAK TO AVERAGE RATIO (PAR)

Obtained results have enhanced peak-to-average ratio (PAR) and electricity bills by 47% and 23.9%, respectively [185]. In terms of energy management efficiency, the proposed method was compared to a GA-based strategy, it has enhanced energy management efficiency by 33% compared to other reported competitive research works [185]. The obtained results from the simulation work presented in [77] have curtailed the average cost and averaged PAR for both adjustable and un-adjustable to 12.5% and 45.5%, respectively.

2) LOADS CONTROL-BASED DR

Simulation results from [199] showed that the proposed method for controlling the microgrid lighting loads can make the consumption level changes by pricing signals. If energy cost is recorded high, energy-consumption of lighting loads has changed to low. This has caused an increment in profit for microgrid operations and subsequently a decrement in the electricity cost. Results recorded in [42] have used 240 residential buildings in the pilot study. The proposed system in [64] has enhanced the lighting reduction level by about 16.22%.

Results of the proposed DR management have kept building's ED within a pre-defined limit for a better management of supply-side to achieve a SG environment [200]. Applying the method presented in [202] can contribute to use buildings as energy suppliers in SGs utilizing DR of building systems and elements e.g., HVAC and TES. As a result, this could be a benefit to load shifting.

Results from simulation scenarios [188] showed ability to un-centrally control loads towards energy reduction and thus that would lead to substantial smart energy retrofit. Results mentioned in [205] have mentioned that 16.5% of annual energy cost-saving was obtained, consumer energy-consumption reduction was 15.9, CO_2 reduction was 27%, and generation cost reduction made by RER was 45.3%. About 43% and 17% of reduction during peak loads were obtained in the building modeled by EnergyPlus as reported in [190] and [213], respectively.

3) HVAC CONTROL

In [5], results from the simulation work have achieved fast energy reduction when a DR request has been sent to the building. Results reported in [230] showed that storage of chiller has been reduced by 24% and the total energy cost has been reduced by 29.7%. Obtained results from [228] showed that the frequency regulation quality is higher than other competitive research works. The fast DR strategy presented in [20] has achieved 12.7% more energy reduction as an instant response to SG requests.

EDR in cluster-level [221] and aggregated [207] buildings was considered. For [221], it has achieved 10% of aggregated demand reduction during peak times and achieved 5% saving related to electricity cost. And for [207], simulated results mentioned prominent EDR from multiple or aggregated buildings. EDR in [224] and [208] was 11.2% and 23%, respectively.

TES capacity was reported that it enhances EDR. In [209], results showed capability of using pumps in enhancing thermal storage systems in buildings by increasing their capacity which leads to more EDR and shifting loads specifically during peak periods. It was found that HVAC loads control strategy associated with TES capacity increment can enhance DR and help reduce energy cost [215].

Results reported in [214] mentioned that 34% of energy costs can be saved as a result of using preheating strategies with the help of TES.

In [216], results have mentioned that even though an increase of energy-consumption by about 8%, the environmental impact did not increase due to operation occurrence in certain intervals of times with lower CO_2 emissions in energy generation.

D. PROGRAMMABLE DR STRATEGIES

The paper [239] has evaluated performance(s) of several proposed systems including MILP model of building energy management and related results have been compared. Strategies of the dynamic pricing DR, RES-based generation systems, charge and discharge of energy of smart appliances like ESD, and EVs, PV in a bi-directional mode have been embedded in the evaluation. Obtained results have proven that the modelling system considering thermal characteristics is better than other competitive research works in terms of DR in which reduction percentage in electricity price has been recorded to be 29.5%.

Results in [242] have used 10,000 aggregated units. The dynamic DR controller [72] has enhanced energy-saving and load shifting to off-peak by reducing demand on peak periods; where energy cost reduction was 14% annually utilizing real-time pricing.

E. AI-BASED DR

For RL, results obtained from [244] stated that lighting can be automatically controlled inside the building. It is also stated that the online interaction between SG and the building can lead to achieve an efficient DR.

For ML, results stated that applying the predictive algorithm [247] could be able to contribute to reduce energy cost for customers and cost for utility generation by 41.8 and 39%, respectively. It has also reduced CO_2 emissions by 37.9%.

GA has enhanced energy cost-saving as reported in [79] and [248]. Annual reduction in electricity bill has been recorded to be 25.23% after the proposed system has been applied [79]. Besides, GA-based sizing algorithm has reduced energy-consumption by 61.43%. Results mentioned that when using load prediction uncertainty, it is able to enhance energy cost-saving by about 7.3% daily [248].

Regarding NN, in [249], about 120 building air-conditioning services were used where simulated results showed that a NN-based DR system has reduced the ED level by more than 30%. Results reported in [252] showed an effectively forecasting performance model of aggregated and disaggregated loads with one-hour accuracy which is more accurate than conventional competitive methods.

F. OTHER TECHNOLOGIES AND SYSTEMS APPLIED FOR DR IN SG

1) OPTIMIZATION-BASED DR

Results obtained in [43] have reported that it is necessary to model energy-use of a residential building to come up with an optimal DR policy. It is necessary to consider information of the dynamic energy price for better performance of heuristic DR policy. The OpenADR [81] has been demonstrated to be beneficially integrated with BEMS. In another residential building scenario, reported results showed that the annual EDR made by HVAC has been reduced by 19.25% [256]. Results reported in [255] mentioned that the energy cost could be reduced by 12.1 - 58.3% while energy pricing plans and thermal comfort are considered.

2) PREDICTION-BASED DR

The results presented in [263] showed that the proposed framework can meaningfully improve the load estimation's accuracy. Root mean square error (RMSE) is reduced by 15 - 22% when compared to other competitive research studies where 2500 smart meters have been used.

3) SCHEDULING-BASED DR

The proposed framework has contributed to a DR service to solve the charging scheduling problem associated with SG-connected appliances e.g., EV [273]. The proposed model has attempted to use SG to solve the problem of charging scheduling of a smart EV. It has utilized SG to implement a DR as a service. Results related to scheduling and control of appliances of smart DR have mentioned that 15% of electricity cost was reduced [270].

VII. ANALYSIS

A. DR-RELATED METHODS AND STRATEGIES APPLIED BY REVIEWED ARTICLES

Most commonly applied methods and strategies by reviewed articles are analyzed. In this analysis, main methods have

TABLE 3. Analysis of DR-related methods and strategies applied by reviewed articles.

Method	Strategy	Number of usages	%	[References]
Control	HVAC control	37	22.02%	[5, 20, 25, 69, 76, 78, 206-228, 230, 275-280]
	Loads control	27	16.07%	[21, 42, 52, 63, 64, 68, 72, 75, 187-191, 194-205, 241, 242]
	Automated control	4	2.38%	[18, 73, 231, 281]
Incentive	-	24	14.29%	[11, 54, 74, 147-154, 158-163, 282-288]
Price	-	21	12.5%	[26, 144, 166-174, 177-184, 289, 290]
Other	Optimization	14	8.33%	[43, 81, 165, 253-262, 291]
	Scheduling	8	4.76%	[164, 268-274]
	Communication services	8	4.76%	[71, 84, 232-237]
	Prediction	10	5.95%	[41, 44, 263-267, 292-294]
	PAR	2	1.19%	[77, 185]
AI	NN	5	2.98%	[70, 249-252]
	ML	3	1.79%	[245-247]
	RL	3	1.79%	[243, 244, 295]
	GA	2	1.19%	[79, 248]

been classified into certain groups. However, methods applied and proposed by researchers have borrowed some other strategies. This review has analyzed the reviewed articles with consideration to methods and strategies to highlight them in terms of number of usages. For this, they have been sort from largest to smallest in percentage(s). Relative references have also been mentioned. Analyzed results have been provided in Table 3.

Table 3 has shown that the control-based methods for the purpose of DR in SG-adopted buildings have been the most used methods amongst others with about 22.02% utilizing HVAC, 16.07% loads control, and 2.38% automated control. A total of 68 reviewed articles (or 40.48%) has considered the control-based methods for achieving DR. Following, are incentive- and price-based methods centric for occupants to encourage them to cooperate with DR interaction to constitute demand-responsive buildings. For these two methods, studies from 24 and 21 articles representing 14.29% and 12.5%, respectively, have been obtained. Analysis's results provided in Table 3 might indicate that the proposed systems, presented in the reviewed articles, dedicated for DR tend to utilize the controllable loads to better perform with SG requests. The reason(s) why controllable loads are preferable to DR systems will be investigated and discussed in the Research Question-based Analysis Section later on.

B. ANALYSIS OF METHODS USED IN RELATION TO CASE-STUDY BUILDING TYPE AND SCENARIO TYPE

Distribution of reviewed articles in which case studies (CS) building type, methods applied, and year(s) will be analyzed and provided in Table 4.

From Table 4, it can be understood that most proposed DR-related systems and studies tend to apply DR to residential buildings. The percentage(s) of CS residential buildings and other case studies have been calculated. Distribution of articles, [%], based on the CS building type has been shown in Figure 10.

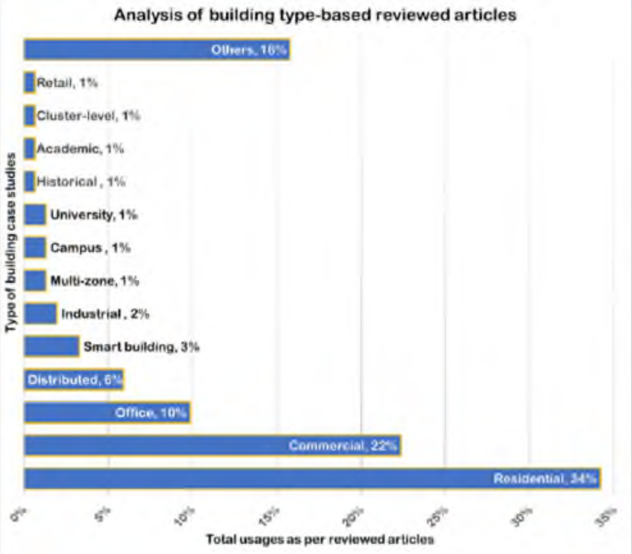


FIGURE 10. Distribution of articles according to CS building type.

In Figure 10, it is noticeable that residential and commercial buildings occupy more than 50% of all CS buildings. Besides, distributed and industrial buildings have been considered by less than 10% whereas if this percentage is increased up to, for example, 30%, more energy-saving rates might be achieved as industrial buildings have heavy loads. Further distributed or industrial buildings focused research studies are encouraged to increase energy-savings and that might reduce CO_2 due to the reduction in ED then.

1) METHODS VS. SCENARIO TYPE

It is also of importance to highlight methods used with scenario types. An analysis of distribution of reviewed articles regarding the method (strategy) applied to the scenario type, as shown in Figure 11.

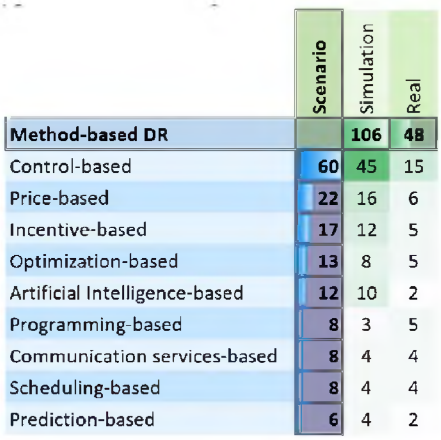
As shown in Figure 11, there are five areas, explained as follows: the far-left area with a blue-colored background represents strategy (method) used by articles, the left area with blue-colored bars represents the total number of articles applying relative strategy, the far-top area with

TABLE 4. Analysis of methods applied to several CS buildings types.

Ref.	Year	Method – strategy	Case study (CS) building type
[43]	2013	Optimization	Residential
[273]	2016	Scheduling	Smart
[44]	2016	Prediction	Residential
[246]	2012	AI	Residential
[185]	2020	Peak-to-average ratio (PAR) control	Residential
[226]	2018	HVAC control	Residential
[275]	2017	Control	Residential
[73]	2017	Control	Residential
[239]	2017	Programming model	Residential
[71]	2012	Communication services of data exchange	Residential & commercial
[41]	2016	Programming-based services enhancement of DR	Commercial
[42]	2015	Control of smart appliances	Residential
[242]	2012	A programmable controllable loads method of DERs	Aggregated units
[72]	2014	Programming simulator	Residential
[249]	2015	NN model	Office
[238]	2017	Programming model	Smart
[177]	2018	Dynamic price signals-based DR controller	Commercial
[251]	2016	NN-based DR model	Office
[200]	2015	Control	Office
[204]	2012	Control model	Distributed
[276]	2018	Control	Residential
[278]	2018	Control	Residential
[77]	2013	PAR control	Residential
[237]	2018	Communication services of data delay in DR	Distributed
[179]	2018	Real-time energy price-based DR controller	Residential
[75]	2013	Loads control-focused DR	Smart
[78]	2017	ESS for DR	Residential
[188]	2020	Loads control-based DR	Residential
[168]	2020	Price-based energy flexibility indicator	Residential & commercial
[277]	2018	Control	Commercial
[205]	2016	Loads control-based DR	Commercial & office
[218]	2016	TES control- & TOU electricity tariffs-based DR	Residential
[219]	2019	Thermal storage charging/discharging control	Commercial
[170]	2019	Price-based DR participants' incentives	Residential
[206]	2017	HVAC system active controller-based DR	Residential
[198]	2014	Loads and EVs scheduling model for DR	Residential
[268]	2017	Scheduling of PV batteries for charging and discharging	Commercial
[189]	2015	Active building cold storages control-based DR	Commercial
[256]	2017	Optimization	Residential
[153]	2015	TOU and RTP incentive- and fuzzy logic-based DR	Residential
[257]	2016	Optimization	Industrial
[159]	2016	Customer participation in energy patterns' changing-based DR	Residential
[258]	2018	Optimization	Residential & commercial
[220]	2015	TES-based load management for DR (dynamic pricing)	Office
[221]	2019	TES- and game theory-based load control for DR	Cluster-level, office & commercial
[270]	2018	Control and scheduling building's appliances for a smart DR	Residential
[190]	2017	Major loads control-based DR	Commercial & office
[271]	2018	EVs scheduling	Office
[160]	2018	Occupants' incentive	Residential
[222]	2019	Active TES control method-based fast DR	Commercial
[223]	2019	TES control-based DR	Residential
[207]	2016	Ventilation system control-based DR	Residential
[154]	2014	Occupants' incentive towards carbon reduction	Commercial, industrial & offices
[180]	2019	Price	University
[259]	2017	Optimization	Commercial
[247]	2019	ML-based control method for DR	Residential
[208]	2018	Air-conditioning systems' direct load control-based fast DR	Commercial
[261]	2016	Game theory-based optimization for automatic DR	Residential, commercial & office
[209]	2016	Control of pumps in HVAC systems-based DR	Multi-zone building
[171]	2015	Real-time price-based optimization for TES control	Retail, office & commercial
[172]	2015	Price	Commercial
[210]	2015	Cold storages control-based DR	Commercial
[211]	2017	Air conditioning direct load control-based DR	Commercial
[212]	2013	Heat pumps and RERs-based load control for fluctuations regulation	Residential
[213]	2014	Controlled heat pump-based DR enhancement	Residential
[54]	2017	Occupants' incentive for RERs-based cooling systems for DR enhancement	Residential
[173]	2015	Heat pump control for DR management	Residential
[216]	2018	Heat storage control-based DR	Residential

TABLE 4. ***(Continued.)*** **Analysis of methods applied to several CS buildings types.**

[191]	2018	Loads control	Commercial
[264]	2011	Prediction	Campus
[194]	2018	Smart appliances control-based DR	Historical residential
[225]	2014	TCLs-based DR	Residential
[151]	2010	Occupants-controlled appliances-based DR	commercial & campus
[262]	2016	DR optimization for district cooling and heating networks	Residential
[69]	2015	HVAC control-based DR	Office
[260]	2019	Optimization	Residential & commercial
[245]	2015	ML-based DR predictor	Commercial
[241]	2019	Programing model for demand reduction	Residential & commercial
[266]	2019	Prediction	Residential, commercial & industrial
[195]	2016	Smart appliances control-based DR	Academic & university
[236]	2018	Communication services-based DR management of distributed buildings	Office
[196]	2010	Smart appliance control-based DR	Residential
[19]	2019	Supply-demand-side control method-based DR	Office
[150]	2016	Occupants' cooperation-centric DR	Residential
[224]	2016	Active chillers direct control-based DR	Commercial
[29]	2017	DERs for supply	Distributed and large-scale



Method-based DR	Scenario	Simulation	Real
Method-based DR		106	48
Control-based	60	45	15
Price-based	22	16	6
Incentive-based	17	12	5
Optimization-based	13	8	5
Artificial Intelligence-based	12	10	2
Programming-based	8	3	5
Communication services-based	8	4	4
Scheduling-based	8	4	4
Prediction-based	6	4	2

FIGURE 11. **Distribution of articles based on two criteria; method applied and scenario type.**

a green-colored background represents scenario type, the top area with green-colored bars represents the total number of articles which adopted the relative scenario either a real or simulation one, and the middle-right area with a white-colored background highlights distribution of articles per every two corresponding areas (i.e., strategy/method vs. scenario type). For example, there exist 15 articles that implement real scenarios using the control-based method for DR. Analysis shown in Figure 11 indicates that 82 articles (about 68.8%) have adopted simulation-implemented scenarios. It has indicated that, 45 articles ($\approx$ 42.45% of simulation scenarios and $\approx$ 29.2% of the total number of simulation and real scenarios) belongs to articles that have utilized control methods to apply DR in SG-adopted buildings. Hence, many control-related DR strategies tend to control loads to enhance DR performance in SG-adopted buildings. This analysis has noticeably shown that simulation scenarios are preferable specifically with control-, price-, incentive-, optimization-, artificial intelligence-, and prediction-based methods.

2) CS BUILDING TYPE VS. SCENARIO TYPE

We have analyzed the reviewed articles depending on two criteria which are CS building type and scenario type (i.e., real or simulation) to highlight two issues, which are: 1) which scenario is being implemented more than the other in general? and 2) which scenario is being implemented more than the other per each CS building type? Obtained results from this analysis are shown in Figure 12.

In Figure 12, real and simulation scenarios implemented to CSs building types by reviewed articles are calculated per reviewed articles. It is shown that, for example, 24% of articles amongst all analyzed articles have implemented simulation scenarios for only residential buildings where as 10% have implemented real scenarios for the same type of buildings. By comparing these two values in relation to the total of 34%, about 70.58% of scenarios implemented are a simulation. Analyzed results show that: 1) in general, simulation scenarios have been implemented more than real ones, 2) per each CS building type, the simulation scenario has more rates than the real scenario but historical buildings due to the historical buildings probably might require real implemented strategies such as retrofitting systems. Besides, it is noticeable with several case studies, real scenarios are not considered by articles-related studies. That indicates real scenarios implementation is still of shortage.

3) CS BUILDING TYPE VS. SCENARIO VS. PLACE OF STUDY

Distribution of total reviewed articles in relation to three criteria, which are CS building type, scenario, and place of study in which method has been implemented, is shown in a 4D-heatmap illustrated in Figure 13.

