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Revolutionizing Demand Response Management: Empowering Consumers through Power Aggregator and Right of Flexibility

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Abstract: This paper introduces a groundbreaking approach to demand response management, aiming to empower consumers through innovative strategies. The key contribution is the concept of "acquiring flexibility rights", wherein consumers engage with power aggregators to curtail energy usage during peak-load periods, receiving incentives in return. A flexibility right coefficient is introduced, allowing consumers to tailor their participation in demand response programs, ensuring their well-being. Additionally, a lighting intensity control system is developed to enhance residential lighting network efficiency. The study demonstrates that high-energy consumers, adopting a satisfaction factor of 10, can achieve over 61% in electricity cost savings by combining the lighting control system and active participation in demand response programs. This not only reduces expenses but also generates income through the sale of flexibility rights. Conversely, low-energy consumers can fully offset their expenses and accumulate over USD 33 in earnings through the installation of solar panels. This paper formulates an optimization problem considering flexibility rights, lighting control, and time-of-use tariff rates. An algorithm is proposed for a distributed solution, and a sensitivity analysis is conducted for evaluation. The proposed method showcases significant benefits, including cost savings and income generation for consumers, while contributing to grid stability and reduced blackout occurrences. Real data from a residential district in Tehran validates the method's effectiveness. This study concludes that this approach holds promise for demand response management in smart grids, emphasizing the importance of consumer empowerment and sustainable energy practices.

Keywords: demand response management; flexibility rights; lighting intensity control; energy cost savings; optimization algorithm

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1. Introduction

The existing power grid infrastructure faces challenges due to increased demand and potential future strain from electric vehicles [1]. To address these issues, demand response (DR) programs have gained prominence. This paper proposes a new approach to DR management by introducing flexibility rights and a lighting intensity control system. Previous studies have focused on energy consumption management, with limited attention to the comprehensive integration of lighting control and DR programs [2,3].

The contemporary challenges faced by power grid infrastructures worldwide necessitate innovative approaches to address increasing demand and integrate sustainable energy practices. With the impending surge in electric vehicles and the strain on aging power grids, the implementation of effective demand response (DR) programs becomes paramount [4].

Existing studies have explored diverse facets of energy consumption management, ranging from energy-saving methods in public buildings [5,6] to the analysis of residential energy consumption before and after structural modifications [7–9]. Additionally, recent research has delved into the synergies between photovoltaic (PV) generation and residential load curves, emphasizing the importance of adaptive optimization and control modules for maximizing rooftop PV usage [10,11].

Prior investigations have delved into various aspects of energy management. These include endeavors to estimate energy costs [12], examinations of residential energy consumption patterns before and after structural modifications [13], as well as comparative analyses of energy utilization across residential locales [14–16]. In [17], it is shown that with the help of lighting control in a smart home and the use of special sensors, it is even possible to save 54% of energy consumption. In [18], the effect of building automation control systems on the consumption performance of consumers in Italy has been studied. The obtained results show that building energy control systems can improve the energy performance of homes significantly. DR provides an opportunity for customers to play a significant role in consumption management by reducing or shifting their energy consumption during peak-load hours in response to time-of-use (TOU) rates or other incentive programs [19]. On the other hand, DR is a program that is implemented voluntarily by consumers and generally consists of incentive-based and price-based programs. An incentive-based program creates incentives for the user to participate in DR programs by paying incentives [20]. The price-based program increases the tariff rate during peak-load hours and decreases it during off-peak hours which helps to reduce the congestion of distribution networks and power losses during peak-load hours [18].

Furthermore, the advent of edge and fog computing, coupled with the Internet of Things (IoT), has facilitated direct load optimization and control, providing flexibility services for citizen energy communities [21]. As part of the broader landscape, optimization strategies leveraging dynamic tariffs and game-theoretic frameworks have emerged, aiming to enhance electricity consumption flexibility [22]. The integration of such advanced technologies highlights the evolving nature of demand response management.

This paper contributes to this evolving landscape by introducing a novel strategy, "acquiring flexibility rights", to revolutionize demand response management. In this paradigm, consumers engage with power aggregators, receiving incentives for curtailing energy usage during peak-load periods. An integral aspect is the introduction of a flexibility right coefficient, allowing consumers to tailor their participation in DR programs [12,22]. This study also presents a sophisticated lighting intensity control system designed to enhance residential lighting network efficiency; a facet not comprehensively explored in prior research [23].

To strengthen the theoretical foundations of this work, we incorporate insights from related studies such as "Mind the gap between PV generation and residential load curves", emphasizing IoT-based adaptive optimization [24], and "Optimizing the Electricity Consumption with a High Degree of Flexibility", employing dynamic tariffs and Stackelberg game theory [13,22]. Additionally, we integrate recent research on edge and fog computing utilizing IoT for direct load optimization and control [21].

As we delve into the optimization problem formulation and algorithm proposal, the discussion extends beyond traditional DR programs. The methodology and findings presented herein showcase a forward-looking perspective on demand response, incorporating the latest advancements in technology and adaptive control strategies. The subsequent sections provide an in-depth exploration of the electrical energy tariff rate, irradiation modeling, automatic lighting control systems, and the formulation of the optimization problem. Through simulation results and analysis, we demonstrate the efficacy of the proposed approach, emphasizing its potential impact on reducing electricity costs, enhancing grid stability, and mitigating blackout occurrences.

2. Electrical Energy Tariff Rate

This paper presents a time-of-use (ToU) tariff rate, dividing 24 h into three periods with different rates. This study focuses on tariff rates applicable in 2022, providing specific cost details for various energy consumption levels.

As part of the time-of-use (ToU) tariff rate, the 24 hours in a day are divided into three time periods and a different rate is defined for each part. The peak periods are from 12:00–15:00 p.m. and 20:00–22:00 p.m., for which the highest energy price is intended. The time periods between 7:00–12:00 p.m. and 15:00 to 20:00 p.m. are considered mid-peak periods and from 22:00 p.m.–7:00 a.m. the next day is considered an off-peak period. This study focuses on the tariff rates applicable in 2022. During this period, the cost of energy consumption stands at USD 0.0075 per kWh for off-peak hours, USD 0.015 per kWh during mid-peak hours, and USD 0.03 per kWh during peak-load hours. The amount of the inclining block rate (IBR) is also according to Table 1.

Table 1. Tariff rate for moderate areas [4].

Avg. Monthly Energy Consumption (kWh per Month)	Base Price per kWh (USD)
0–100	0.022
100 to 200	0.026
200 to 300	0.057
300 to 400	0.102
400 to 500	0.118
500 to 600	0.148
more than 600	0.1633

3. Irradiation Modeling

The lighting control system relies on accurate information about irradiation levels at different times. This study employs data on average solar energy radiation for various months of the year, demonstrating a commitment to detail in optimizing the proposed lighting control system.

For managing the lighting control system, it is necessary to have enough information about the amount of irradiation at different times. In this regard, the information regarding the average amount of solar energy radiation included in [25] has been used. Figure 1 shows the average level of irradiation for all months of the year.

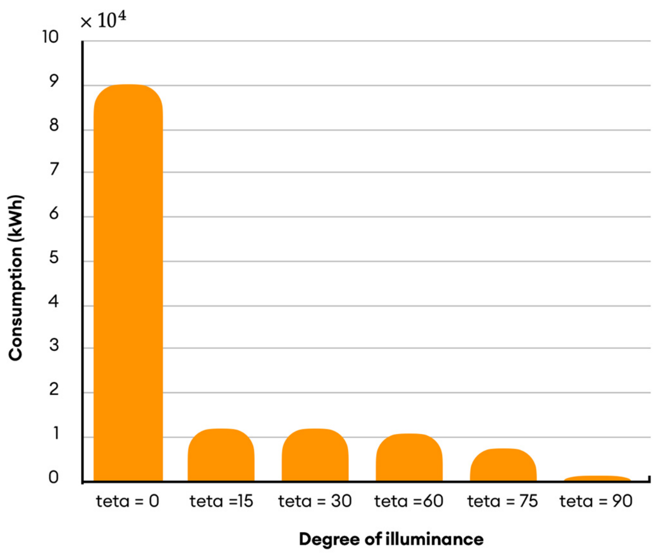

Figure 1. Average irradiation level for different months of the year [25].

4. Automatic Lighting Control System

The developed lighting control system adjusts intensity based on natural daylight and consumer preferences. A detailed model is presented, considering different modes and parameters for effective lighting management. This paper highlights the independent control mechanism of the lighting system, particularly during nighttime hours.

In order to manage electrical consumption, daylight can also be used in this field. In fact, by adjusting the lighting intensity with the help of natural ambient light and the controllable lighting system, it is possible to schedule maintaining the standard level of intensity as well as optimizing the energy consumption of the lighting system. The intensity of the ambient lighting is automatically adjusted based on the current level of natural sunlight. The system dynamically regulates the lighting to optimize the use of available natural light at any given time. According to the designed model discussed in Refs. [26–28], four different modes can be defined based on the changes in the parameter θ (Figure 2). This parameter expresses the angle of sunlight from the top of the window in the room or other different parts of the residential house. In all four of these modes, a light sensor is used to extract the brightness value and its value is calculated through (1). In this regard, the parameter φ indicates the density of the measured illuminance intensity in the ambient area under study and is regarded as an input to the lighting control system. Coefficients b and h indicate the length and width of the irradiated area, and the parameter δ is considered as the tool.