Figure 13 shows distribution of articles based on place of study, CS building type, and scenario type. To read it easily, for example, USA contains 31 case studies (i.e., total articles), nine of which are of residential buildings (seven and two CSs are classified as simulation and real scenarios, respectively), eight of which are of commercial buildings, four of which are

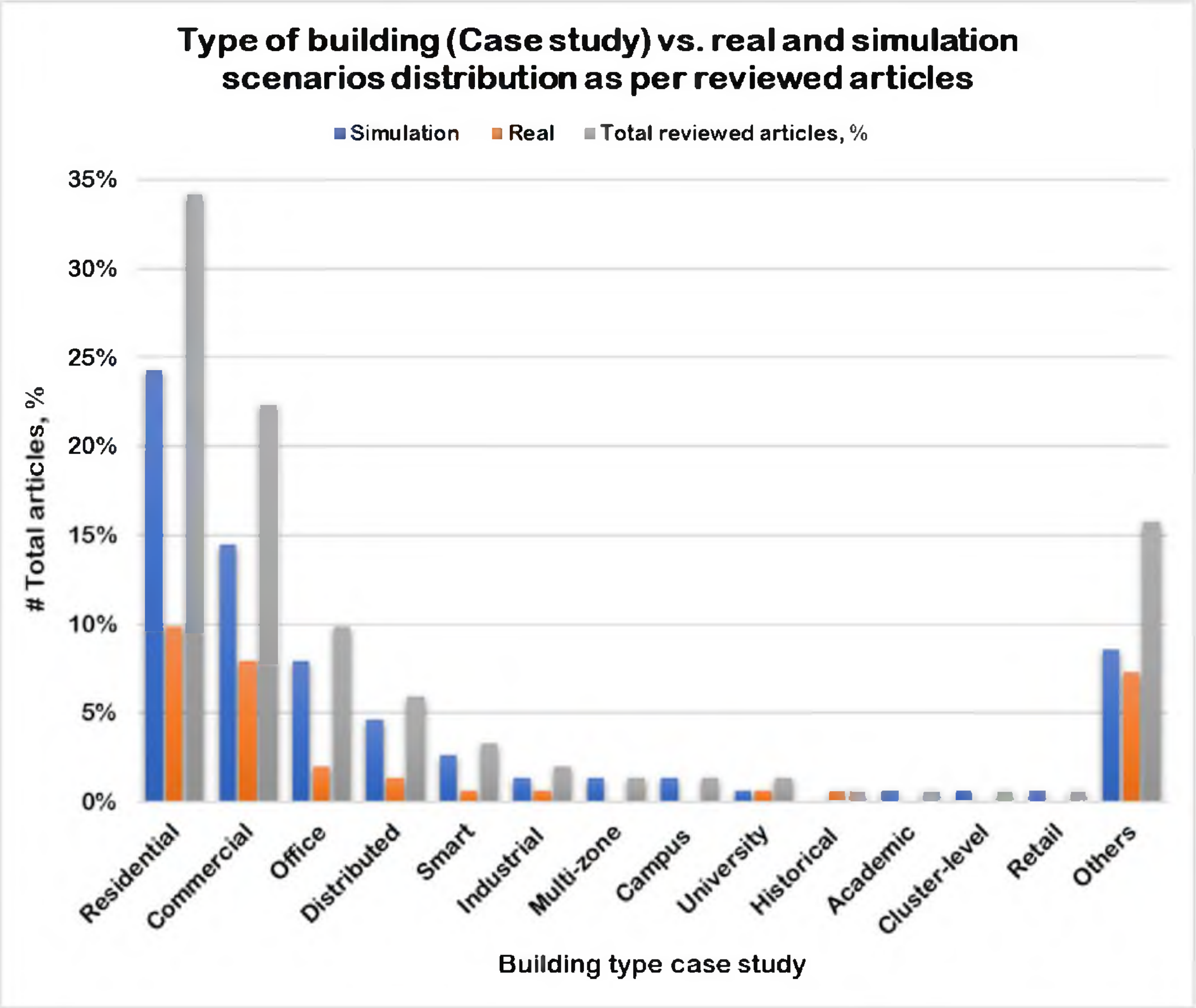


FIGURE 12. Analysis of CS building type considering simulation and real scenarios.

of office buildings, three of which are of distributed buildings, and seven of which are of other types of buildings. The USA-implemented 31 case studies are distributed as 25 and 6 for simulation and real scenarios. Figure 13 shows that the most case studies implemented are, in a descending order, 13, 9, 8, and 7, as highlighted in green-colored background(s).

4) METHOD VS. PLACE OF STUDY

The following analysis highlights place-of-study-used methods. This analysis also counts frequency of each method used in a certain place of study. Besides, this analysis shows if a certain method is being adopted in several places of study. Another interesting feature is that, what methods are highly used within a study's place have been highlighted. Results from this analysis are shown in Figure 14.

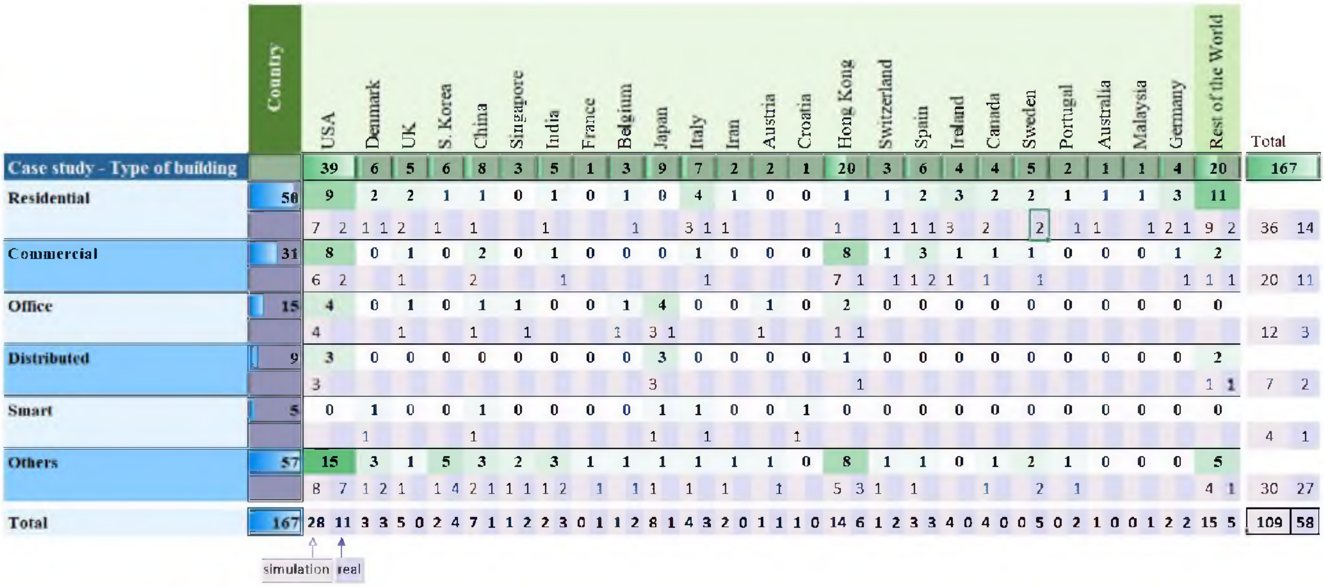
Figure 14 shows the total number of articles for two criteria which are a place of study and method used. The analysis results showed that USA has the highest number of implemented case studies by which the related methods are selected. This analysis shows that the control method has been highly utilized by SG participants to achieve DR. This analysis pointed out methods being adopted in a certain place of study. That would be of feature to researchers on what interests amongst that place of study are or what methods which are not yet used in that place of study so it can be useful to keep enhancing existing methods or focus on a new type of methods. In line with this, a simple World map-based distribution of DR strategies implemented is illustrated in Figure 15.

The distribution shown in Figure 15 has been viewed in a timeline using a video file format and is available and downloadable via a link to be provided, however.

C. ANALYSIS OF APPLICATIONS REPORTED IN REVIEWED ARTICLES

In this sub-section, a heatmap-based analysis to highlight distribution of articles according to application(s) reported, methods applied, and CS building type implemented in the reviewed articles will be presented.

A 3D-based comparative analysis will be derived from all reviewed articles to come out with a comprehensive



	Country	USA		Denmark		UK		S. Korea		China		Singapore		India		France		Belgium		Japan	
Case study - Type of building		39		6		5		6		8		3		5		1		3		9	
Residential	50	9		2		2		1		1		0		1		0		1		0	
		7	2	1	1	2		1		1				1					1		
Commercial	31	8		0		1		0		2		0		1		0		0		0	
		6	2			1				2					1						
Office	15	4		0		1		0		1		1		0		0		1		4	
		4				1				1			1					1		3	1
Distributed	9	3		0		0		0		0		0		0		0		0		3	
		3																		3	
Smart	5	0		1		0		0		1		0		0		0		0		1	
				1						1										1	
Others	57	15		3		1		5		3		2		3		1		1		1	
		8	7	1	2	1		1	4	2	1	1	1	1	2		1		1	1	
Total	167	28	11	3	3	5	0	2	4	7	1	1	2	2	3	0	1	1	2	8	1
		simulation	real																		

	Italy		Iran		Austria		Croatia		Hong Kong		Switzerland		Spain		Ireland		Canada		Sweden		Portugal		Australia		Malaysia		Germany		Rest of the World		Total	
Case study - Type of building	7		2		2		1		20		3		6		4		4		5		2		1		1		4		20		167	
Residential	4		1		0		0		1		1		2		3		2		2		1		1		1		3		11			
	3	1	1						1			1	1	1	3		2			2		1	1			1	2	1	9	2	36	14
Commercial	1		0		0		0		8		1		3		1		1		1		0		0		0		1		2			
		1							7	1		1	1	2	1		1			1								1	1	1	20	11
Office	0		0		1		0		2		0		0		0		0		0		0		0		0		0		0			
					1				1	1																					12	3
Distributed	0		0		0		0		1		0		0		0		0		0		0		0		0		0		2			
										1																			1	1	7	2
Smart	1		0		0		1		0		0		0		0		0		0		0		0		0		0		0			
		1					1																								4	1
Others	1		1		1		0		8		1		1		0		1		2		1		0		0		0		5			
	1		1			1			5	3	1		1				1			2		1							4	1	30	27
Total	4	3	2	0	1	1	1	0	14	6	1	2	3	3	4	0	4	0	0	5	0	2	1	0	0	1	2	2	15	5	109	58

FIGURE 13. A 4D-heatmap analysis according to CS building type, place of study, scenario type, and reviewed articles.

overview that highlights how many numbers of articles (studies, designs, case studies, scenarios either real or simulated ones …etc.) have implemented a single type of method. Besides, how many applications can be suitable to (or have been utilized by) such a method, will be highlighted as shown in Figure 16. Additionally, distribution of applications reported in articles according to CS building type is shown in Figure 17.

Analysis results shown in Figure 16 show that there is an interest in DSM application. It means that DR strategies have exploited control methods to enhance DSM for SG-adopted buildings. This analysis shows that 47 out of 152 articles (30.9%) focus on DSM in which all methods' types are inclusive. In regard to the method type, 19 out of 60 articles (31.67%) reported the DSM application. Similarly, and in regard to the application, 19 out of 47 (40%) articles have highlighted that they tend to adopt the control method to gain suitability of the relative application to DSM. Thus, strength of relation the application (as an example, DSM) to the method (as an example, control) is higher according to results (31.67% and 40%) obtained. Hence and due to that 'control' and 'DSM' locate at top of results (considering rows and columns), this points out that control method (amongst other methods) is more suitable to be used to achieve DSM. Similarly, DSM-related articles are the highly frequent application utilizing control methods. The application of energy storage locates secondly, after DSM, with 34 articles out of 152 (22.36%). Similarly, 17 out of 34 applications have adopted the control method to achieve energy storage within SG-adopted buildings.

In Figure 17, distribution of articles shows the following: 1) the top three applications are energy storage, DSM, and loads control and scheduling, 2) about 68.4% (104 out of 152) of articles are within the top three amongst others, 3) there are two CS building types of top interest and concern reported in reviewed articles which are residential and commercial buildings, 4) the highly frequent distribution of articles belongs to only one application (energy storage) and two CS building types (residential and commercial), 5) approximately 20% (30/152) of articles locate within the energy storage application for only residential and commercial buildings, and the highest three concerns shown by this analysis are as follows: energy storage in residential buildings, energy storage in commercial buildings, and DSM in residential buildings, according to distribution of articles equals to 16, 14, and 10, respectively.

D. ANALYSIS RELATED TO APPLIANCES AND ELEMENTS

This analysis considers appliances being used by different research studies and systems proposed in related articles. In this sub-section, three types of analyzed results obtained according to articles are presented. There have been three analyses implemented which are in detail described and shown in Table 5, Figure 18, and Figure 19.

The first one highlights smart or ordinary appliances, elements, or facilities that have been considered by other articles' proposed systems. A list of related appliances used by reviewed articles is provided in Table 5.

In Table 5, appliances and other elements used by proposed DR strategies applied to SG-adopted buildings. Besides, methods used and scenario type are inclusive. Amongst these, frequency of usages of elements varies and a related statistical analysis to highlight distribution of elements usages over years as extracted from reviewed articles is shown in Figure 18.

A timeline is provided in Figure 18 to preview periods of years (2010 - 2020) over which elements are distributed. As shown in Figure 18, it is noticeable that numerous types

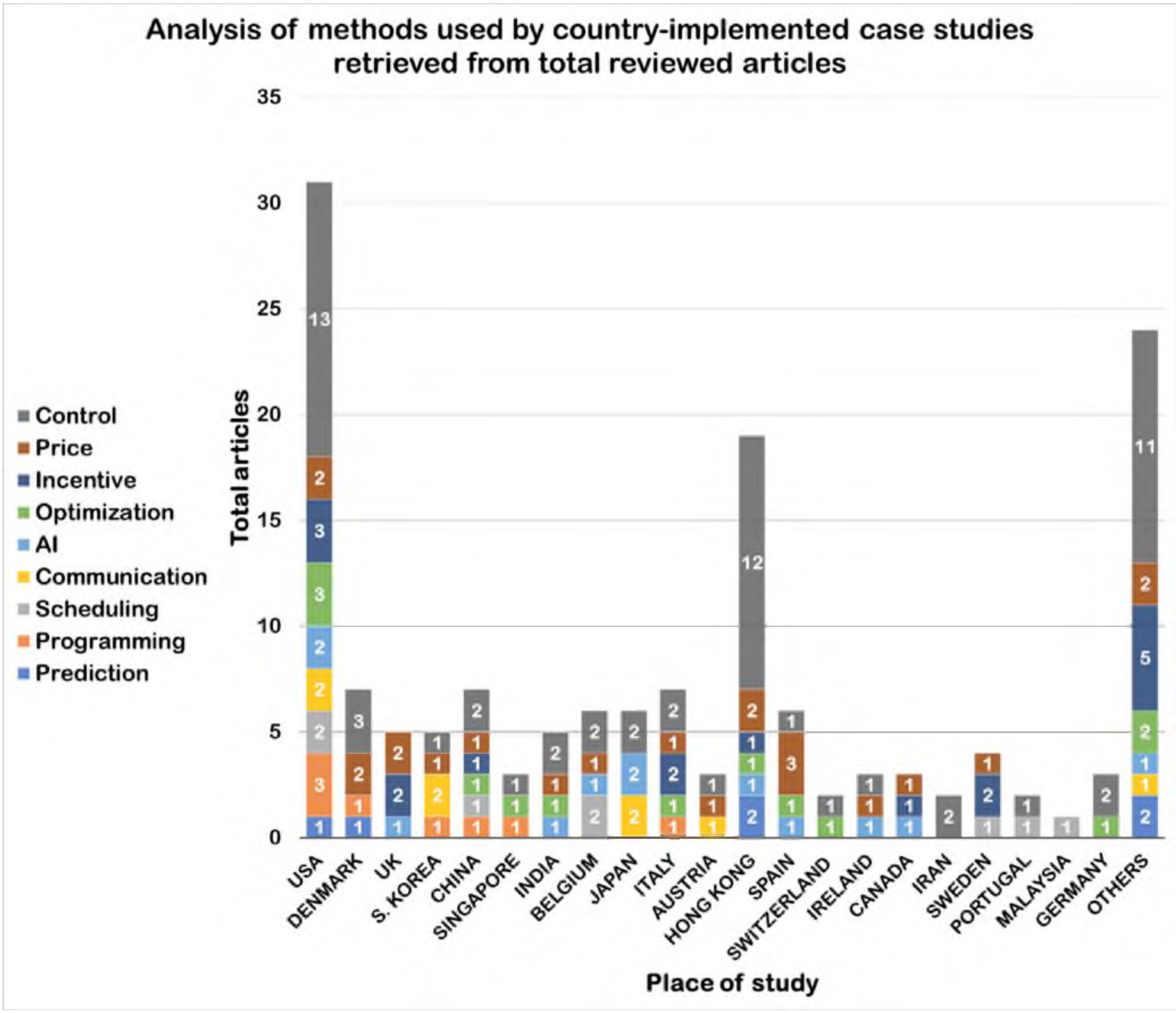


FIGURE 14. Distribution of articles as per place of study and methods.

of appliances/elements are most frequent after the year 2015. Also, a number of appliances are highly used over the whole period (2010 - 2020) e.g., loads and HVAC. Thus, an additional analysis to highlight the percentage of usages of appliances over others is shown in Figure 19.

Figure 19 shows that only two appliances (controllable loads and HVAC) have been used with a percentage of (~40%). This indicates how much DR strategies depend on controlling these two elements to achieve better performance inside SG-adopted buildings. However, some other elements by which achieving enhancement in DR strategies' role in SG-adopted buildings is applicable might be of use due to their role in terms of information exchange between utilities. Smart meters and EVs, for example, can lead in this direction and other directions such as scheduling of charging and EDR.

E. ANALYSIS OF PROGRAMMING LANGUAGES AND SIMULATION TOOLS ACCORDING TO REVIEWED ARTICLES

In this analysis, the focus is to highlight the programming languages and simulation tools being used with DR strategies applied to SG-adopted buildings. There are six analyses described in Table 6, Table 7, Table 8, Figure 20, Figure 21, and Figure 22. Firstly, an analysis related to programming tools used by reviewed articles is provided in Table 6.

Table 6 shows a list of programming and modelling-languages, simulation tools, and other software used to perform either simulation, real scenarios, or even both. A statistical analysis summarizing total usages of these languages and tools according to number of real and simulation scenarios is shown in Figure 20.

As shown in Figure 20, it is noticeable that "MATLAB" has the largest number of usages amongst all other

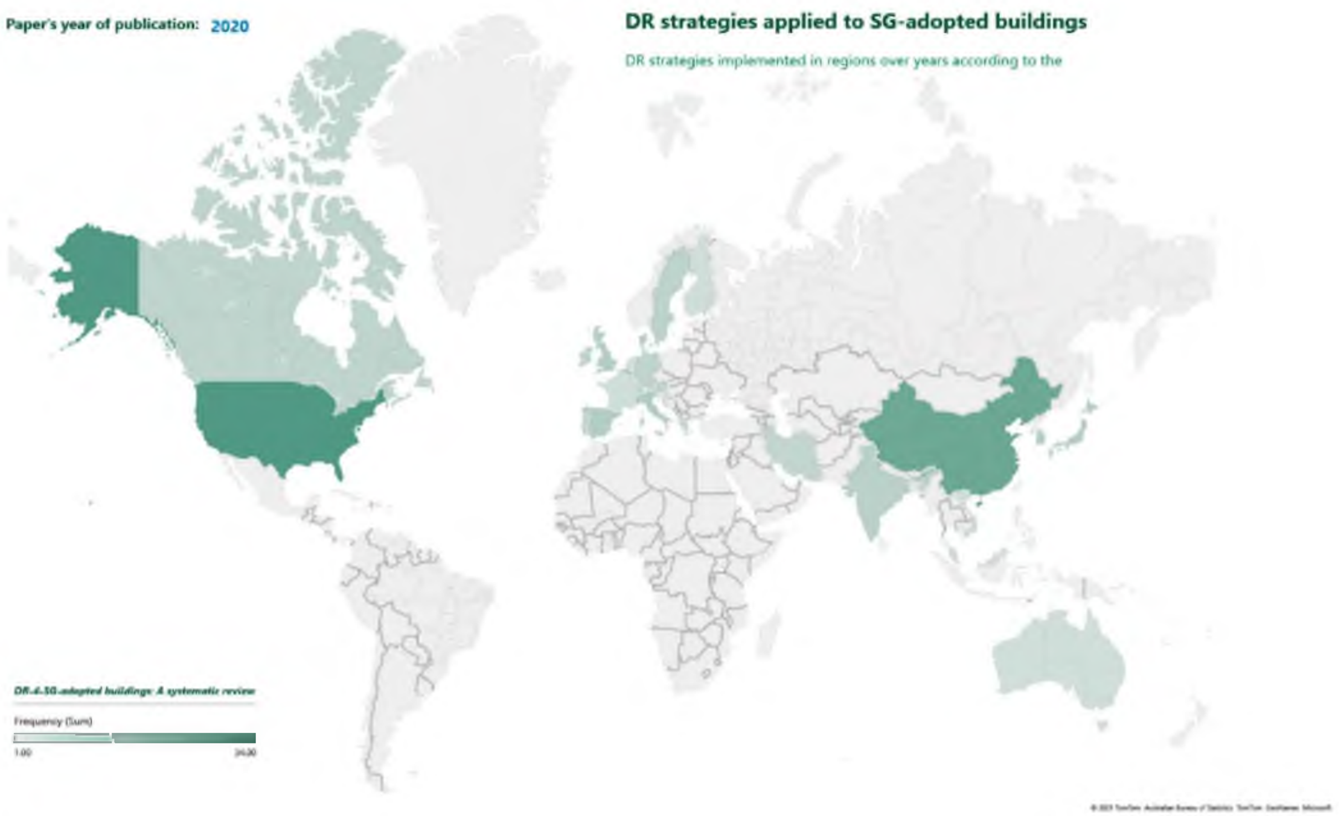
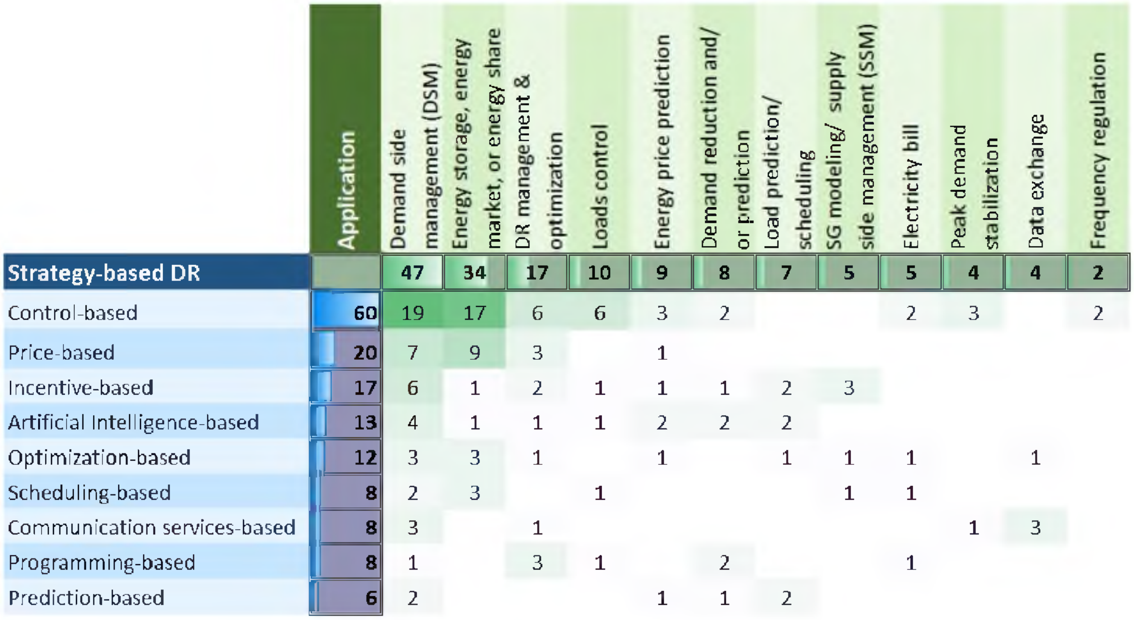


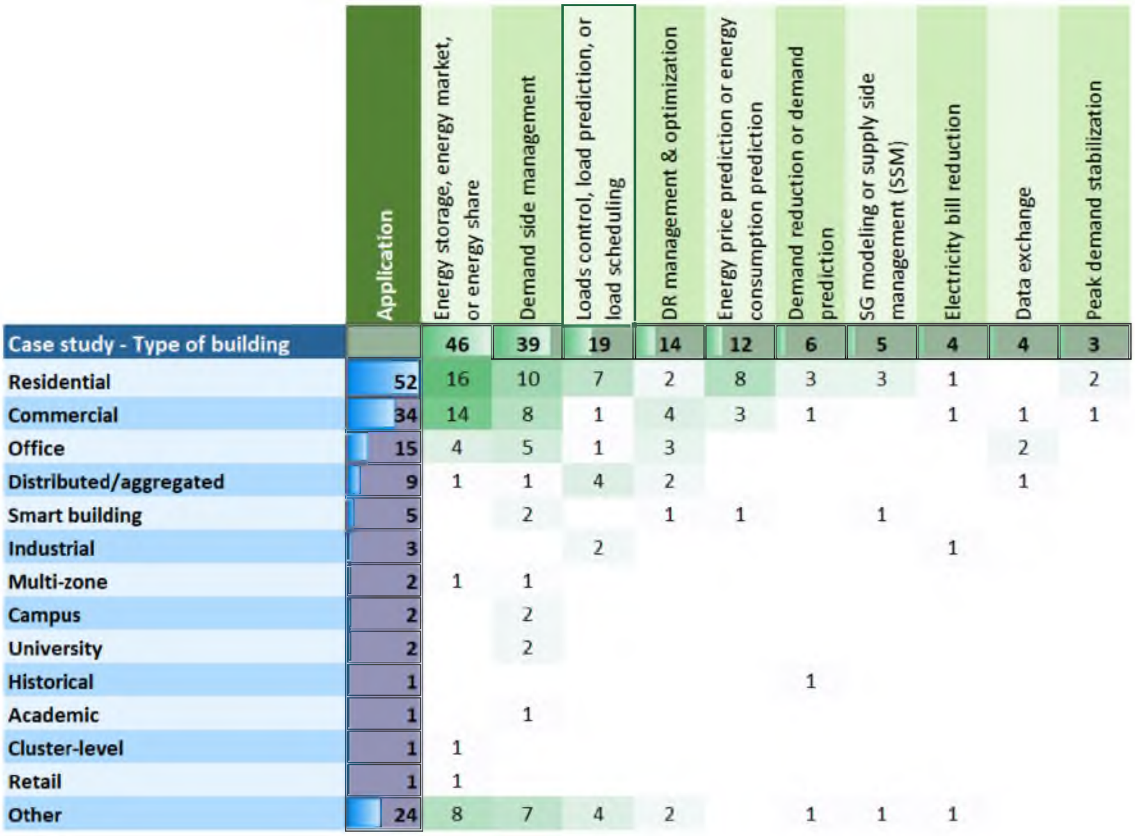
FIGURE 15. World map-distributed implemented DR strategies according to 201-reviewed papers. Statistics of this analysis are based on information retrieved from reviewed papers in this review research. Illustration of Figure 15 is designed by authors using Microsoft Excel 2016.



	Application	Demand side management (DSM)	Energy storage, energy market, or energy share	DR management & optimization	Loads control	Energy price prediction	Demand reduction and/ or prediction	Load prediction/ scheduling	SG modeling/ supply side management (SSM)	Electricity bill	Peak demand stabilization	Data exchange	Frequency regulation
Strategy-based DR		47	34	17	10	9	8	7	5	5	4	4	2
Control-based	60	19	17	6	6	3	2			2	3		2
Price-based	20	7	9	3		1							
Incentive-based	17	6	1	2	1	1	1	2	3				
Artificial Intelligence-based	13	4	1	1	1	2	2	2					
Optimization-based	12	3	3	1		1		1	1	1		1	
Scheduling-based	8	2	3		1				1	1			
Communication services-based	8	3		1							1	3	
Programming-based	8	1		3	1		2			1			
Prediction-based	6	2				1	1	2					

FIGURE 16. Distribution of applications reported in articles according to the methods used.

programming languages and simulation tools, with 21 times. The "EnergyPlus" and "TRNSYS" come next in the list with 19 and 17 times, respectively. It is noticeable that simulation scenarios for these three modeling tools are higher than real ones. The highest model used for simulation-purposed scenarios is "EnergyPlus" with 17 times. The term "Others"



Case study - Type of building	Application	Energy storage, energy market, or energy share	Demand side management	Loads control, load prediction, or load scheduling	DR management & optimization	Energy price prediction or energy consumption prediction	Demand reduction or demand prediction	SG modeling or supply side management (SSM)	Electricity bill reduction	Data exchange	Peak demand stabilization
		46	39	19	14	12	6	5	4	4	3
Residential	52	16	10	7	2	8	3	3	1		2
Commercial	34	14	8	1	4	3	1		1	1	1
Office	15	4	5	1	3					2	
Distributed/aggregated	9	1	1	4	2					1	
Smart building	5		2		1	1		1			
Industrial	3			2					1		
Multi-zone	2	1	1								
Campus	2		2								
University	2		2								
Historical	1						1				
Academic	1		1								
Cluster-level	1	1									
Retail	1	1									
Other	24	8	7	4	2		1	1	1		

FIGURE 17. Distribution of applications reported in articles according to CS building type.

at the bottom in the list includes several programming languages, tools, and models used for simulation and real scenarios, where this includes about 21 listed elements. Detailed and further information is available.

Reviewed articles showed that these programming/ modelling languages and tools have been helped by using other elements in the relative SG-adopted buildings. A detailed list highlighting usage of programming languages with other associated buildings-related elements is provided, where several elements are listed in Table 7.

As shown in Table 7, a certain programming language or simulation tool can be used to do its role or tasks with a varied group of elements. That means "MATLAB", for example, is applicable with varied elements such as "HVAC", "controllable loads", "RTP", "lights", and few others to perform modeling tasks. More statistical information related to programming languages and simulation tools and their associated elements according to the articles utilizing both is in detail summarized and shown in Figure 21.

Figure 21 shows that there are a lot of programming languages and modelling and simulation tools that can be used with many other building-related elements which make these programming languages and simulation tools applicable with a wide range of applications towards enhancing DR performance in SG-adopted buildings. In order to show what types of methods utilizing programming languages and modelling and simulation tools and what the most methods are used with the largest frequency of programming languages, a reviewed articles-derived summary related to methods versus programming languages and simulation tools is listed in Table 8.

In Table 8, it is noticeable that the relationship between programming languages and methods is of type many-to-many. There are many methods utilizing many programming languages. Besides, a heatmap-based analysis highlighting frequency of use of each of programming languages and simulation tools with methods is shown in Figure 22.

Figure 22 shows that most frequent programming languages have been "MATLAB", "TRNSYS", and "EnergyPlus" with a total use equal to 23, 20, and 17, respectively. That indicates applicability of using many modelling and simulation tools with several types of methods. Also, it is noticeable that the control method, for example, has ability to utilize most of listed programming languages and simulation tools.

VIII. RESEARCH QUESTIONS-BASED ANALYSIS AND EVALUATION

In this analysis, each reviewed article has been investigated and checked according to the four research questions. Each article has been displayed to answer questions one-by-one. Here, we present answers to research questions retrieved from

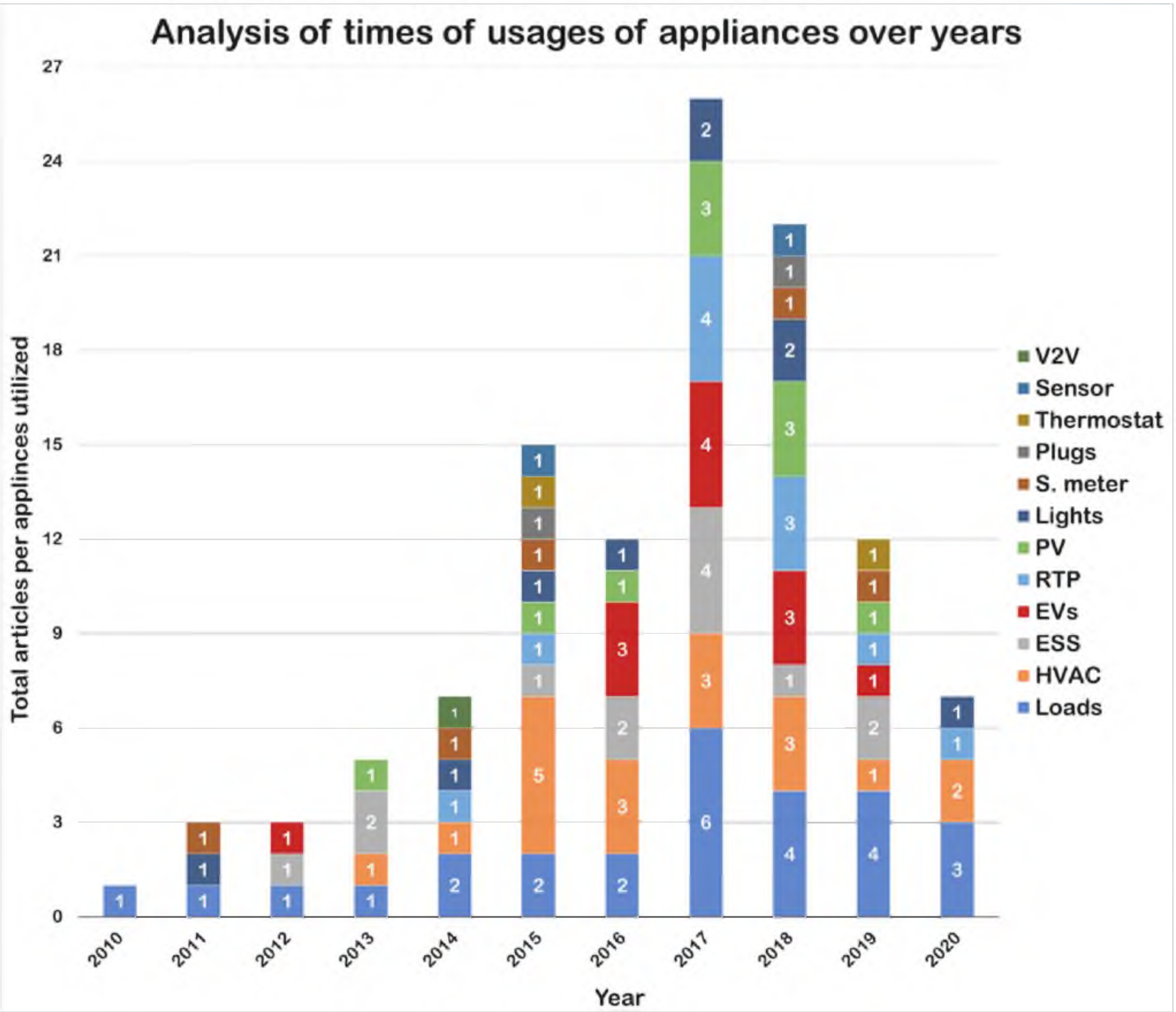


FIGURE 18. Analysis of times of usages of appliances/ elements in DR systems over years as per reviewed articles.

reviewed articles. A total of 113 articles have been used in this type of analysis. The number of articles is determined by the possibility of the article to provide an answer to the research questions.

Each research question's answers are gathered and classified based on method's type. The reason is to evaluate and compare between answers according to type of method proposed by each reviewed article. This help understand the purpose of the article's proposed system or design based on the method selected. After that, a list of findings found will be provided, analyzed, and evaluated. Additionally, relationships between the first and second research questions will be derived and investigated for further understanding and recommendation for future research works in terms of improvement of DR strategies applied to SG-adopted buildings. Finally, most commonly used methods and most effective methods related to DR strategies applied to SG-adopted buildings will be highlighted.

A. RESEARCH QUESTION 1: "WHAT ARE THE REASONS/NEEDS FOR WHICH SUCH A REVIEWED ARTICLE HAS DESIGNED THE PROPOSED SYSTEM?"

To answer this question, each article has provided an answer to it. All answers collected from reviewed articles used in this analysis have been listed in a separate table; *related data is available with authors*. A distribution procedure has been applied to create a classification criterion of produced answers.

1) CLASSIFIED ANSWERS TO RQ1

Each article has its own answer based on the purpose or the need each article aims to consider. By analyzing all those

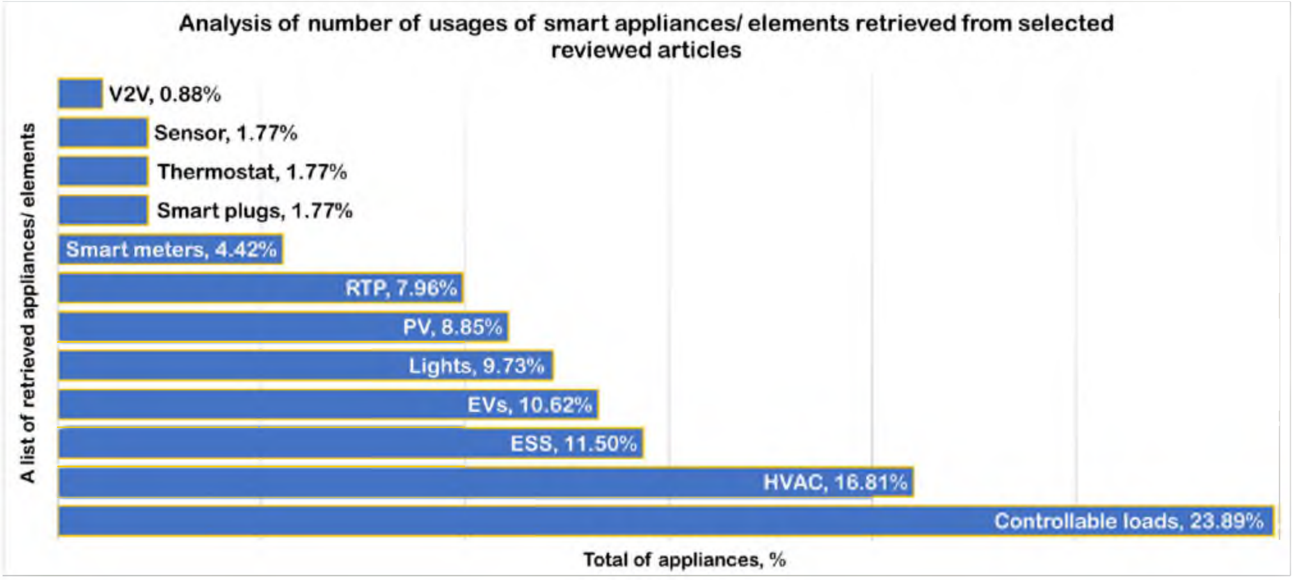
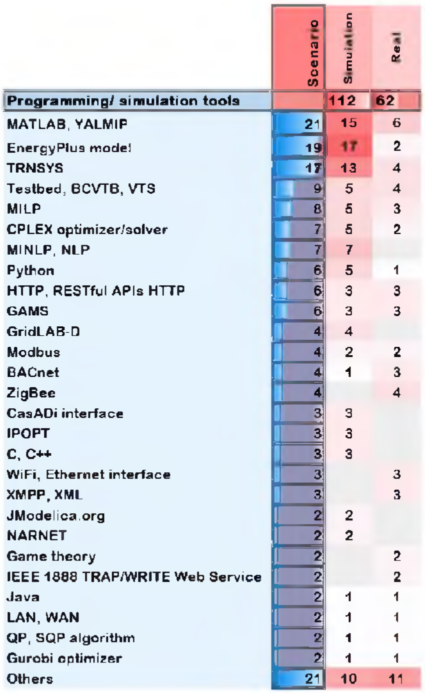


FIGURE 19. Analysis of smart appliances in terms of total of usages [%].