$$I_{\theta_i} = \left\{ \begin{array}{ll} \varphi\left[\frac{1}{2}(b_1 \times h_1) + (b_2 \times x)\right] \pm \delta & 0^\circ \leq \theta_1 \leq 15^\circ \\ \frac{\varphi}{2}\left[(b_3 \times h_2) + (b_4 \times h_3)\right] \pm \delta & 15^\circ \leq \theta_1 \leq 30^\circ \\ \varphi\left[\frac{1}{2}(b_6 \times x) + (b_5 \times x)\right] \pm \delta & 30^\circ \leq \theta_1 \leq 45^\circ \\ \varphi\left[\frac{1}{2}(b_6 \times x) + (b_5 \times x)\right] \pm \delta & 45^\circ \leq \theta_1 \leq 60^\circ \\ \varphi x^2 & otherwise \end{array} \right\} \quad (1)$$

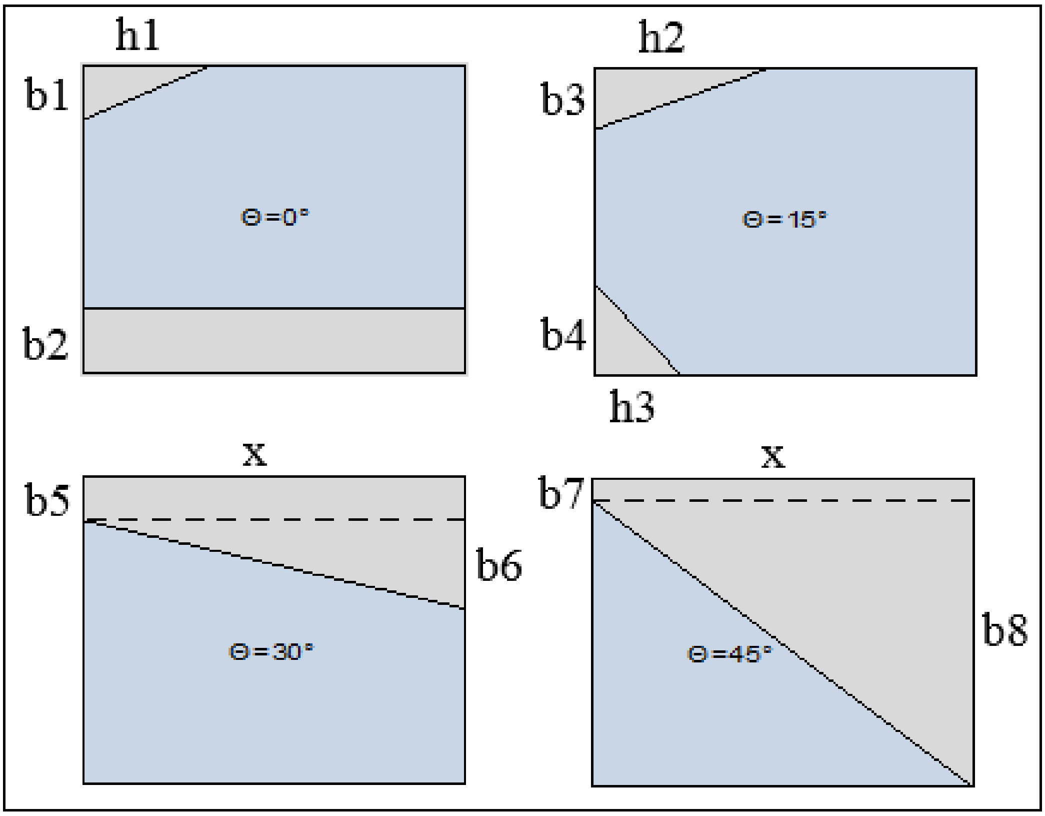

Figure 2. Area covered by sunlight at different times of the day [26].

In this research, the lighting system is equipped with an independent control mechanism, distinct from other household appliances. During nighttime hours, when natural lighting is unavailable, all the lamps within the residential dwelling are activated to ensure adequate illumination. On the other hand, during the day and according to angles of sunlight, first, the lighting sensors measure the intensity level of the ambient light and compare it with the standard values defined for those hours of the day and type of application. Finally, the necessary brightness intensity is determined and then the required lamps are turned on. In other words, in these conditions, there is no need to use the maximum power of the lighting system and only a part of the lighting system is used to meet the defined standards.

5. Formulation of the Optimization Problem

The methodology for evaluating the proposed approach involves formulating an optimization problem. The optimization problem aims to maximize social welfare, considering flexibility rights, lighting control, and time-of-use tariff rates. This paper introduces an algorithm for solving the optimization problem in a distributed manner, emphasizing the efficiency and practicality of the proposed approach.

To formulate the objective function, the starting and ending times for each controllable device are defined by the consumers. The status of the controllable devices must be scheduled according to (2). The objective function of this research is defined according to (3), which minimizes the difference between the consumer's cost and income.

$$\alpha_a \leq TS_a \leq \beta_a - LOT_a - \alpha_a + 1 \tag{2}$$

α_a: Beginning of the allowable time interval for controllable devices;
β_a: Ending of the allowable time interval for controllable devices;
TS_a: Starting time of controllable devices;
LOT_a: No. of time steps required for a controllable device's operation.

The total cost consists of the cost of consumed energy for the lighting system, fixed devices, and controllable devices which is calculated as (4). The total income consists of two terms which are related to incentive and injected power (5). In fact, the first term is related to the incentive revenue with regard to offering the right of flexibility, and the second term is related to injecting energy into the grid by operation of solar panels. In (4), the parameter λ is used, which expresses the priority of starting the controllable device, which is determined by the user. In fact, this term is included to model the waiting time, which is called the customer satisfaction coefficient, which can adjust the scheduling hours of the controllable equipment according to the user's opinion. In this situation, the more value that is allocated to the user's adjustment factor, the more the waiting time will decrease, but the cost of energy consumption will probably increase, and on the contrary, if the priority factor set for starting the controllable equipment is selected as a low value, then the number of waiting hours will increase and the cost of energy consumption will be reduced due to operation of the equipment during off-peak hours.

$$\text{Min } O.F = Cost - Rev \tag{3}$$

$$Cost = \sum_{t\in T}\left(P^t_{illum} + P^t_{fix} + \sum_{a\in A}\left(\frac{TS_a - \alpha_a}{\beta_a - LOT_a - \alpha_a + 1}\cdot\lambda_a\right)\cdot P^t_{shift}\right)\cdot k^t \tag{4}$$

$$Rev = \sum_{t'\epsilon T_{peak}} P^{t'}_{flex}\cdot k^{t'} + \sum_{t''\epsilon T} P^{t''}_{gen}\cdot k^{t''} \tag{5}$$

where,

P^t_{illum}: Consumed power by the lighting (or illumination) system in the time period t (kW);
P^t_{fix}: Consumed power by the fixed devices in the time period t (kW);

P^{t}_{shift}: Consumed power by the controllable devices in the time period t (kW);
$P^{t'}_{flex}$: Amount of shifted power according to right of flexibility (kW);
$P^{t''}_{gen}$: Amount of injected power by solar arrays (kW);
k^{t}: Tariff rate of electrical energy in the time period t (USD/kWh).

The consumed power of the lighting system in these conditions is also obtained by (6). In order to optimize the amount of energy consumption, it is necessary to consider a set of constraints. In (7), it is stated that the total power of the residential load (consisting of fixed load, lighting system, and controlled load) must be less than the maximum allowable power consumption. Equations (6)–(8) show the equality and inequality constraints associated with the objective function. Equation (8) shows that the consumption power of each controllable device must be within its defined permissible range.

$$P_{illum_a} = \left(I_{\theta_{ref}} - I_{\theta}\right) \times E^{a} \tag{6}$$

$$P^{t}_{fix} + P^{t}_{illum} + P^{t}_{shift} \leq P^{max} \tag{7}$$

$$P^{min}_{a} \leq P_{a} \leq P^{max}_{a} \qquad \forall\, a \in A \tag{8}$$

where:
$I_{\theta_{ref}}$: Density of light intensity (Lum/m^2);
I_{θ}: Brightness level of daylight illumination (Lum);
E^{a}: Gain of lighting system (kW/Lum).

5.1. Participation Level: Virtual Contract

As stated in the previous section, consumers can determine their level of participation in DR programs by determining the satisfaction coefficient (λ). Determination of this coefficient is achieved by a mobile application. Based on the collection of all consumers' information, the tariff rate, and the estimated amount of consumption for the next day, the level of consumer participation is determined. At this stage, if the consumer approves the level of participation specified in order to reduce the consumption in peak-load hours, he will receive an incentive according to shifted kWh. The proposed incentive rate considered in this research is equal to 0.03 USD/kWh and increases with more participation. Since this approach is designed based on a virtual contract between the consumers and the power aggregator, any violation of this contract causes penalties for both sides. In fact, if they exceed the permitted consumption rate, they will be fined. The proposed penalty rate is equal to 0.0375 USD/kWh, which increases in a stepwise manner.

It should be noted that the consumer can use special mobile applications to obtain information regarding real-time consumption and the upper bound of the peak-load consumption constraint. Determination of the satisfaction coefficient is also achieved through this system and until a new value is defined for it, based on the last previously determined value, scheduling is performed for the following days. If the amount of electric energy consumption during peak-load hours approaches the defined upper bound by the power aggregator, an SMS will be sent to the consumer, a warning of the consumption pattern reminding him that if the amount of consumption increases, he will be fined.