Programming/ simulation tools	Scenario	Simulation	Real
		112	62
MATLAB, YALMIP	21	15	6
EnergyPlus model	19	17	2
TRNSYS	17	13	4
Testbed, BCVTB, VTS	9	5	4
MILP	8	5	3
CPLEX optimizer/solver	7	5	2
MINLP, NLP	7	7	
Python	6	5	1
HTTP, RESTful APIs HTTP	6	3	3
GAMS	6	3	3
GridLAB-D	4	4	
Modbus	4	2	2
BACnet	4	1	3
ZigBee	4		4
CasADi interface	3	3	
IPOPT	3	3	
C, C++	3	3	
WiFi, Ethernet interface	3		3
XMPP, XML	3		3
JModelica.org	2	2	
NARNET	2	2	
Game theory	2		2
IEEE 1888 TRAP/WRITE Web Service	2		2
Java	2	1	1
LAN, WAN	2	1	1
QP, SQP algorithm	2	1	1
Gurobi optimizer	2	1	1
Others	21	10	11

FIGURE 20. A heatmap analysis for occurrences of usages of programming languages, simulation tools, and other tools found in reviewed articles according to the type of scenario used (i.e., either a real or simulation one).

answers (based on each article's need(s)), a total of 16 classified answers has been derived and excluded. We found that, a group of articles are close to some other articles in terms of article's purpose. Meaning, there have at least more than an article shared almost the same answer to RQ1. A list of grouped/classified answers is provided in Table 9.

Data shown in Table 9 will be represented to highlight the percentage related to number of articles that share the same answer, i.e., A1, A2, . . . in relation to the total number of reviewed articles used in this analysis. Distribution of reviewed articles based on the classified answer is shown in Figure 23.

As shown in Figure 23, the distribution of values of percentages is from the highest to the lowest. The highest percentage is of interest. According to Figure 23, 16.81% of analyzed articles have the following answer to RQ1: "A14: The need to reduce energy-consumption". Thus, the purpose of using DR in SG-adopted buildings with the highest percentage amongst articles is to reduce energy-consumption.

As of an answer to the question previously mentioned: "why do we need DR?", it is to reduce energy-consumption, according to 16.81% of total articles' answers. Objective of evaluation related to RQ1 is to find out what the reason an article has utilized DR by the designed system/method of the reviewed article. It is found that an article's purpose to design a system that utilizes DR for reducing energy-consumption has a probability of 0.168.

Another group's answer to the question was "the need to respond to demand or SG requests", with a 10.62% amongst other articles. Similarly, the group of articles answering RQ1 with: "A7: the need to manage energy during peak periods" has a percentage of 10.62%. Subsequently, groups of articles according to classified answers are highlighted in Figure 23.

2) THE RQ1-CONCLUDED POINT IS THAT

SG or energy grid has been utilized by 16.81% of reviewed articles to help buildings reduce their energy-consumption via DR. Besides, SG has been used to either respond to demand requests or to manage energy network during peak hours by

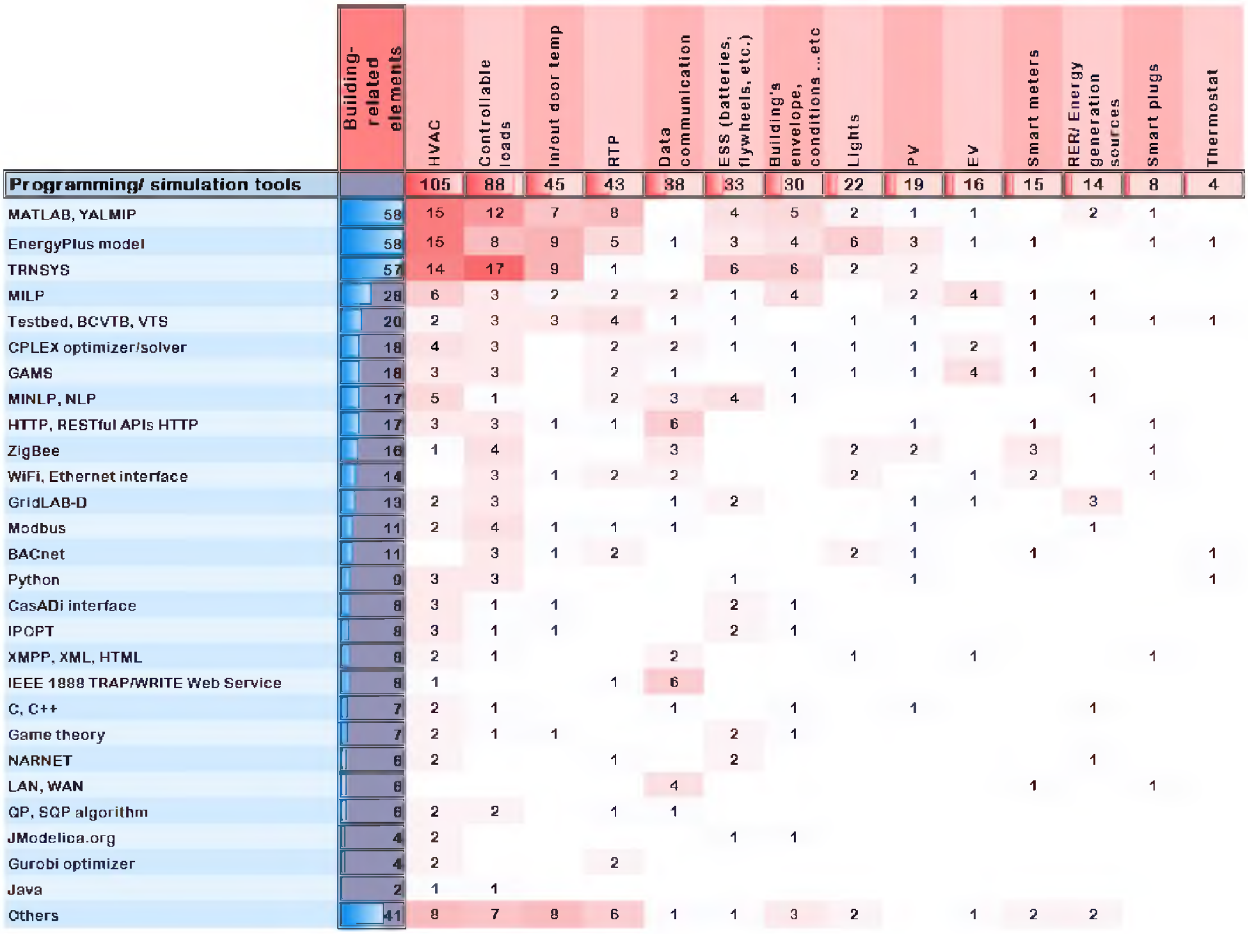
TABLE 5. Analysis of smart/ordinary appliances/elements/facilities according to reviewed articles.

Method's description	A list of appliances/ elements/ facilities	Scenario	Ref.
Controllable loads-based DR	Air conditioners, indoor temperature data, rooftop units	Real	[63]
Programming language - MATLAB	Smart plugs	Real	[240]
Controllable loads	Energy storage, EVs, controllable end-use loads	Simulation	[242]
GA-based DR energy management system	Battery energy storage	Simulation	[79]
NN-based DR system	Air-conditioning	Simulation	[249]
Optimization modelling of DR	EVs, storage systems, smart charging, V2G	Real	[238]
Price-based DR management and control	Solar power, heat pump, inflexible loads, EVs, lighting systems and air conditioners	Simulation	[177]
PAR control method	Battery, HVAC, lights	Simulation	[77]
RTP-based DR	Air conditioner, temperature sensing utilizing IoT, RTP utilizing cloud servers	Simulation	[179]
Loads control-focused DR	Controllable loads, battery, PV, RES	Simulation	[75]
HVAC loads control DR	HVAC, energy cost, comfort parameter inconsistency	-	[76]
Energy storage for DR	RC network, air conditioners, building's thermal mass	Simulation	[78]
Price-based DR	EVs, V2B switching method, energy prices	Simulation	[181]
HVAC cooling & control-based DR	HVAC	Simulation	[5]
NN-based HVAC thermal behavior predictor for DR	HVAC, ESS	Simulation	[70]
Price-based DR for energy market	Price signals, loads, OpenADR communication protocol	Simulation	[182]
HVAC's pumps control-based DR	Test rig, HVAC, indoor temperature, HVAC's pumps	Real	[228]
Buildings-installed lifts control-based DR	ZigBee, testbed, LEDs, lifts	Real	[187]
Loads control-based DR	LEDs	Simulation	[188]
Price-based DR	EVs, wind micro-turbine, RTP signal	Simulation	[166]
Buildings' loads control-based DR	PV, ice storage systems	Simulation	[205]
HVAC system active controller-based DR	PV, heating systems, RTP signals	Simulation	[206]
Loads and EVs scheduling model for DR	V2V, loads, RTP	Real	[198]
PV batteries scheduling	PV charging battery, PV providing energy to building, battery discharging energy to building	Real	[268]
TOU and RTP incentive-based DR	Wireless sensors, PCT, RTP signals, HVAC, indoor and outdoor temperature	Simulation	[153]
Dynamic pricing	Lighting, air temperature, pumps	Simulation	[220]
Control and scheduling building's appliances for smart DR	XBee, Controller, smart plugs, PV system	Real	[270]
Major loads control-based DR	Lighting, coffee maker, copy machines, LCD monitors, laser printers, computers	Simulation	[190]
EVs scheduling for energy storage purposes-based DR	PV, EVs, smart meters	Simulation	[271]
Communications services for binary information exchange	Ventilation system, fans	Simulation	[235]
Communication protocols-based DR enhancement	BACnet, ZigBee, smart meters, fluorescent lamp	Real	[84]
ML-based control for DR	Smart meter, indoor temperature	Simulation	[247]
Occupants' promotion utilizing incentive DR	Heat pump, boilers, TES	Simulation	[161]
Game theory-based optimization for automatic DR	Plug-in hybrid EVs, AC, water heater, lights, washers	Simulation	[261]
Heat pump control for DR management	HVAC, heat pumps, PVs	Simulation	[173]
Plug-loads control-based DR	Smart meters, plug-loads, ZigBee, lamps	Real	[197]
Programing model for demand reduction	Thermal batteries, smart thermostats	Simulation	[241]
Smart appliances control-based DR	AC, battery, EVs, plug-in hybrid vehicle and charger, heat-pump water heater, and solar inverter	Simulation	[195]
Smart appliance control-based DR	LCD TV	Real	[196]

the percentages of 10.62% for both of them. Furthermore, SG has been used to reduce the ED by 8.85%. Mentioned are four needs for which SG-adopted buildings aim to fulfill from utilizing DR. Thus, to come up with a simple resultant conclusion from this, these four needs are evaluated in terms of nature of the answer.

As for A14 and A9, it is noticeable that the energy consumed by or demanded by buildings is needed to be reduced. For A1, the answer mentions that there is a need to respond to demand or SG requests, where usually the demand requests demand-side (buildings) to reduce their energy-consumption(s). As for A7, the purpose of the related articles needs is to manage the energy network during peak periods. That is because of the heavy loads caused by the huge demand from buildings. At these periods, energy-consumption rates are high and need to be managed. That indicates, the purpose is to have fewer peak periods by producing more periods at which energy-consumption rates are reduced.

Therefore, the four needs or purposes ordered in a descending format according to value (A14, A1, A7, and A9) have utilized SG and DR to reduce buildings' energy-consumption. Thus, the average percentage can be calculated to be 46.9%.



Programming/ simulation tools	Building-related elements	HVAC	Controllable loads	In/out door temp	RTP	Data communication	ESS (batteries, flywheels, etc.)	Building's envelope, conditions ...etc	Lights	PV	EV	Smart meters	RER/ Energy generation sources	Smart plugs	Thermostat
		105	88	45	43	38	33	30	22	19	16	15	14	8	4
MATLAB, YALMIP	58	15	12	7	8		4	5	2	1	1		2	1	
EnergyPlus model	58	15	8	9	5	1	3	4	6	3	1	1		1	1
TRNSYS	57	14	17	9	1		6	6	2	2					
MILP	28	6	3	2	2	2	1	4		2	4	1	1		
Testbed, BCVTB, VTS	20	2	3	3	4	1	1		1	1		1	1	1	1
CPLEX optimizer/solver	18	4	3		2	2	1	1	1	1	2	1			
GAMS	18	3	3		2	1		1	1	1	4	1	1		
MINLP, NLP	17	5	1		2	3	4	1					1		
HTTP, RESTful APIs HTTP	17	3	3	1	1	6				1		1		1	
ZigBee	16	1	4			3			2	2		3		1	
WiFi, Ethernet interface	14		3	1	2	2			2		1	2		1	
GridLAB-D	13	2	3			1	2			1	1		3		
Modbus	11	2	4	1	1	1				1			1		
BACnet	11		3	1	2				2	1		1			1
Python	9	3	3				1			1					1
CasADi interface	8	3	1	1			2	1							
IPOPT	8	3	1	1			2	1							
XMPP, XML, HTML	8	2	1			2			1		1			1	
IEEE 1888 TRAP/WRITE Web Service	8	1			1	6									
C, C++	7	2	1			1		1		1			1		
Game theory	7	2	1	1			2	1							
NARNET	6	2			1		2						1		
LAN, WAN	6					4						1		1	
QP, SQP algorithm	6	2	2		1	1									
JModelica.org	4	2					1	1							
Gurobi optimizer	4	2			2										
Java	2	1	1												
Others	41	8	7	8	6	1	1	3	2		1	2	2		

FIGURE 21. A heatmap-based analysis of frequency of uses of programming languages versus building-related elements. Numbers on top and left bars show a total number of uses. Numbers on the white background show frequency of use of programming languages (far-left) in the presence of elements (far-top).

B. RESEARCH QUESTION 2: "WHAT ARE FACTORS WHICH CONTRIBUTE TO/SUPPORT THE REVIEWED ARTICLES' SYSTEMS MEET THE NEEDS/FULFILL THE PURPOSES?"

1) CLASSIFIED ANSWERS TO RQ2

After an analysis has been carried out in two steps first of which implements a distribution procedure of all answers all reviewed articles have, the other of which implements a grouping procedure to produce classified answers and the results are provided in Table 10.

Data shown in Table 10 will be represented to highlight the percentage related to number of articles that share the same answer, i.e., B1, B2, …in relation to the total number of reviewed articles used in this analysis. Distribution of reviewed articles based on the classified answer is shown in Figure 24.

In Figure 24, the highest percentage of articles tends to have the answer "B8: Ability to control loads". At this point, the analyzed results indicate that 32.74% of reviewed articles have mentioned that the "ability to control loads" is the factor that supports articles (or their proposed systems) to meet the needs or fulfill the aimed purposes.

As of the question, "why do we need DR?", there should be factors that support fulfilling such need(s). Hence and according to 32.74% of total analyzed articles, they have said that "B8: ability to control loads" is the factor supports this direction.

2) THE RQ2-CONCLUDED POINT IS THAT

SG or energy grid has been considered by 37 out of 113 articles or (32.74%, as B8) that SG-provided factors can include the "ability to control loads". Meaning, 32.74% utilized SG and DR due to their systems can be supported by the use of SG and DR to control loads. Besides, 15.04% of reviewed articles has mentioned that the "B3: ability to apply energy storage, or use buildings as suppliers" is the support factor.

It is very important to understand that energy storage is utilized by buildings to store energy to be discharged later a charging source to the building. In addition, energy storage can be effectively implemented once DR through SG has been well exploited. Therefore, with a probability equals to 0.15, the ESSs can support the building be adopted with SG. In other words, the factor of the ability of ESS existing can

	Method	Control	Price	Incentive	Optimization	ANN	Communication services	Scheduling	Programming	Prediction
Programming/ simulation tools		75	27	19	19	18	16	10	8	3
MATLAB, YALMIP	23	10	5	2	3	1		1	1	
TRNSYS	20	13	2	1	3			1		
EnergyPlus model	17	9	2		2	2		1	1	
MILP	10	5	2		1			2		
Testbed, BCVTB, VTS	9	3	2			1		1	2	
CPLEX optimizer/solver	7	2	1		1	1		2		
MINLP, NLP	7	3	2	1		1				
GAMS	6	1	1		2			2		
HTTP, RESTful APIs HTTP	6				1	1	2		1	1
Python	6	1		2		1	2			
BACnet	5		1			1	3			
ZigBee	5	3			1		1			
GridLAB-D	4	3							1	
Modbus	4	2	1		1					
XMPP, XML, HTML	4				1		2		1	
C, C++	3	1	1	1						
CasADi interface	3	2		1						
IEEE 1888 TRAP/WRITE Web Service	3	1					2			
IPOPT	3	2		1						
WiFi, Ethernet interface	3	2					1			
Game theory	2	2								
Gurobi optimizer	2	1			1					
Java	2	2								
JModelica.org	2	1		1						
LAN, WAN	2	1					1			
NARNET	2	1				1				
QP, SQP algorithm	2		1	1						
Others	33	4	6	8	2	8	2		1	2

FIGURE 22. A heatmap-based analysis of frequency of uses of programming languages versus methods.

increase the number of SG-adopted buildings. Thus, this is one significant feature of SGs or networks.

C. RQ1-RQ2 BASED ANALYSIS

There will be a rising question, which is: "*Does RQ2 have impact(s) on RQ1?*". The answer might be "YES". To find out either there is a relationship between both of them or RQ2 has an impact on RQ1. A comparative analysis has been implemented where each reviewed article's answer to RQ1 and RQ2 has been recorded in a cross-based mechanism to find out how many crosses for every two paired classified answers there are. This analysis scans classified answers using the rule: one-to-many for each answer. Meaning, the classified answer A1 (for RQ1) will point to a certain reference (i.e., an article) this article will cross with a classified answer from the series (B1, B2, …B9). This mechanism will produce a cumulative value for every two classified answers. Each produced value represents one article with the criterion that this article crosses both classified answers with a possibility equals to 1. That is if the reticle with ref. [i] has answered RQ1 with A2, and has answered RQ2 with B3, a crossed area is created. Then, a value of '+1' will be assigned to the area where A1 crosses with B3. This conception is graphically and mathematically presented and shown in Figure 25.