5.2. The System under Study

In this research, the electrical energy consumption information of one of the residential districts in Tehran was used. In order to provide a detailed evaluation, three types of consumers (low-, normal-, and high-consumption) for a period of 70 days (May to mid-July 2022) were studied. The information of the system under study is presented in Table 2.

Table 2. Characteristics of consumers in residential district.

Type of Consumers	Off-Peak (kWh)	Mid-Peak (kWh)	Peak-Load (kWh)	Total (kWh)
Low consumption	51	93	43	187
Mid. consumption	181	295	160	636
High consumption	589	844	326	1759
Total no. of consumers in residential district			78,234	
Total amount of consumption in this period			43,995,553 kWh	

5.3. Fixed Devices and Lighting System Control

Fixed devices refer to electrical appliances characterized by a consistent power consumption level, rendering them ineligible for inclusion in consumption scheduling strategies. These devices require a specific amount of consumption power and need to operate continuously. On the other hand, smart lighting management systems can adjust the intensity of ambient light to maintain optimal lighting levels while maximizing the use of natural irradiance.

Figure 3 illustrates the consumption pattern of fixed devices, depicting a stable level of power usage over time. Recognizing and analyzing these consumption patterns is crucial for devising comprehensive energy management strategies tailored to both dynamic and fixed loads. In a typical house with three bedrooms and a living area, the required intensity for the living room and bedrooms are considered 300 and 400 Lux, respectively. The consumption power for the living room is 120 W; for two 12 m^2 rooms, it is 60 W; and for one 9 m^2 room, it is 50 W. By implementing smart lighting control, energy consumption during peak periods (12:00–4:00 p.m.) can be reduced on average by 13%, resulting in 21% cost savings.

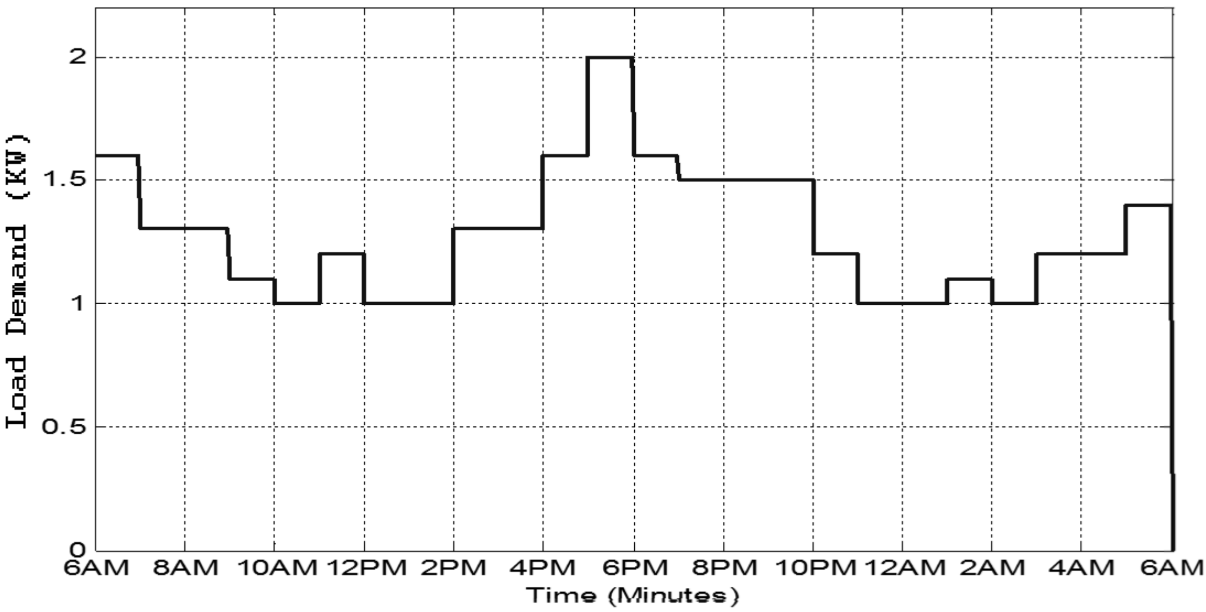

Figure 3. Consumption pattern of fixed devices.

Figure 4 displays the consumption energy for the lighting system in scheduling mode, as referenced in [5]. This figure provides insights into the energy usage patterns of the lighting system when subjected to scheduling protocols, offering valuable data for optimizing energy management strategies. Lighting control systems incorporate communication between various system inputs and outputs related to lighting control with the use of one or more central computing devices. These systems can be used in both indoor and outdoor lighting of commercial, industrial, and residential spaces and are sometimes referred to as smart lighting.