As shown in Figure 25, there are five areas, explained as follows: the far-left area with a blue-colored background represents symbols of classified answers to RQ1 (A1…A16), the left area with blue-colored bars represents the total number of

TABLE 6. Analysis on programming languages and simulation tools used for DR in SG-adopted buildings. Information has been retrieved from reviewed articles.

Building energy simulation tools: Programming language/ modeling language/ simulation software/ program/ tool	Scenario		Ref.
	Real	Simulation	
MATLAB, Testbed, RaZberry module, XMPP, HTTP	✓	-	[240]
GridLAB-D	-	✓	[242]
visual test shells (VTS)	✓	-	[232]
MATLAB & EnergyPlus model via building controls virtual test bed (BCVTB)	-	✓	[72]
CPLEX for MATLAB/YALMIP	-	✓	[177]
GridLAB-D	-	✓	[203]
GridLAB-D	-	✓	[204]
NARNET and MINLP	-	✓	[69]
XMPP, XML	✓	-	[233]
MILP toolbox		✓	[78]
RPi Linux, Python programming language, BACnet	✓	-	[39]
Java	✓	-	[68]
GAMS modeling language, CPLEX solver, OpenDSS, MATLAB	✓	-	[164]
MILP	✓	-	[63]
TRNSYS	-	✓	[5]
EnergyPlus	-	✓	[230]
NARNET, MINLP, CPLEX solver	-	✓	[70]
Grey-Box control model, MATLAB, JModelica.org, CasADi, IPOPT, NLP	-	✓	[202]
Emax 2 Power Controller, XML	✓	-	[81]
EnergyPlus, BCVTB, OpenADR 2.0b, Modbus programmable logic controller, BACnet, KNX, doGate, doMooV	-	✓	[182]
EnergyPlus, MATLAB, linear program- YALMIP tool, CasADi, IPOPT solver	-	✓	[227]
C programming environment, MINLP, testbed, CAN protocol	-	✓	[183]
Modbus Protocol	✓	-	[228]
WEKA software	✓	-	[250]
Testbed, ZigBee	✓	-	[187]
TRNSYS	✓	-	[253]
MILP, GAMS	-	✓	[166]
TRNSYS	-	✓	[20]
MATLAB, TRNSYS, EnergyPlus	-	✓	[168]
TRNSYS	-	✓	[152]
PostgreSQL, Python, ModBus, Testbed	-	✓	[52]
EnergyPlus and TRNSYS	✓	-	[255]
Quadratic programming, CVX solver, MATLAB	✓	-	[147]
MATLAB, TRNSYS	-	-	[248]
EnergyPlus	-	✓	[205]
EnergyPlus	-	✓	[218]
CASSANDRA platform	✓	-	[149]
Game theory	✓	-	[219]
MILP, TRNSYS, MATLAB,	✓	-	[170]
MATLAB	-	✓	[206]
MILP, CPLEX, GAMS	✓	-	[198]
MATLAB, TRNSYS, BCVTB, EnergyPlus	✓	-	[268]
TRNSYS	-	✓	[189]
BACnet, wireless communications, BACnet/IP protocol	✓	-	[234]
EnergyPlus	-	✓	[256]
MATLAB GUI, thermodynamic, wireless sensors, PCT	-	✓	[153]
GAMS solver, Gurobi optimizer in MATLAB, DECIS solver	✓	-	[257]
Numerical and mathematical calculations and methods	-	-	[159]
TRNSYS 16	-	✓	[220]
Game theory, *Nikaido-Isoda* function	✓	-	[221]
EnergyPlus 8.3	-	✓	[190]
MILP, GAMS v.24.7.1, IBM CPLEX Optimizer v.12.6	-	✓	[271]
TRNSYS	-	✓	[222]
GAMS, CPLEX Optimization Studio v.12.8 solver, Java, MILP	-	✓	[223]
Python, SimPy library, Python library BehavSim, RESTful API (HTTP), affinity laws	-	✓	[235]
BACnet, ZigBee	✓	-	[84]
SimApi, MVC framework, Laravel 4.2, PHP, BCVTB, API, JDBC technology, JSON, EnergyPlus	-	✓	[247]
NLP, CasADi interface, IPOPT, Python	-	✓	[161]
TRNSYS, FORTRAN	-	✓	[208]
MATLAB	-	✓	[261]
TRNSYS and MATLAB	-	✓	[209]
ARX function, MATLAB	✓	-	[172]
TRNSYS	-	✓	[210]
MATLAB, GridLAB-D	-	✓	[212]
TRIANA three-step method	-	✓	[213]
NLP problem, sequential quadratic programming (SQP) algorithm, MATLAB	-	✓	[184]

TABLE 6. ***(Continued.)*** **Analysis on programming languages and simulation tools used for DR in SG-adopted buildings. Information has been retrieved from reviewed articles.**

IEEE 13-node test feeder, MATLAB, MILP is modeled by YALMIP and solved by Gurobi, EnergyPlus	-	✓	[215]
JModelica.org, MPCPy, PuLP, Python, Clp, C++	-	✓	[162]
EnergyPlus, C++	-	✓	[173]
TRNSYS v18, TRNSYS3d for Goggle SketchUp	-	✓	[216]
TRNSYS, MATLAB	-	✓	[191]
ZigBee radios, WiFi/Ethernet interface, building LAN,	✓	-	[197]
HTTP REST web service, HTML, Comma Separate Value and Excel	✓	-	[264]
MINLP, MILP, IBM-ILOG CPLEX solver, NARX, EnergyPlus	-	✓	[69]
ModBus, ZigBee, RESTful APIs (HTTP)	✓	-	[260]
EnergyPlus, Matlab,	-	✓	[245]
EnergyPlus	-	✓	[241]
WiFi, ZigBee	-	✓	[195]
IEEE 1888 TRAP Web Service, IEEE 1888 WRITE Web Service, HTTP, WAN	-	✓	[236]
Video Rendering through Key Feature Highlighting (KFH) for LCD TV	✓	-	[196]
TRNSYS	-	✓	[19]
Dynamic programming backward algorithm	-	✓	[150]
TRNSYS	-	✓	[224]

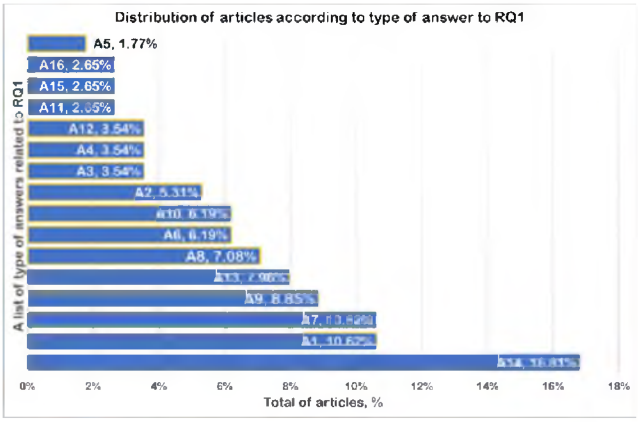


FIGURE 23. Distribution, [%], of articles based on highest percentage(s) related to answers to RQ1.

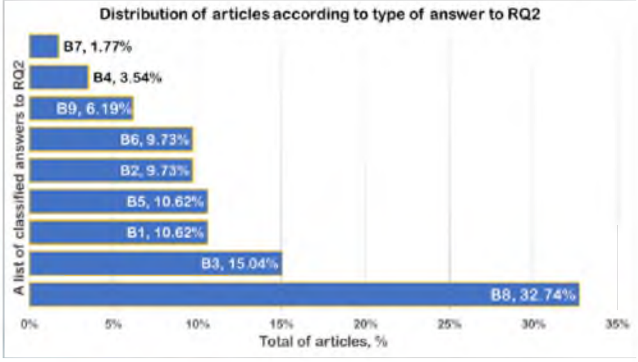
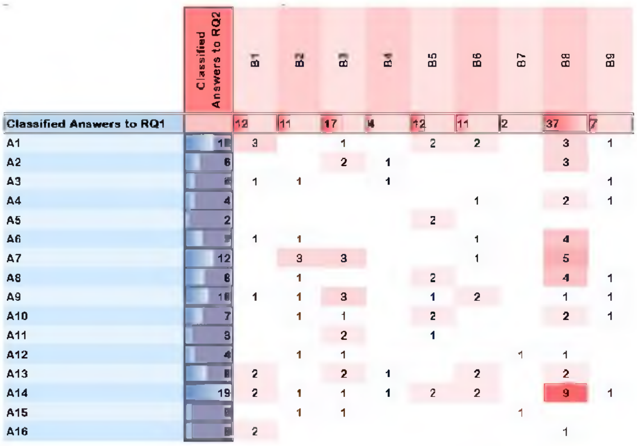


FIGURE 24. Distribution, [%], of articles based on the highest percentage(s) related to answers to RQ2.



	Classified Answers to RQ2	B1	B2	B3	B4	B5	B6	B7	B8	B9
Classified Answers to RQ1		12	11	17	4	12	11	2	37	7
A1	1[illegible]	3		1		2	2		3	1
A2	6			2	1				3	
A3	[illegible]	1	1		1					1
A4	4						1		2	1
A5	2					2				
A6	[illegible]	1	1				1		4	
A7	12		3	3			1		5	
A8	8		1			2			4	1
A9	1[illegible]	1	1	3		1	2		1	1
A10	7		1	1		2			2	1
A11	3			2		1				
A12	4		1	1				1	1	
A13	[illegible]	2		2	1		2		2	
A14	19	2	1	1	1	2	2		9	1
A15	[illegible]		1	1				1		
A16	[illegible]	2							1	

FIGURE 25. A heatmap-based analysis representing "cross"-relationship between RQ1 and RQ2.

articles that answers the relative classified answer to RQ1, the far-top area with a red-colored background represents symbols of classified answers to RQ2 (B1…B9), the top area with red-colored bars represents the total number of articles that answers the relative classified answer to RQ2, and the big white-colored background area represents where every two classified answers to RQ1 and RQ2 cross each other. Each value represents how many articles have shared these two crossed classified answers together. For example, in the area where A9 and B6 are crossed, a value of '2' exists. This integer number points out that number of articles that have answered both A9 and B6 for RQ1 and RQ2, respectively, equals '2'.

In this analysis, the area where the highest values in relation to answers to RQ1 and RQ2 cross, a value of '9' exists, as shown in Figure 25. In regard to answers to RQ1, this means 9 out of 19 (or 47.37%) of those articles which have mentioned that "A14: the need to reduce energy-consumption", have considered that the "B8: ability to control loads" is the supporting factor towards fulfilling their aimed needs/purposes of "the need to reduce energy-consumption".

D. RESEARCH QUESTION 3: "WHAT ARE THE MOST FREQUENTLY IMPLEMENTED METHODS AND STRATEGIES THAT APPLY DR IN SG-ADOPTED BUILDINGS?"

The most frequently implemented/ used methods by analyzed articles have been highlighted and listed in Table 11.

TABLE 7. An analysis related to programming languages used with buildings-related elements.

Building energy simulation tools: Programming language/ modeling language/ simulation software/ program/ tool	Elements included	Ref.
MATLAB, Testbed, RaZberry module, XMPP, HTTP	Smart plugs	[240]
GridLAB-D	PV, ESS (batteries, flywheels, etc.), EV, controllable loads	[242]
visual test shells (VTS)	BACnet, ZigBee	[232]
MATLAB & EnergyPlus model via building controls virtual test bed (BCVTB)	HVAC, RTP	[72]
CPLEX for MATLAB/YALMIP	Dynamic price signal	[177]
GridLAB-D	Large-scale air-conditioning loads, communication system, wind controller	[203]
GridLAB-D	Large-scale appliances, TCLs	[204]
NARNET and MINLP	HVAC, dynamic DR signal, on-site ESS and on-site energy generation system	[69]
MILP	Rooftop solar panel, TES, grid, DC/AC, AC/DC inverters, HVAC and air conditioners	[78]
RPi Linux, Python, BACnet, testbed	T-Stat, fan, BAS controller, PV	[39]
GAMS modeling language, CPLEX solver, OpenDSS, MATLAB	HVAC, hot water, lights, house appliances and motor drives	[164]
MILP	Air conditioners, indoor temperature data, rooftop units' operations	[63]
TRNSYS	HVAC, indoor air temperature	[5]
EnergyPlus	Air-conditioning system, temperature, humidity	[230]
NARNET, MINLP, CPLEX solver	HVAC, on-site ESS, on-site energy generation system	[70]
Grey-Box control model, MATLAB, JModelica.org, CasADi, IPOPT, NLP	HVAC, TES, flexibility properties in buildings	[202]
Emax 2 Power Controller, XML	HVAC, water heaters, lighting sources, EV	[81]
EnergyPlus, BCVTB, OpenADR 2.0b, Modbus programmable logic controller, BACnet, KNX, doGate, doMooV	Price signals, loads, power consumption patterns, zone temperature	[182]
EnergyPlus, MATLAB, linear program- YALMIP tool, CasADi, IPOPT solver	HVAC, indoor air temperature	[227]
C programming environment, MINLP, testbed, CAN protocol	Distributed generation sources, data exchange amongst sockets	[183]
Modbus Protocol	RS-485 interface, HVAC, pumps, frequency	[228]
WEKA software	HVAC operation, indoor temperature	[250]
Testbed, ZigBee	LED, lifts	[187]
TRNSYS	Air-conditioning systems, chillers	[253]
MILP, GAMS	EVs, wind micro-turbine	[166]
TRNSYS	HVAC	[20]
MATLAB, TRNSYS, EnergyPlus	Chillers, pumps	[168]
TRNSYS	HVAC, chillers, pumps, air-handling units, systems	[152]
EnergyPlus and TRNSYS	Lighting, TES	[255]
Quadratic programming, CVX solver, MATLAB	HVAC loads	[147]
MATLAB, TRNSYS	Chiller, Variable speed pump	[248]
EnergyPlus	PV, ice storage systems, HVAC, lighting and plug loads	[205]
EnergyPlus	Heat pump, water storage tank, PV, solar thermal collectors, EV	[218]
CASSANDRA platform	Prices, energy-consumption patterns	[149]
Game theory	Central air-conditioning systems, TES	[219]
MILP, TRNSYS, MATLAB,	Weather conditions, indoor air temperature, on-off controller	[170]
MATLAB	PV, heating systems, signals	[206]
MILP, CPLEX, GAMS	EVs, RTP, controllable and uncontrollable loads	[198]
MATLAB, TRNSYS, BCVTB, EnergyPlus	Ice tank, PV batteries, temperature, RTP	[268]
TRNSYS	Active and passive cold storage, indoor temperature, chillers	[189]
BACnet, wireless communications, BACnet/IP protocol	Loads, lightings, RTP signals	[234]
EnergyPlus	PCM, HVAC, precooling and preheating duration, temperature	[256]
MATLAB GUI, wireless sensors	TOU, RTP signals, HVAC, indoor and outdoor temperature	[153]
GAMS solver, Gurobi optimizer in MATLAB, DECIS solver	HVAC, pricing signals	[257]
Numerical and mathematical calculations and methods	Controllable and non-controllable loads, air temperature	[159]
TRNSYS 16	PV, TES, temperature	[220]
Game theory	PCM, indoor temperature, air-conditioning systems, charging/discharging of active cold storages, chillers	[221]
EnergyPlus 8.3	Lighting, HVAC, zone's temperature, outside weather conditions, copy machines, LCD monitors, laser printers, laptops and computers	[190]
MILP, GAMS v.24.7.1, IBM CPLEX Optimizer v.12.6	PV, EVs, smart metering data	[271]
TRNSYS	Chillers, indoor air temperature, TES	[222]
GAMS, CPLEX Optimization Studio v.12.8 solver, Java, MILP	Heat pumps	[223]
Python, Python library BehavSim, RESTful API (HTTP)	Ventilation systems, fans	[235]
BACnet, ZigBee	Smart meters, fluorescent lamp	[84]
PHP, BCVTB, API, JSON, EnergyPlus	Building temperature, electricity price, electricity meter	[247]
NLP, CasADi interface, IPOPT, Python	Heat pump, boilers, TES	[161]
TRNSYS, FORTRAN	Building envelop, chillers, pumps, fans, air ducts	[208]
MATLAB	Plug-in hybrid EVs, AC, lights	[261]
TRNSYS and MATLAB	HVAC, pump, indoor air temperature, thermal capacity, cooling coils	[209]
MATLAB	Loads, HVAC, price signal	[172]
TRNSYS	Chillers, cooling capacity	[210]
MATLAB, GridLAB-D	Auto-regulating heat pumps, wind energy injection, TES	[212]
NLP problem, sequential quadratic programming (SQP) algorithm, MATLAB	Dynamic pricing, GA, bi-directional information exchange	[184]
IEEE 13-node test feeder, MATLAB, MILP is modeled by YALMIP and solved by Gurobi, EnergyPlus	HVAC, forecasted energy prices	[215]
JModelica.org, Python, C++	Air-source heat pumps	[162]
EnergyPlus, C++	HVAC, building envelope, heat pumps, PVs	[173]
TRNSYS v18, TRNSYS3d for Goggle SketchUp	Air-water heat pump	[216]
TRNSYS, MATLAB	Building envelope, chillers, pumps, fans, hydraulic network, air ducts	[191]
ZigBee radios, WiFi/Ethernet interface, building LAN,	Smart meter, plug-loads, bi-directional communication	[197]
HTTP REST web service, HTML	HVAC, bi-directional communication, information exchange	[264]

TABLE 7. *(Continued.)* **An analysis related to programming languages used with buildings-related elements.**

MINLP, MILP, IBM-ILOG CPLEX solver, EnergyPlus	HVAC	[69]
ModBus, ZigBee, RESTful APIs	HVAC, Heat pumps, PVs, boilers, condensing boilers, data communication	[260]
EnergyPlus, Matlab,	Indoor temperature, lights, HVAC	[245]
EnergyPlus	Window-to-wall ratio, occupancy, building type, smart thermostats	[241]
WiFi, ZigBee	Smart meter, plug-in hybrid vehicle, heat-pump	[195]
IEEE 1888 TRAP Web Service, IEEE 1888 WRITE Web Service, HTTP, WAN	Web services devices, gateways, Internet DummyNets	[236]
TRNSYS	Air-conditioning system, indoor air temperature,	[19]
TRNSYS	Chillers, pumps, hydraulic network, AHUs	[224]

E. RESEARCH QUESTION 4: "WHAT ARE THE MOST EFFECTIVE METHODS AND TECHNIQUES APPLIED TO UTILIZE DR IN THE SG-ADOPTED BUILDINGS SECTOR?"

Here, the most effective methods extracted from analyzed reviewed articles are highlighted. criterion used in this analysis is the efficiency percentage reported in the relative articles.

A list of extracted most effective methods is provided in Table 12. However, other efficiency-reported results have been involved to highlight and discuss further analysis purposes.

From reported results shown in Table 12, the followings are noticeable:

1) According to [152], EDR with a highly reported EDR percentage has been equal to 66.5%. To go a further analysis, the article [152] has answered the RQ2 with the answer: "B1: ability to get cooperation from customers" as a supportive or contributing factor. That might point out that the factor of customers cooperation would be a useful tool and supportive element towards EDR. Meaning, what makes the ED reduced is the cooperation of occupants. This factor has contributed to EDR by 66.5%.
2) According to [184], imbalance reduction can be of improvement up to 59% or even 81% by utilizing conventional energy sources and RES, respectively. Since the article presented in [184] has answered RQ1 and RQ2 with: "A13: the need to consider fluctuations, regulation, or imbalance" and "B4: ability to transfer price information", respectively, it is found that the B4 is a supporting factor towards achieving the purpose denoted by A13. It can be said that transferring RTP information utilizing communication services within SG environment might lead to fulfill the need to consider/enhance fluctuations and imbalance specifically during generation.
3) According to [197], energy-consumption reduction percentage equals to 66% as has been reported. The classified answers for RQ1 and RQ2 were: "A14: the need to reduce energy-consumption" and "B8: ability to control loads", respectively. It is revealed that the ability to control loads has been the supporting factor associated with reduction of energy-consumption. This means, loads control could have supported fulfilling the need to reduce energy-consumption.
4) According to [248], an energy-saving rate equals 7.3% has been reported. This is a low percentage compared to other competitive methods proposed by other articles for example [150], [205], [214]. This low percentage of energy-saving might be caused by the use of prediction method. The prediction method used with [248] has considered transferring price information. Therefore, the use of "B4: ability to transfer price information" as a supporting factor to the purpose of "A3: the need to predict energy" might fail to achieve higher rates of energy-saving.
5) According to [214], the reported energy-saving rate is quite high compared to that one reported in [248]. By analyzing the classified answers of [214] to RQ1 and RQ2, it is found that [214] has answered as "A13: the need to consider fluctuations, regulation, or imbalance" and "B3: ability to apply energy storage, or use buildings as suppliers", respectively. It can be derived that "ability to apply energy storage systems" can reduce imbalance and fluctuations. In general, management and reduction levels of imbalance and fluctuations can reduce the energy generated from supply sources and reduce the energy consumed by demand-side. Reduction levels of imbalance would be more and higher in case RES and RER are supplied to buildings-connected ESS. In addition, ESS can be a supportive and contributing source to save energy at buildings-dispatched energy to other buildings.

IX. CONCLUSION

Expanded is a conclusion to draw a comprehensive overview in regard to the results reported in the reviewed papers and to attempt to provide and suggest solutions for selected researches-related challenges. Conclusion of this review research has been divided into several sub-sections. In the first one, our findings out have been highlighted and explained supportive by a graphical representation. In the second sub-section, concluded remarks are discussed regarding selected research topics, understood insights are highlighted, and a summary related to each topic has been stated. In the third sub-section, three challenges faced by researchers have been discussed. In this sub-section also, potential solutions based on statistical analysis have been proposed towards enhancing DR in SG-adopted buildings. The fourth one provides a number of suggestions in which DR strategies would be enhanced for future approaches. Besides, proposed and

TABLE 8. A summarized analysis of programming languages and simulation tools versus methods.

Building energy simulation tools: Programming language/ modeling language/ simulation software/ program/ tool	Description of method used	Ref.
MATLAB, Testbed, RaZberry module, XMPP, HTTP	Programming focused DR method	[240]
GridLAB-D	Programmable controlling method	[242]
VTS	Programmable method for BACS	[232]
MATLAB & EnergyPlus model via BCVTB	Control-based DR method utilizing programmable modeling	[72]
CPLEX for MATLAB/YALMIP	Price	[177]
GridLAB-D	Load control for a real-time DR co-simulation method	[203]
GridLAB-D	Control model for dynamical behaviors	[204]
NARNET and MINLP	HVAC control focused DR	[69]
XMPP, XML	Communication services for DR interaction with SG units	[233]
MILP toolbox	Control method for HVAC	[78]
RPi Linux, Python programming language, BACnet	ANN-based DR for SG operations	[39]
Java	Public lighting systems monitoring and control	[68]
GAMS modeling language, CPLEX solver, OpenDSS, MATLAB	Loads scheduling for optimization-based DR	[164]
MILP	Controllable loads-based DR	[63]
TRNSYS	HVAC cooling and control-based DR	[5]
EnergyPlus	Air-conditioning system controlling-based DR	[230]
NARNET, MINLP, CPLEX solver	NN-based HVAC thermal behavior predictor for DR	[70]
Grey-Box control model, MATLAB, JModelica.org, CasADi, IPOPT, NLP	Energy storage for DR	[202]
Emax 2 Power Controller, XML	Optimization	[81]
EnergyPlus, BCVTB, OpenADR 2.0b, Modbus programmable logic controller, BACnet, KNX, doGate, doMooV	Price-based DR for energy market	[182]
EnergyPlus, MATLAB, linear program- YALMIP tool, CasADi, IPOPT solver	Control of HVAC and building's thermodynamics-based DR for building flexibility	[227]
C programming environment, MINLP, testbed, CAN protocol	Price-based DR method	[183]
Modbus Protocol	Control-based DR	[228]
WEKA software	NN-based Load prediction for energy system control	[250]
Testbed, ZigBee	Control-based DR	[187]
TRNSYS, EnergyPlus	Optimization for fast DR	[253, 255]
MILP, GAMS	Price-based DR	[166]
MATLAB, TRNSYS, EnergyPlus	Price-based energy flexibility indicator	[168]
TRNSYS	Occupants-targeted incentives-based fast DR	[152]
PostgreSQL, Python, ModBus, Testbed	Loads control-based DR	[52]
Quadratic programming, CVX solver, MATLAB	Incentive	[147]
MATLAB, TRNSYS	Optimization	[248]
EnergyPlus, EnergyPlus 8.3, C++	Control	[173, 190, 205, 218]
CASSANDRA platform	Incentive	[149]
Game theory	Control	[219]
MILP, TRNSYS, MATLAB,	Price	[170]
MATLAB	Control	[206]
MILP, CPLEX, GAMS	Scheduling	[198]
MATLAB, TRNSYS, BCVTB, EnergyPlus	Scheduling	[268]
BACnet, wireless communications, BACnet/IP protocol	Communication services-based gateway protocol for DR	[234]
EnergyPlus	Optimization	[256]
MATLAB GUI, thermodynamic, wireless sensors, PCT	Incentive	[153]
GAMS solver, Gurobi optimizer in MATLAB, DECIS solver	Optimization	[257]
Numerical and mathematical calculations and methods	Incentive	[159]
TRNSYS, TRNSYS 16	Control	[20, 189, 220, 222]
Game theory, Nikaido-Isoda function	Control	[221]
MILP, GAMS v.24.7.1, IBM CPLEX Optimizer v.12.6	Scheduling	[271]
GAMS, CPLEX Optimization Studio v.12.8 solver, Java, MILP	Control	[223]
Python, SimPy library, Python library BehavSim, RESTful API (HTTP), affinity laws	Communications services	[235]
BACnet, ZigBee	Communication protocols-based DR enhancement	[84]
SimApi, MVC framework, Laravel 4.2, PHP, BCVTB, API, JDBC technology, JSON, EnergyPlus	AI	[247]
NLP, CasADi interface, IPOPT, Python	Incentive	[161]
TRNSYS, FORTRAN	Control	[208]
MATLAB	Optimization	[261]
ARX function, MATLAB	Price	[172]
MATLAB, GridLAB-D	Control	[212]
NLP problem, sequential quadratic programming (SQP) algorithm, MATLAB	Price	[184]
IEEE 13-node test feeder, MATLAB, MILP is modeled by YALMIP and solved by Gurobi, EnergyPlus	Control	[215]
JModelica.org, MPCPy, PuLP, Python, Clp, C++	Incentive	[162]
TRNSYS v18, TRNSYS3d for Goggle SketchUp	Control	[216]
TRNSYS, MATLAB	Control	[19, 191, 209, 210, 224]
ZigBee radios, WiFi/Ethernet interface, building LAN,	Control	[195, 197]
HTTP REST web service, HTML, Comma Separate Value and Excel	Prediction	[264]
MINLP, MILP, IBM-ILOG CPLEX solver, NARX, EnergyPlus	Control	[69]
ModBus, ZigBee, RESTful APIs	Optimization	[260]
EnergyPlus, Matlab,	AI	[245]
EnergyPlus	Programming	[241]
IEEE 1888 TRAP Web Service, IEEE 1888 WRITE Web Service, HTTP, WAN	Communication services-based DR	[236]
Dynamic programming backward algorithm	Occupants' cooperation-centric DR	[150]

TABLE 9. Distribution of reviewed articles according to the class of answers to RQ1.

No.	Classified Answers to RQ1	Answer's Symbol	Ref.
1.	The need to respond to demand events and/ or SG requests	A1	[5, 41, 42, 81, 84, 180, 208, 222, 240, 246, 258]
2.	The need to use/ exploit buildings for energy storage	A2	[164, 166, 202, 207, 227, 239]
3.	The need to predict energy	A3	[70, 248, 251, 267]
4.	The need to use/ focus on REG, RER, RES	A4	[73, 76, 238, 252]
5.	The need to manage communication	A5	[233, 237]
6.	The need to control/ shift loads	A6	[69, 150, 190, 191, 230, 242, 270]
7.	The need to manage energy/network during peak periods	A7	[11, 26, 63, 77, 167, 170, 177, 213, 218-220, 256]
8.	The need to reduce cost of energy or electricity bill	A8	[68, 79, 183, 185, 206, 215, 223, 247]
9.	The need to reduce the ED	A9	[18, 20, 39, 165, 172, 181, 189, 209, 221, 255]
10.	The need to enhance SG infrastructure/ environment	A10	[75, 78, 178, 182, 203, 250, 274]
11.	The need to reuse/ exploit ESS (e.g., EV)	A11	[198, 201, 271]
12.	The need to share energy	A12	[162, 163, 168, 205]
13.	The need to consider fluctuations, regulation, or imbalance	A13	[52, 144, 152, 161, 184, 212, 214, 224, 228]
14.	The need to reduce energy-consumption	A14	[19, 64, 71, 72, 74, 147, 149, 153, 160, 187, 188, 197, 200, 226, 231, 232, 249, 253, 254]
15.	The need to reduce CO_2 emissions	A15	[54, 154, 216]
16.	The need to aware occupants to participate in energy-use	A16	[148, 151, 179]

TABLE 10. Distribution of reviewed articles according to the class of answers to RQ2.

No.	Classified Answers to RQ2	Answer's Symbol	Ref.
1.	Ability to get cooperation from customers	B1	[41, 74, 144, 148, 150-152, 160, 165, 169, 240, 267]
2.	Ability to apply smart cooling/ preheating utilizing smart appliances	B2	[54, 162, 170, 172, 177, 178, 185, 200, 251, 256, 270]
3.	Ability to apply energy storage, or use buildings as suppliers	B3	[26, 78, 166-168, 181, 198, 201, 202, 209, 212, 214, 216, 220, 222, 253, 255]
4.	Ability to transfer price information	B4	[72, 184, 239, 248]
5.	Ability to utilize data communication means in smart buildings	B5	[39, 42, 71, 79, 84, 182, 183, 232, 233, 237, 271, 274]
6.	Ability to respond to emergency DR and SG's urgent requests (e.g., OpenADR)	B6	[11, 18, 20, 52, 69, 81, 187, 224, 238, 254, 258]
7.	Ability to offer incentives	B7	[154, 163]
8.	Ability to control loads	B8	[5, 19, 63, 64, 68, 73, 75-77, 147, 153, 161, 164, 179, 180, 188, 190, 191, 197, 203, 205-207, 213, 215, 218, 219, 221, 223, 226-228, 230, 231, 242, 246, 249]
9.	Ability to predict demand or building's temperature	B9	[70, 149, 189, 208, 247, 250, 252]

TABLE 11. Distribution of reviewed articles according to the class of answers to RQ3.

Methods	Ref.
Incentives towards rationalization energy-consumption or Occupants' cooperation-centric DR	[54, 74, 144, 147-154, 160-163, 170]
Price-based	[26, 166, 167, 169, 172, 177-180, 182-184]
Control methods	[5, 18-20, 41, 42, 52, 63, 64, 69, 72, 73, 75-77, 187-191, 197, 198, 200, 202, 203, 205-209, 212-216, 218, 219, 221, 223, 224, 226-228, 230, 231, 242]
Communication services	[71, 84, 232, 233, 237]
Energy storage	[68, 78, 181, 201, 220, 222, 238, 253]
Programming	[239, 240]
Prediction	[70, 165, 248, 250-252]
Artificial intelligence and ML	[39, 79, 185, 246, 247, 249]
Optimization	[81, 255, 256, 258]
Scheduling	[164, 270, 271, 274]

suggested directions aim to reduce ED, CO_2, fluctuations of supply-side for better usage of RERs aiming to reach higher levels of sustainability of energy systems in the SG-adopted buildings sector have been highlighted in this sub-section. A number of concluded points for future directions have been drawn in the following sub-section. This is followed by listing a number of insights related to informing policy and industry decisions for SG in buildings. Then, benefits of DR in sg-adopted buildings in terms of financial savings, environmental impact, and improved energy reliability have been highlighted. After that, a number of potential limitations of the study have been listed in the next sub-sections. The last three sub-sections are dedicated to addressing gaps in future research on DR strategies, listing several potential ethical implications of DR in SG-adopted buildings with their concerns, and discussing generalizability of findings in this systematic review to buildings and regions with different energy infrastructure and policies.

A. OUR FINDINGS OUT

Analyzed results have helped to come out with a number of concluded points mentioning that DR potentially has impacts

TABLE 12. Distribution of reviewed articles according to the class of answers to RQ4.

Method	Answers of RQ4	Reported results-related performance [%]	[Ref]
Occupant/incentive	Occupants-centric incentives towards rationalization energy-consumption	EDR =66.5%	[152]
	Price- and incentive-based DR	demand fluctuation reduction =40% energy-saving =8.3%	[144]
	Occupants' cooperation-centric DR	Energy-saving =14.55%	[150]
Price	Price considered DR	peak demand reduction =26% electricity price reduction =11%	[26]
	Price-based DR for energy market	energy cost reduction =60%	[182]
	MPC and price-based incentives method	daily energy cost reduction =18.65%.	[170]
	dynamic pricing-based DR improvement	imbalance reduction by RES =81% imbalance reduction by conventional energy sources =59%	[184]
Control	Lighting dimming control method	energy-consumption reduction =16.22%	[64]
	PAR control method for supply and demand	PAR cost reduction =45.5%	[77]
	Air-conditioning system controlling-based DR	energy cost reduction =29.7%	[230]
	Buildings' loads control-based DR	annual energy-saving =16.5% energy-consumption reduction =15.9% carbon emission reduction =27% generation cost reduction made by RER =45.3%	[205]
	Thermal storage control using game theory	Peak demand reduction =10%	[219]
	TES- and game theory-based load control for DR	demand reduction =10% energy-saving =5%	[221]
	Integrated controlling method for major loads-based DR	peak load reduction =43%	[190]
	Air-conditioning systems' loads control-based fast DR	energy reduction =23%	[208]
	Controlled heat pump-based DR enhancement	peak reduction =17%	[213]
	Heat pumps-based load control and management	Energy-saving =34%	[214]
	Plug-loads control-based DR	energy-consumption reduction =66%	[197]
	Supply-demand-side control method-based DR	energy reduction =18.3%	[19]
	Active chillers direct control-based DR	EDR =11.2%	[224]
Programmable	Dynamic DR controller of HVAC	annually energy cost reduction =14%	[72]
AI	ANN	PAR reduction =47% electricity bill reduction =23.9% energy management efficiency =33%	[185]
	GA-based and dynamic pricing-based DR energy management system	annual electricity bill reduction in =25.23% energy-consumption reduction =61.43%	[79]
	NN-based automated DR	EDR >30%	[249]
	DR control with load prediction uncertainty	daily energy-saving =7.3%	[248]
	ML-based control method for DR	energy cost reduction =41.8 utility generation cost reduction =39% CO_2 emission reduction =37.9%	[247]
Optimization	Operation optimization DR for many buildings	energy cost reduction =58.3%	[255]
	Optimization of PCM for TES as DR resource	annual EDR =19.25%	[256]
	DR-based on optimization distribution method amongst mixed-use buildings	energy cost reduction =48.8%	[258]
Scheduling	Control and scheduling building's appliances for a smart DR	energy cost reduction =15%	[270]

on all our environmental aspects. Selected findings out are listed in Figure 26.

B. CONCLUDED REMARKS, INSIGHTS, AND SUMMARY

A number of concluded remarks, insights, and summaries related to selected topics which have been reported in reviewed articles to have difficulties to achieve semi-optimal performance regarding DR and in the SG-adopted buildings sector are listed in Table 13 with the relative references.

In Table 13, challenges faced by researchers have been discussed. Suggested tips which attempt to provide potential solutions have been provided as well.

C. CHALLENGES

1) REAL OR SIMULATION CONDUCTED STRATEGY?

A number of researchers have mentioned that it is difficult to find opportunities to conduct validation of experiments on real buildings in real SG, therefore, they alternatively have applied computer-based simulations as an effective means to test and virtually validate their proposed strategies in a building integrated with a SG.

2) FORECASTING STRATEGIES

Those strategies or forecasting-dependent buildings are facing one of the most hazardous problems specifically when these buildings are huge consumers of energy either due to the building's size or the purpose the building needs energy for such as when buildings need heating or cooling. The energy demand in these cases will be high. Suppose that these buildings face errors in forecasting of, for example, renewable energy supply times. This issue will cause many other issues for example CO_2 emissions, high ED, SG request to buildings, and many others. The effect of problem can be partially reduced using a number of strategies, some of which are mentioned in the Conclusion section.

3) SHIFTABLE, NON-SHIFTABLE, OR CONTROLLABLE SMART APPLIANCES (SA)?

Smart appliances (SAs) are still of challenge in terms of ability to consume less energy during peak hours than in off-peak hours. In order to show behaviors of SAs during SG requests, an evaluation scheme based on SA compatibility with DR is provided in Table 14. Besides, this evaluation is expanded to be represented by values that ease produce a

TABLE 13. A list of concluded remarks, insights, and summaries for selected research-discussed topics.