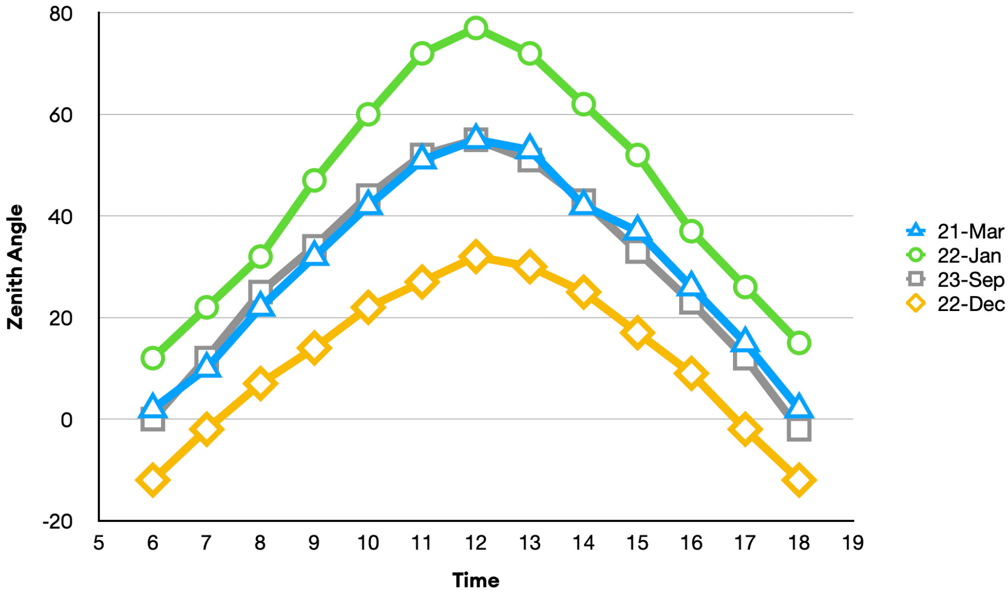

Figure 4. Consumption energy for lighting system (scheduling mode) [5].

6. Results and Discussion

This section presents the results and analysis of the proposed method using real data from a residential district in Tehran. This study evaluates the performance of the approach by comparing costs and revenues for different consumer types under various scenarios, including normal conditions, illumination control, and illumination plus DR participation.

This section presents the results and discussion of the proposed method for energy management in residential households with the considered lighting system. The results are based on the real data from a residential district in Tehran, which consists of three types of consumers: low-, normal-, and high-consumption. The data cover a period of 70 days from May to mid-July 2022. This paper evaluates the performance of the proposed method in terms of costs and revenues for different types of consumers as well as the effect of using renewable resources, such as solar arrays.

6.1. Use of Renewable Resources

This subsection investigates the effect of using solar arrays as an additional source of income for consumers. It is assumed that each house has a solar panel with a capacity of 5 kW, which can directly inject the generated energy into the distribution network. The average solar irradiation is taken from [27,29]. It is also assumed that the tariff rate for selling the generated energy is the same as the tariff rate for buying the consumed energy. The average amount of income obtained by each consumer through selling the generated energy in this period is about USD 31.94.

6.2. Evaluation of Consumer Participation in DR Programs

This subsection evaluates the effect of consumer participation in DR programs, which involves trading the right of flexibility during peak-load hours between consumers and a power aggregator. Consumers can determine their level of participation and satisfaction by using a mobile application, which also provides them with real-time information and feedback. The consumers can receive incentives for reducing their energy consumption during peak-load hours or pay penalties for exceeding their permitted consumption rate. The proposed incentive rate is 0.03 USD/kWh and the proposed penalty rate is 0.0375 USD/kWh, both increasing with more participation or violation.

This paper compares the costs and revenues for different types of consumers under three scenarios: normal condition, illumination control, and illumination plus DR participation. The normal condition refers to the case where the consumers do not use any lighting control system or participate in any DR program. The illumination control refers to the case where the consumers use a smart lighting control system that adjusts the ambient lighting intensity by using daylight and controllable distributed lights, which can save energy and maintain the standard lighting level. Illumination plus DR participation refers to the case where the consumers use both the smart lighting control system and participate in the DR program, which can further reduce their energy consumption and allow them to receive incentives.

The results are shown in Table 3, which indicates that by using the proposed method, not only are significant savings made for the consumer's cost, but they can also earn revenue by mounting solar arrays and trading the right of flexibility. According to Table 3, high-consumption consumers can save more than 61% on their electricity costs by using the smart lighting control system and participating in the DR program and earn more than USD 80 as income by mounting solar arrays and trading the right of flexibility. On the other hand, low-consumption consumers can cover their costs completely and earn more than USD 34 as income by mounting solar panels and trading the right of flexibility. Finally, if all the studied consumers are equipped with 5 kW solar arrays, the total income obtained by them will reach more than USD 2,475,000 in this period.