Research Topic	Concluded remarks	Ref.	Insights	Summary
TES capacity	**Energy flexibility** (1) depends on ESS in buildings such as TES. One of the main key supportive sources in this direction is the **capacity of TES**. Besides, the operational control associated with TES is also a key and an essential assistant. The way the building's occupants interact with DR programs that utilize TES in energy flexibility is of importance towards enhancing both DR and energy flexibility. One of the biggest considerable issues that helps occupants to interact in this line is to provide incentives allowing for extra energy share(s) and less ED as well as less fluctuations during energy supply.	[161]	This concluded remark indicates that the capacity factor can contribute to energy flexibility. Such a scenario can enhance DR services.	DR is enhanced thru energy flexibility as a result of **TES** and its capacity sizing.
	HVAC can be used to solve the problems of frequency regulation that has affected the reliability of energy grids caused by the **intermitted nature of RERs in remote areas** where HVAC can utilize the thermal storage capacity of buildings. Pumps in HVAC have been found to be a promising resource contributing to renewable resources-generated energy. Pumps have effectively assisted in thermal **capacity increment** of building. Almost 30kW capacity has been achieved according to [209].	[209]	This is a future direction to enhance RERs reliability and frequency regulation by utilizing HVAC in capacity increment of thermal storage of buildings. Ancillary services (frequency regulation) are of importance to better support grid-responsive buildings.	DR is enhanced thru less ED as a result of capacity increment. **Capacity of TES** enhances frequency regulation.
	Using **auto-regulating air-source heat pumps** in **regulating fluctuations** of DERs (wind energy injection), to control load flow fluctuations. It is concluded that using heat pumps can balance supply and demand. Also, **TESs** in buildings have been found that more regulation and accommodation of large fluctuations caused by high penetration of wind energy causes, can be achieved with the help of auto-regulating heat pumps.	[212-214]	Auto-regulating heat pumps with the help of thermal mass in buildings can effectively reduce and regulate fluctuations caused by high penetration of energy to DERs. Insight is to utilize active control of heat pumps to limit peak ED made by demand-side. Subsequently, DR and SG requests to reduce energy-consumption and ED will be less. Thus, DR will be enhanced since the number of SG requests decreases.	DR is indirectly enhanced thru an enhancement to SG infrastructure represented by smoothing loads and their fluctuations as a result of using self-regulating **heat pumps** and **TES** in buildings.
Forecasting	**Forecasting** of energy management utilizing building measurements and inputs contributes to provide a supervisory control framework and DR management. Price signals can lead to contribute to effective interaction as a response to demand by proposing a simple strategy or practice such as precooling. An application [172] has proven such a practice to enhance **load shifting** behavior in ED for a building specifically its HVAC system.	[172]	Effective forecasting utilizing energy real-time energy price signals contributes very much to enhance behavior of loads shifting. Besides, forecasting of a building's ED is useful for decision making where it can be used as thermal storage to shift cooling loads which will be scheduled by a supervisory controller.	DR is being enhanced thru load shifting as a result of effective **forecasting**.
	Cold storage systems have helped in **EDR** and increased cooling capacity. To better reduce ED utilizing active cooling storages with a maximum benefit from low energy prices, **prediction** of real-time prices is of importance. Since, for example, during nights, electricity prices are usually the lowest. Then, charging energy storages is suitable to be run in the lowest-price periods to maintain the optimal load curve during peak times. This enhances SG in terms of optimization management. Therefore, prediction is affected by accurate estimation of energy insufficiency in SG during events of real-time process-based DR.	[210, 211]	Accurate prediction of EDR and indoor temperature with the help of using active cold storages. It is recommended to use active cold storage due to it helps save energy, reduce ED and enhance building demand management. The insight is that the using of active cold storage can help in an immediate EDR and to increase additional cooling capacity used during peak hours.	DR is enhanced thru EDR as a result of both an accurate prediction strategy of indoor temperature and using **active cold storage systems**.
	Errors in forecasting of, for example, wind-based energy supply can be partially solved by performing **preheating** or precooling strategies. Besides, preheating buildings can solve the problem of **demand during peak times**. Therefore, loads will be shifted and DR will be highly enhanced.	[214]	To avoid peak demand periods, preheating is a highly recommended alternative strategy.	DR is enhanced thru peak periods avoidance and loads can be shifted as a result of using **preheating** or precooling strategies.
Price-based strategies	**Price**-based **DR** strategies have been used by several studies to reduce ED, reduce energy imbalance, reduce energy daily cost, and also shift loads. Pricing strategies better work with the help of occupants' centric incentive activation.	[184]	It is suggested to use GA-based price strategies to help the grid to search for better dynamic prices utilizing results obtained from an aggregated analysis of DR. Also, dynamic price pricing strategies utilizing incentives help in interaction between demand and supply-sides.	DR is enhanced through load shifting and energy daily cost reduction as a result of **incentive-based dynamic price** strategies and methods.
RERs	**RERs**-related strategies are of high efficiency in reducing **global warming, CO_2,** and **enhancing DR** when PVs are used by ED sides.	[54]	It is recommended to use, for example, PVs to reduce CO_2 emission and global warming. Besides, RERs strategies enhance will reduce request of supply-side requests to grid adopted buildings, due to the lower number of ED(s) that occurs.	DR is enhanced thru a smaller number of energy demand(s) to generation units as a result of using **PVs**.
Preheating	**Preheating** strategies are exploited to perform **less ED** and **decarbonization** levels. Either to use preheating at low-demand and high-supply or using RERs such as PVs, decarbonization or less energy-demand are capable to be as optimal as could. Also, TESs are supportive resources towards preheating to avoid SG requests of energy reduction and DR.	[216]	One of the best green technologies that enhances DR and SG environment is to apply preheating via RERs.	DR is getting enhanced thru decarbonization as a result of using **preheating** either during low-demand and high-supply periods or using renewables.

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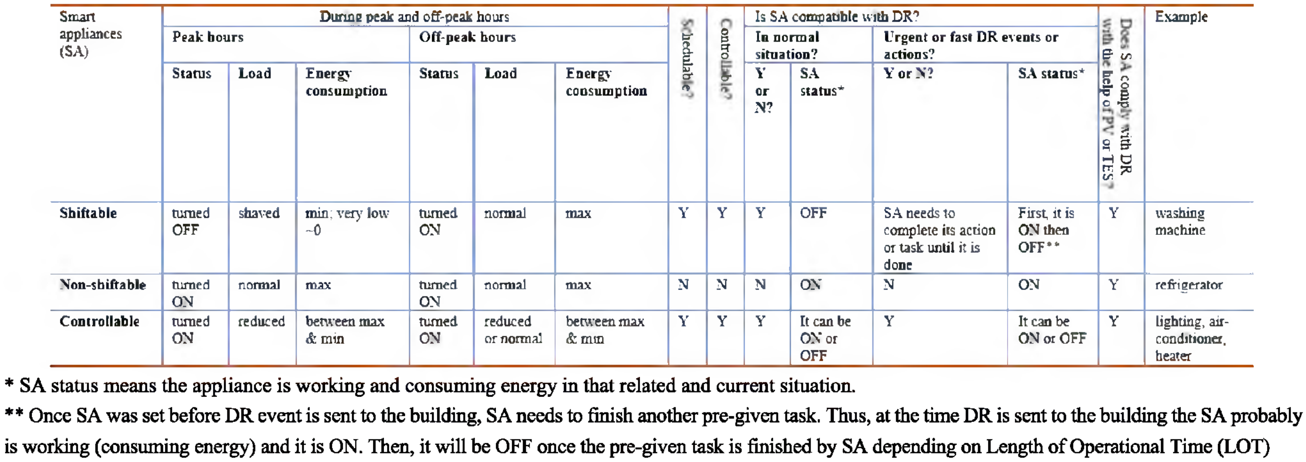
(1) The factor written in a **GREEN** color font enhances the element written in a **BLUE** color font.

TABLE 14. Shiftable, non-shiftable, or controllable SAs during peak and off-peak hours in terms of energy-consumption.



Smart appliances (SA)	During peak and off-peak hours						Schedulable?	Controllable?	Is SA compatible with DR?				Does SA comply with DR with the help of PV or TES?	Example
	Peak hours			**Off-peak hours**					**In normal situation?**		**Urgent or fast DR events or actions?**			
	Status	**Load**	**Energy consumption**	**Status**	**Load**	**Energy consumption**			**Y or N?**	**SA status***	**Y or N?**	**SA status***		
Shiftable	turned OFF	shaved	min; very low ~0	turned ON	normal	max	Y	Y	Y	OFF	SA needs to complete its action or task until it is done	First, it is ON then OFF**	Y	washing machine
Non-shiftable	turned ON	normal	max	turned ON	normal	max	N	N	N	ON	N	ON	Y	refrigerator
Controllable	turned ON	reduced	between max & min	turned ON	reduced or normal	between max & min	Y	Y	Y	It can be ON or OFF	Y	It can be ON or OFF	Y	lighting, air-conditioner, heater

*** SA status means the appliance is working and consuming energy in that related and current situation.**

**** Once SA was set before DR event is sent to the building, SA needs to finish another pre-given task. Thus, at the time DR is sent to the building the SA probably is working (consuming energy) and it is ON. Then, it will be OFF once the pre-given task is finished by SA depending on Length of Operational Time (LOT)**

heat-map that shows which type of SAs has the highest level of compatibility with DR. That means, most compatible SAs with DR will be highlighted. This is an attempt to provide solutions to SG-adopted buildings on the best types of SAs that should be installed to achieve less ED during peak hours. Further details could be found in Figure 27.

In Figure 27, at Second Area, an equivalent value is assigned to each field (represented in Figure 27 at First Area). For example, during *peak hours*, the "*non-shiftable SA*" does not respond to DR because it cannot reduce its energy-consumption status or it cannot be turned-off during these periods; therefore, it is assigned a 'Zero' value in Figure 27, at Second Area.

The green-colored fields represent the level of being SA is compatible with DR. The dark green field located at the bottom of "Total Points" column has the highest value amongst other SAs. Thus, it indicates that "controllable SA" is the highly compatible smart appliances that best respond in all or almost situations of DR events and SG requests. The reason is that, the controllable SAs can be adjustable or able to change their statuses according to DR events and SG needs.

In this analysis shown in Figure 27, there is a real problem, which is that many SAs are located in under the class "shiftable and/ or non-shiftable SA" therefore either a lot of energy-consumption exists [196] and loads will be high or they will be directly controlled and turned OFF. Thus, there will be two scenarios. In the first scenario, i.e., "highly energy consumed" situation, DSM will suffer and supply-side needs to produce more energy. This will increase and affect many other factors such as fluctuations and CO_2 emissions. For the second scenario, one of the biggest issues that probably occur is the comfort of occupants. In both scenarios, the problem is still there and further solution(s) will be a must.

One of the presented solutions [196] is to implement technical functionalities related to the "non-shiftable SAs" so that they can be working as "controllable SAs" in case they are able to run with reduced energy-consumption. For example, modes of such LCD TVs are dimmable played. Besides, audio control of many TVs can contribute to DR specifically with urgent events and/ or during peak hours.

It could be concluded that: 1) A "controllable SA" is the most compatible with DR shown in Figure 27 in the "Total Points" field, 2) a "shiftable SA" has a good level of compatibility as it scores '3' shown on Figure 27, and 3) a "non-shiftable SA" has no compatibility with DR as it scores '0' shown on Figure 27 in the "Total Points" field.

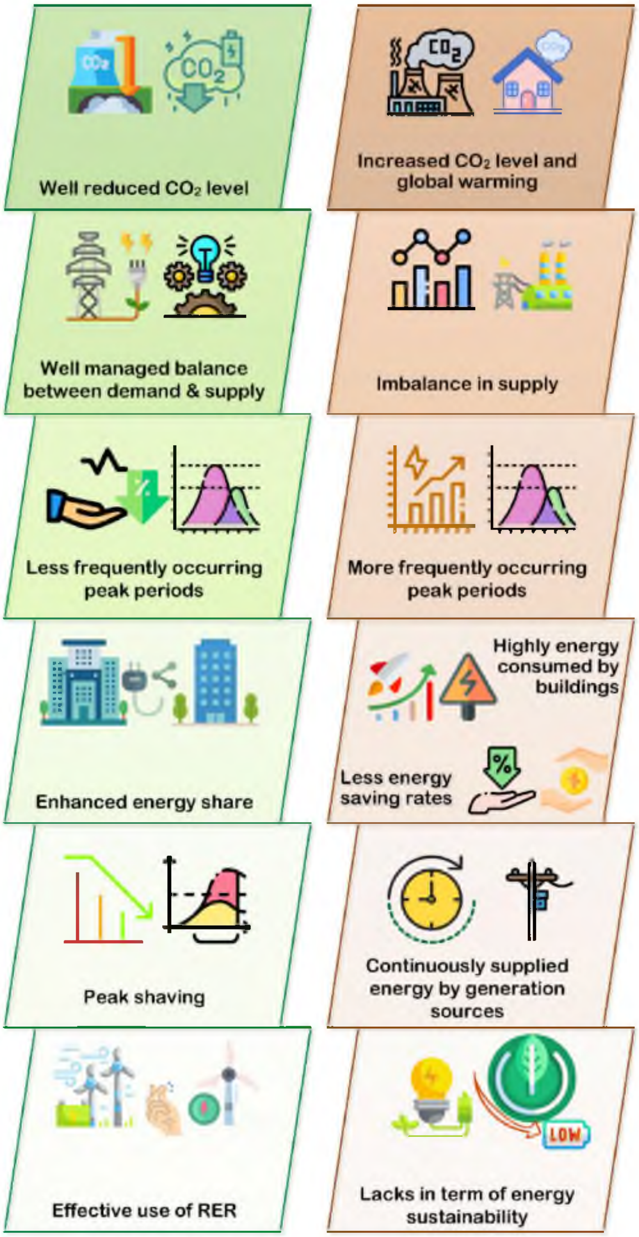
This subsection has introduced an attempt to find out the best SAs types achieving less ED during peak hours and the related evaluation shown in Figure 27 has mentioned that controllable SAs can achieve high energy-saving and less ED. Thus, controllable SAs are the most suitable installed devices for SG-adopted buildings and have most compatibility with DR. but, the use of these SAs in the relative buildings is still of a challenge due to many reasons.

D. OUR SUGGESTIONS

1) A FRAMEWORK FOR AN EFFICIENT DR METHOD – DEMAND-SIDE PERSPECTIVE (DSP)

We developed a framework for DR to guide designers on specifications and properties of buildings applied DR for a better service in a SG environment. This is a minimum quota of specifications that are necessary to be included in a DR strategy and can be further enhanced based on requirements, conditions, and criteria of the scenario applied to a CS of the SG-adopted building. The proposed DSP framework of an efficient DR method applied to a SG-adopting building is illustrated in Figure 28.

We developed a simple and initial framework for DR strategies used to assist designers, what factors/elements should be considered to design a DR scheme for such an associated purpose. Figure 28 has included five potential purposes placed inside the center part (shapes-green part). That means the use of, for example, TES and/or EVs would enhance DR in terms of energy flexibility. Another example mentioned in Figure 28 is that using RER or incentive offers leads to enhance supply imbalance and that would lead to an energy-



a significant outcomes b insignificant outcomes

FIGURE 26. The potential outcomes of DR towards SG and its buildings. With effective utilization of DR, significant outcomes (a) to demand and supply-sides' utilities, but without it, our environment may be affected by insignificant outcomes (b) hence. Images are licensed. Design is made by authors.

sustainable grid. This framework is applicable for further enhancement. That is, if there is a need to enhance, for example, prediction strategies, TES and its capacity size would be a supportive tool.

2) A FRAMEWORK FOR AN EFFICIENT DR METHOD – SUPPLY-SIDE PERSPECTIVE (SSP)

There is a need to develop another framework for supply-side. SSP proposes that the supply-side part designs a prediction model of the demand-side behavior of energy-consumption. In this framework, supply-side would be able to predict the energy load curves in certain times so that SSP will be able to overcome several issues such as fluctuations and emergency DR requests. Proposed SSP framework can be more adequate with occupancy in office, large-scale, academic buildings. SSP framework aims to assist generators reduce several issues, reduce frequency of ED, and reduce frequency of peak periods.

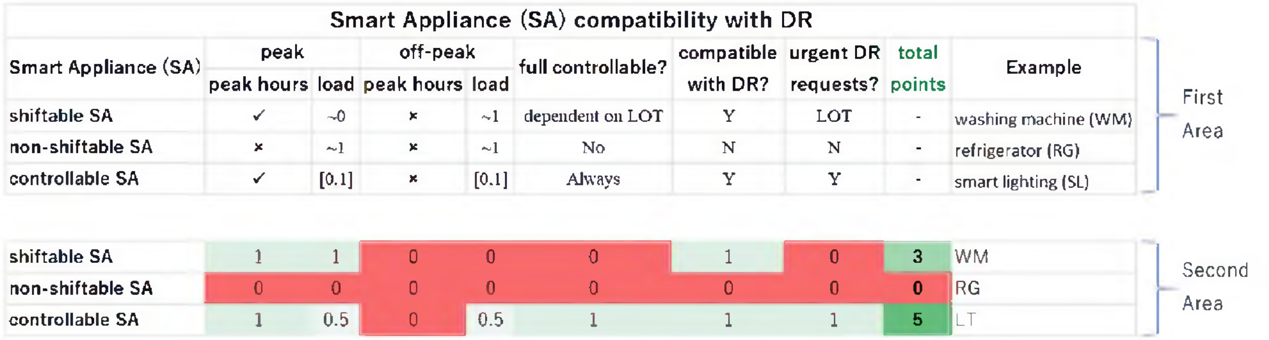
3) OUTCOMES

We propose a prediction strategy of energy-consumption behavior in buildings by the supply-side such as generation and distribution sources and units. We called this a "reverse forecasting approach" or ReFA. We suggest that ReFA be implemented as an integrated prediction strategy alongside other demand-side related forecasting strategies such as price-based or loads forecasting. ReFA basically enables supply-side managers monitor energy-consumption behavior(s) of participants in SG-adopted buildings. Next, ReFA produces two classifications for output which are 1) when behavior of energy-consumption of SG-adopted buildings is low and 2) when behaviors of energy-consumption are high. This variety of outputs very much helps generation and distribution units (supply-side) to increase production in specific times and reduce it otherwise times. ReFA principle aims to smooth heavy loads and demand curve spike(s). ReFA Features can be simply summarized as: 1) ReFA maintains prices almost static, 2) ReFA maintains less fluctuations, and 3) ReFA maintains few peak demand periods.

E. OTHER CONCLUDED POINTS FOR FUTURE DIRECTIONS

Points of strength and weakness concluded from the reviewed articles are in detail highlighted and discussed to open directions that might potentially enhance future proposed DR strategies applied to SG-adopted buildings. A number of concluded points are listed in this subsection.

1) SGs or networks enhance performance of energy management through DR strategies applied to buildings. One of the featured enhancements(s) is the ability of involvement energy systems connected to SG-buildings. Therefore, ESS' presence may boost SG involvement.
2) SG strategies can improve DR, utilizing RESs for energy storage is an added advantage for EDR, and SG-enabled buildings can exploit this to enhance DR. DR events have been shown to influence electricity prices [84], [296].
3) SGs help improve and reduce the imbalance and fluctuation during generation phases if specifically, RTP information has been well transferred between SG and its participants [184].
4) SG can support DR strategies to be able to control loads to achieve a high percentage of energy-consumption reduction [197].
5) It is highlighted that: 1) ESSs may increase energy saving in buildings [214] and 2) occupants cooperation could contribute to EDR [152].



Smart Appliance (SA) compatibility with DR									
Smart Appliance (SA)	peak		off-peak		full controllable?	compatible with DR?	urgent DR requests?	total points	Example
	peak hours	load	peak hours	load					
shiftable SA	✓	~0	×	~1	dependent on LOT	Y	LOT	-	washing machine (WM)
non-shiftable SA	×	~1	×	~1	No	N	N	-	refrigerator (RG)
controllable SA	✓	[0.1]	×	[0.1]	Always	Y	Y	-	smart lighting (SL)

shiftable SA	1	1	0	0	0	1	0	3	WM
non-shiftable SA	0	0	0	0	0	0	0	0	RG
controllable SA	1	0.5	0	0.5	1	1	1	5	LT

FIGURE 27. A heatmap representing behaviors of SAs compatibility during DR events and SG requests. Included are two areas first of which describes SAs behaviors during peak and off-peak hours and second of which assign values to situations representing ways of behaviors. Both areas concern SAs compatibility with DR as a result of SG requests during peak and off-peak hours. In the first area, SAs are evaluated in terms of compatibility with DR. If a SA is compatible with DR in terms of compatibility, a true sign will be assigned; otherwise, a false sign is assigned. In terms of load, if there is no load (no energy consumed by that SA), a '0' value is assigned to indicate compatibility of SA; otherwise, a '1' is assigned to indicate that SA is not compatible with DR and a load exists and energy is consumed. For the 'controllable SA', its load will be consuming less energy during DR event than before DR even is occurred, therefore 'controllable SA' will be assigned the value [0,1] to indicate less energy consumed between 0 and 1. The reason is that, controllable SA can reduce its energy-consumption level and load will be reduced as well. In the second one, only values are assigned to represent signs and other values placed-in for the first area. Thus, for this purpose, 1) there will be '1' representing both the true sign and ~0, 2) the value '0' represents both the false sign and ~1, and 3) the value '0.5' represents [0,1].