Table 3. Comparison of costs/revenues for different types of consumers.

Status	Scenario	Type of Consumers		
		Low Consumption	Mid. Consumption	High Consumption
Cost	Normal condition	USD 1.43	USD 19.33	USD 178.67
	Illumination control	USD 1.30	USD 16.04	USD 153.65
	Illumination + DR participation	USD 1.23	USD 13.34	USD 117.92
Revenue	Right of flexibility	USD 2.32	USD 8.4	USD 48.9
	Right of flexibility + Solar arrays	USD 34.26	USD 40.34	USD 80.84

7. Conclusions

This paper concludes that the proposed enhanced demand response management approach, incorporating a smart lighting control system, is promising for optimizing residential energy consumption. The integration of flexibility rights and lighting control not only yields significant cost savings but also contributes to reducing network congestion and potential blackouts. The use of renewable resources, such as solar arrays, further enhances the economic benefits for consumers. This study emphasizes the need for a holistic approach in managing energy consumption in smart grids.

This paper presents an efficient method for energy management in residential households, considering lighting systems. The main idea is to trade the right of flexibility during peak-load hours between consumers and the power aggregator, which allows consumers to reduce their energy consumption and receive incentives, while the power aggregator can optimize the power flow in the distribution network. The consumers can determine their level of participation and satisfaction by using a mobile application, which also provides them with real-time information and feedback. This paper also proposes a smart lighting control system that adjusts the ambient lighting intensity by using daylight and controllable distributed lights, which can further save energy and maintain the standard lighting level. This paper evaluates the performance of the proposed method by using real data from a residential district in Tehran and compares the costs and revenues for different types of consumers. The results show that the proposed method can achieve significant savings and income for the consumers as well as reduce the congestion and possible blackouts in the distribution network. This paper also discusses the use of renewable resources, such as solar arrays, as an additional source of income for consumers. This paper concludes that the proposed method is a promising approach for demand response management in smart grids.

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Nomenclator of Variables

α_a	Beginning of the allowable time interval for controllable devices
β_a	Ending of the allowable time interval for controllable devices
TS_a	Starting time of controllable devices
LOT_a	No. of time steps required for a controllable device's operation
P^t_{illum}	Consumed power by the lighting (or illumination) system in the time period t (kW)
P^t_{fix}	Consumed power by the fixed devices in the time period t (kW)
P^t_{shift}	Consumed power by the controllable devices in the time period t (kW)
$P^{t'}_{flex}$	Amount of shifted power according to right of flexibility (kW)
$P^{t''}_{gen}$	Amount of injected power by solar arrays (kW)
k^t	Tariff rate of electrical energy in the time period t (USD/kWh)
$I_{\theta_{ref}}$	Density of light intensity (Lum/m^2)
I_θ	Brightness level of daylight illumination (Lum)
E^a	Gain of lighting system (kW/Lum)

References

1. Junaidi, N.; Abdullah, M.P.; Alharbi, B.; Shaaban, M. Blockchain-Based Management of Demand Response in Electric Energy Grids: A Systematic Review. *Energy Rep.* **2023**, *9*, 5075–5100. [CrossRef]
2. Stanelyte, D.; Radziukyniene, N.; Radziukynas, V. Overview of Demand-Response Services: A Review. *Energies* **2022**, *15*, 1659. [CrossRef]
3. Oprea, S.V.; Bâra, A. Mind the gap between PV generation and residential load curves: Maximizing the roof-top PV usage for prosumers with an IoT-based adaptive optimization and control module. *Expert Syst. Appl.* **2023**, *212*, 118828. [CrossRef]
4. Tang, R.; Wang, S.; Li, H. Game Theory Based Interactive Demand Side Management Responding to Dynamic Pricing in Price-Based Demand Response of Smart Grids. *Appl. Energy* **2019**, *250*, 118–130. [CrossRef]
5. Zhu, J.; Deying, L. Current situation of energy consumption and energy saving analysis of large public building. *Procedia Eng.* **2015**, *121*, 1208–1214. [CrossRef]
6. Sekki, T.; Miimu, A.; Arto, S. Impact of building usage and occupancy on energy consumption in Finnish daycare and school buildings. *Energy Build.* **2015**, *105*, 247–257. [CrossRef]
7. Thomsen, K.E.; Jørgen, R.; Morck, S.J.; Iben, Ø. Energy consumption in an old residential building before and after deep energy renovation. *Energy Procedia* **2015**, *78*, 2358–2365. [CrossRef]
8. Barzamini, R.; Hajati, F.; Gheisari, S.; Motamadinejad, M.B. Short term load forecasting using multi-layer perception and fuzzy inference systems for Islamic countries. *J. Appl. Sci.* **2012**, *12*, 40–47. [CrossRef]
9. Barzamini, R.; Menhaj, M.B.; Khosravi, A.; Kamalvand, S.H. Short term load forecasting for Iran national power system and its regions using multi layer perceptron and fuzzy inference systems. In Proceedings of the 2005 IEEE International Joint Conference on Neural Networks, Montreal, QC, Canada, 31 July–4 August 2005; pp. 2877–2882.
10. Hashmi, M.S.; Khan, N.M.; Anpalagan, A.; Aalsalem, M.Y. A survey of smart grid architectures and communication technologies. *IEEE Access* **2017**, *5*, 303–325.
11. Oprea, S.V.; Bâra, A. Edge and fog computing using IoT for direct load optimization and control with flexibility services for citizen energy communities. *Knowl.-Based Syst.* **2021**, *228*, 107293. [CrossRef]