6) The prediction methods might fail to achieve higher levels and rates of energy-saving [248].
7) DERs could have more benefits than centralized generation sources from the economic and environmental sectors' perspectives [28], [29].
8) Since industrial buildings contain heavy controllable loads, further distributed or industrial buildings focused studies are encouraged to increase energy-savings and that might reduce CO_2 due to ED reduction.
9) Analysis of simulated and real scenarios implemented by case studies shows a shortage of real scenarios inclusion. Therefore, more consideration of real scenarios-implemented case studies is of importance. So that, further future works in this direction could enhance DR and improve ED leading to more sustainability in terms of energy supply.
10) From figures 16 and 17,
    a. As a direction of future works, control methods are preferable and can achieve better performance with DSM towards enhancement of DR and SGs.
    b. Prediction-based methods utilizing DR are of shortage. There is a need to focus more on prediction methods to achieve better DR performance within SG-adopted buildings.
    c. DSM can be enhanced utilizing control-based method for DR.
    d. Residential and commercial buildings-related DR strategies have focused on energy storage and DSM.
    e. Other types of buildings that had the least concern in accordance to number of applications include, for example, retail, academic, historical, industrial, and smart; they are ordered from least to most.
11) From analysis presented in Figure 22, we can reveal that:
    a. Programming languages such as "MATLAB", "TRNSYS", and "EnergyPlus" are of importance to be used with many methods applied to several types of buildings and scenarios. They can be very well utilized to be applied with types of buildings performing several tasks for a varied list of elements.
    b. There are many programming languages and simulation tools suitable to perform both real and simulated scenarios and some others are suitable to perform either real or simulated scenarios.
12) DR programs have not fully utilized smart meters, as mentioned in previous analyses regarding appliances. However, smart meters have the potential to provide real-time information to utilities, improving SG efficiency, reducing energy demand, and promoting energy sustainability and security.
13) Prediction-related strategies for DR programs have a less share of frequency of use compared to others.
    a. There is a need to enhance this type of strategies. Obtained results whose related methods and designs depend on prediction have achieved less amount of energy-saving rates and higher ED.
    b. Besides, there is a small number of scenarios and CS building types adopting prediction-based strategies.
    c. Less programmable elements and smart appliances alongside simulation tools are used.
    d. Prediction-based strategies have a real weakness point that is they fail to accurately: 1) forecast weather changes, 2) predict RTP variations, and 3) predict peak and off-peak hours.
    e. One of the solutions to overcome such weakness is to use TES, preheating, and precooling for the building. In case, the prediction strategy has failed

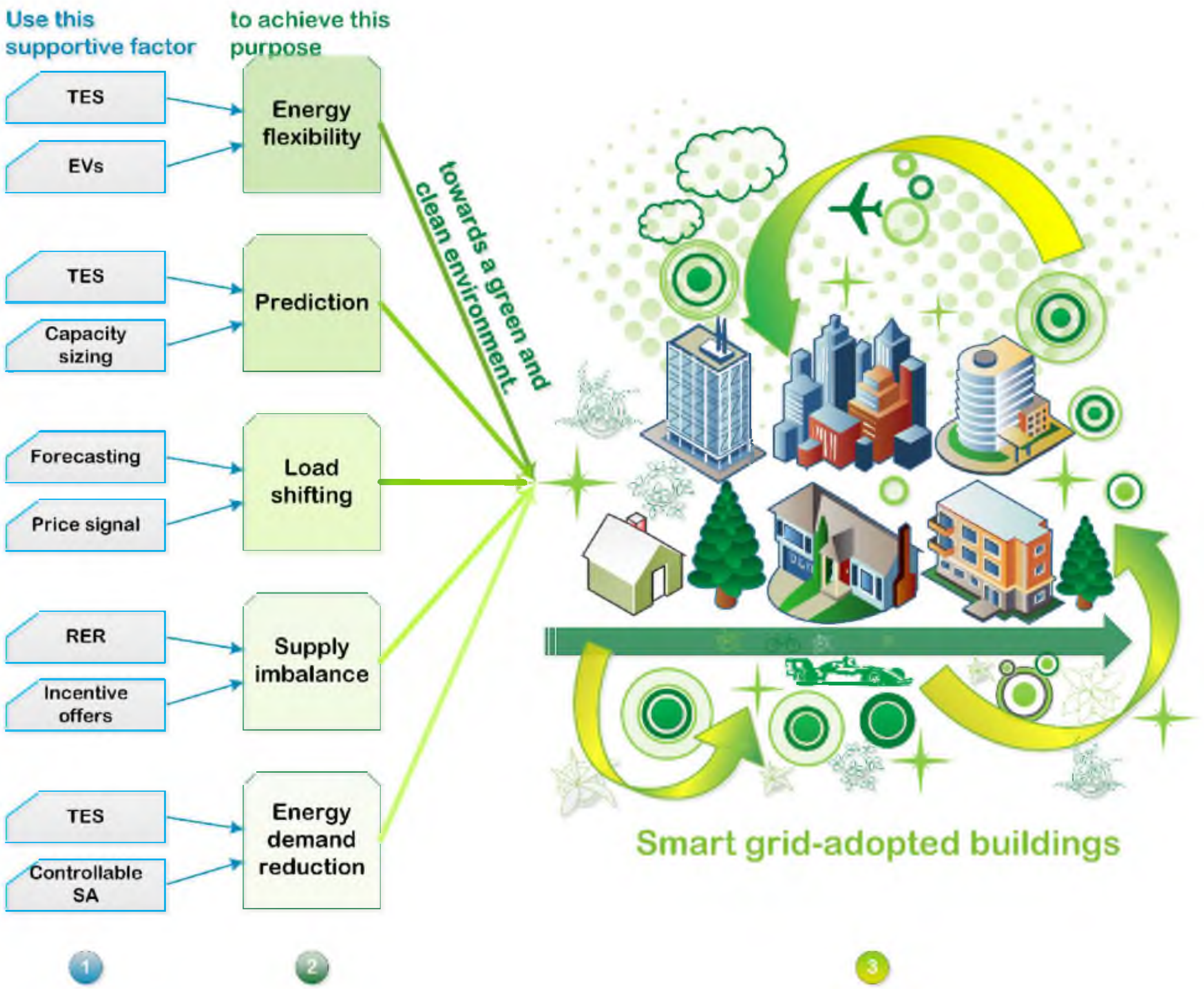


FIGURE 28. Framework – demand-side (designers). There are three main parts in Figure 28 which are described as follows: 1) on the left in blue-color shapes, factors/solutions/ or supportive tools that might enhance mentioned and associated issues, 2) on the center in green-color shapes, purposes which need to be achieved or issues need to be solved, and 3) on the right, there is a demo-illustrated representation of a SG-adopted building(s) aiming to reach.

to accurately predict or detect periods of RTP, for example, TES can be used as a supplier.

f. Prediction strategies with the help of TES, can be also a good solution to overcome imbalance of supply curve caused by any potential mistake in forecasting RER such as winds.

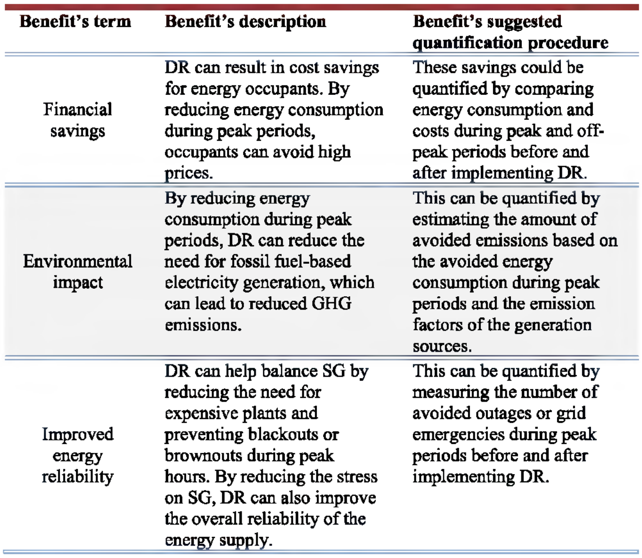
14) Sustainable energy achievement could be of possibility since RERs have been continuously developed through effective utilization of DR strategies amongst SG.
    a. A potential trend in the so near future is to efficiently utilize various DR schemes.
    b. Associated buildings are a good player in this trend.
    c. DR role may indirectly contribute to sustainable energy through effective management of RERs-dependent supply to SG buildings replacing power plant-dependent supply.
    d. DR role is simply to shape the rationalization of different resources of renewables

F. INSIGHTS: INFORMING POLICY AND INDUSTRY DECISIONS FOR SGS IN BUILDINGS THROUGH DR

This review could provide valuable insights into potential benefits of implementing DR strategies in buildings to support sustainable energy in SGs [297]. These insights could enable findings inform policy and industry decisions related to the development and implementation of SGs in buildings in different ways such as:

1) Promoting DR strategies by highlighting importance of promoting DR strategies in buildings to reduce energy consumption during peak periods. Policymakers and industry leaders can use this information to develop policies and incentives to encourage building occupants to participate in DR strategies [298].
2) Investing in technology by identifying several DR strategies, such as automated DR and AMI, that can be integrated with energy management systems to improve energy efficiency and support sustainable energy in SGs. Policymakers and industry leaders can use this

TABLE 15. **Description of benefits gained from DR in SG-adopted buildings in terms of financial savings, environmental impact, and improved energy reliability and their related quantification procedures.**



Benefit's term	Benefit's description	Benefit's suggested quantification procedure
Financial savings	DR can result in cost savings for energy occupants. By reducing energy consumption during peak periods, occupants can avoid high prices.	These savings could be quantified by comparing energy consumption and costs during peak and off-peak periods before and after implementing DR.
Environmental impact	By reducing energy consumption during peak periods, DR can reduce the need for fossil fuel-based electricity generation, which can lead to reduced GHG emissions.	This can be quantified by estimating the amount of avoided emissions based on the avoided energy consumption during peak periods and the emission factors of the generation sources.
Improved energy reliability	DR can help balance SG by reducing the need for expensive plants and preventing blackouts or brownouts during peak hours. By reducing the stress on SG, DR can also improve the overall reliability of the energy supply.	This can be quantified by measuring the number of avoided outages or grid emergencies during peak periods before and after implementing DR.

information to invest in the development and deployment of these technologies [299].

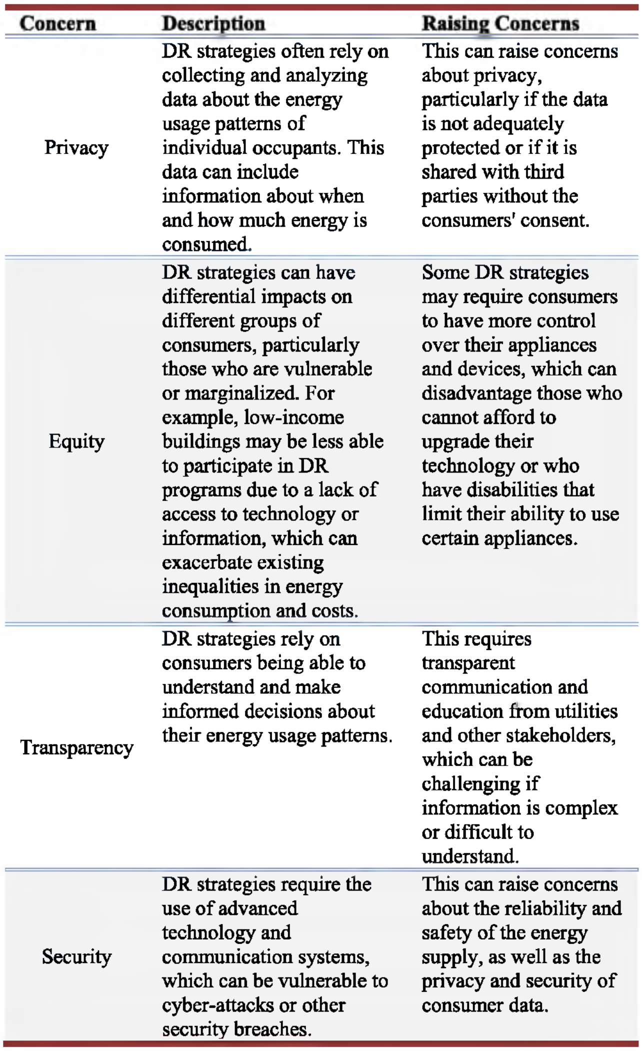
3) Supporting research and development by highlighting the need for further research and development to optimize DR strategies in buildings and improve their effectiveness. Policymakers can use such information to support research and development initiatives aimed at improving the design, implementation, and evaluation of DR strategies in buildings.

In conclusion, findings of this review paper can inform policy and industry decisions related to the development and implementation of SGs in buildings by promoting DR strategies, investing in technology, and supporting research and development. This can lead to more efficient and sustainable energy use, improved grid stability, and a more resilient energy system [300].

G. QUANTIFYING BENEFITS OF DR IN SG-ADOPTED BUILDINGS IN TERMS OF FINANCIAL SAVINGS, ENVIRONMENTAL IMPACT, AND IMPROVED ENERGY RELIABILITY

Since DR is encouraging energy occupants to adjust their energy usage patterns during peak periods in response to price signals, grid reliability concerns, or other incentives, for the SG-adopted buildings, DR can yield various benefits as a result. Such benefits in some cases could be able to be quantified in terms of, for example, financial savings, environmental impact, and improved energy reliability. Further description of these benefits and how such a benefit could be quantified (measured) are provided in Table 15.

TABLE 16. **Raising concerns: Potential ethical implications of DR strategies in SG-adopted buildings towards sustainable energy.**



Concern	Description	Raising Concerns
Privacy	DR strategies often rely on collecting and analyzing data about the energy usage patterns of individual occupants. This data can include information about when and how much energy is consumed.	This can raise concerns about privacy, particularly if the data is not adequately protected or if it is shared with third parties without the consumers' consent.
Equity	DR strategies can have differential impacts on different groups of consumers, particularly those who are vulnerable or marginalized. For example, low-income buildings may be less able to participate in DR programs due to a lack of access to technology or information, which can exacerbate existing inequalities in energy consumption and costs.	Some DR strategies may require consumers to have more control over their appliances and devices, which can disadvantage those who cannot afford to upgrade their technology or who have disabilities that limit their ability to use certain appliances.
Transparency	DR strategies rely on consumers being able to understand and make informed decisions about their energy usage patterns.	This requires transparent communication and education from utilities and other stakeholders, which can be challenging if information is complex or difficult to understand.
Security	DR strategies require the use of advanced technology and communication systems, which can be vulnerable to cyber-attacks or other security breaches.	This can raise concerns about the reliability and safety of the energy supply, as well as the privacy and security of consumer data.

H. POTENTIAL LIMITATIONS OF THE STUDY

As with any systematic review, there may be potential limitations or biases found. In this section, a number of these potential limitations will be listed:

Publication bias: Those papers with significant positive results are more likely to be published than those with negative or inconclusive results. Therefore, the review may have an overrepresentation of studies reporting positive effects of DR on sustainable energy in the SGs-adopted buildings sector.

Selection bias: Inclusion and exclusion criteria of the systematic review could introduce selection bias. If certain papers were excluded or included based on particular criteria, it may affect the overall conclusions of the review.

Quality of the included papers: The quality of the papers included in the review could vary, and this could impact the overall conclusions. For example, if some papers have a high risk of bias, it could have a potential impact on the conclusions.

Lack of diversity in the included papers: The papers included in the review may be limited to a particular geographical region or certain types of buildings, which could limit the generalizability of the findings.

Confounding factors: The papers included in the review may not have adequately accounted for potential confounding factors that could affect the relationship between DR and sustainable energy in the SGs-adopted buildings sector. For instance, factors such as the weather, the time of day, or the type of building could affect the effectiveness of DR programs.

I. ADDRESSING GAPS AND LIMITATIONS IN FUTURE RESEARCH ON DR STRATEGIES: BUILDING UPON THIS REVIEW'S FINDINGS

This review paper has provided a comprehensive overview of the current state of research on DR in SG-adopted buildings sector. To build upon the findings of this review paper and address the gaps or limitations identified in the reviewed studies, future research could consider the following approaches:

1) Conducting further empirical studies: This review has highlighted a limited number of empirical studies available in the literature. Future research could focus on conducting more empirical studies to provide more concrete evidence on the effectiveness of DR in different contexts.
2) Examining DR's economic viability: This review paper has indicated that DR economic viability needs to be well considered to be well understood. Future research could explore the economic benefits of DR, including the potential for cost savings, revenue generation, and environmental benefits.
3) Investigating DR's impact on different stakeholders: Future research could examine how DR affects stakeholders and identify ways to optimize its benefits for all parties involved.
4) Assessing DR's scalability: Future studies could investigate the scalability of DR solutions and identify barriers that may impede its widespread adoption.
5) Developing innovative DR solutions: It is preferable for involving more innovative DR solutions in SG-adopted building. Future research could focus on developing new and innovative DR solutions, such as using artificial intelligence and machine learning to optimize DR strategies.

To put it briefly, future research could build upon the findings of the review paper by conducting more empirical studies, examining the economic viability of DR, investigating the impact of DR on different stakeholders, assessing the scalability of DR, and developing innovative DR solutions.

J. POTENTIAL ETHICAL IMPLICATIONS OF DR IN SG-ADOPTED BUILDINGS: CONCERNS

Since DR strategies in SG-adopted buildings could have significant benefits for sustainable energy, there are also potential ethical implications that need to be considered. Discussed in Table 16 are various concerns including privacy, equity, and security.

K. GENERALIZABILITY OF FINDINGS IN THIS SYSTEMATIC REVIEW TO BUILDINGS AND REGIONS WITH DIFFERENT ENERGY INFRASTRUCTURE AND POLICIES

The generalizability of the findings of this review to different types of buildings or regions with varying energy infrastructure and policies may be limited. The extent to which the findings can be generalized depends on the characteristics of the buildings and regions included in the review and the applicability of the results to other contexts.

The review may have included studies from a specific geographical region or certain types of buildings, and the findings may not be generalizable to other regions or types of buildings. For instance, some regions may have different energy infrastructure or policies that could impact the effectiveness of DR programs.

Furthermore, the effectiveness of DR programs may depend on various factors such as the building type, the climate, the energy infrastructure, the regulatory framework, and the socioeconomic conditions of the region. Therefore, the results of the review may not be generalizable to other buildings or regions with different characteristics.

Since the systematic review provides valuable insights into the role of DR in sustainable energy in the SGs-adopted buildings sector, the findings may have limited generalizability to other types of buildings or regions with varying energy infrastructure and policies. It is important to consider the specific context of the buildings or regions in question when applying the findings of the review to inform policy or practice.

ACKNOWLEDGMENT

The authors would like to thank the team of freepik.com. Licensed images are borrowed from (https://www.freepik.com/).

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