12. Gruber, J.K.; Milan, P.; Raúl, A. Estimation and analysis of building energy demand and supply costs. *Energy Procedia* **2015**, *83*, 216–225. [CrossRef]
13. Oprea, S.V.; Bâra, A.; Ifrim, G.A. Optimizing the Electricity Consumption with a High Degree of Flexibility Using a Dynamic Tariff and Stackelberg Game. *J. Optim. Theory Appl.* **2021**, *190*, 151–182. [CrossRef]
14. Shibuya, T.; Croxford, B. The effect of climate change on office building energy consumption in Japan. *Energy Build.* **2016**, *117*, 149–159. [CrossRef]
15. Zhang, Y.; He, C.Q.; Tang, B.J.; Wei, Y.M. China's energy consumption in the building sector: A life cycle approach. *Energy Build.* **2015**, *94*, 240–251. [CrossRef]
16. Babaei, T.; Abdi, H.; Lim, C.P.; Nahavandi, S. A study and a directory of energy consumption data sets of buildings. *Energy Build.* **2015**, *94*, 91–99. [CrossRef]
17. Li, L.; Xiaoguang, H.; Ke, C.; Ketai, H. The applications of WiFi-based Wireless Sensor Network in Internet of Things and Smart Grid. In Proceedings of the 6th IEEE Conference on Industrial Electronics and Applications (ICIEA), Beijing, China, 21–23 June 2011.
18. Ippolito, M.G.; Riva Sanseverino, E.; Zizzo, G. Impact of building automation control systems and technical building management systems on the energy performance class of residential buildings: An Italian case study. *Energy Build.* **2014**, *69*, 33–40. [CrossRef]
19. Guo, G.; Gong, Y. Multi-Microgrid Energy Management Strategy Based on Multi-Agent Deep Reinforcement Learning with Prioritized Experience Replay. *Appl. Sci.* **2023**, *13*, 2865. [CrossRef]
20. Faria, P.; Vale, Z. Demand Response in Smart Grids. *Energies* **2023**, *16*, 863. [CrossRef]
21. Zhang, Y.; Zhang, Y.; Zhou, X.; Chen, Y.; Wang, L. Multi-Stage Robust Energy Management of Integrated Energy Systems Considering Electric and Thermal Storage Units. *Energies* **2018**, *11*, 3300.
22. Zhang, X.; Xia, Q.; Chen, Y. Multi-Objective Joint Bidding Strategy for Virtual Power Plant Aggregator Considering Risk Response. *Energies* **2018**, *11*, 3039.
23. Assad, U.; Hassan, M.A.S.; Farooq, U.; Kabir, A.; Khan, M.Z.; Bukhari, S.S.H.; Jaffri, Z.A.; Oláh, J.; Popp, J. Smart Grid, Demand Response and Optimization: A Critical Review of Computational Methods. *Energies* **2022**, *15*, 2003. [CrossRef]
24. Sun, Y.; Chen, D. Demand response in the smart grid based on ZigBee home area network technology. *IEEE Trans. Smart Grid* **2017**, *8*, 1932–1942.
25. Offermans, S.; Gopalakrishna, A.K.; van Essen, H.; Özçelebi, T. Breakout 404: A smart space implementation for lighting services in the office domain. In Proceedings of the 2012 Ninth International Conference on Networked Sensing (INSS), Antwerp, Belgium, 11–14 June 2012; IEEE: Piscataway, NJ, USA, 2012; pp. 1–4.
26. Khan, M.; Silva, N.B.; Han, K. Internet of things based energy aware smart home control system. *IEEE Access* **2016**, *4*, 7556–7566. [CrossRef]
27. Deng, R.; Yang, Z.; Chow, M.Y.; Chen, J. A Survey on Demand Response in Smart Grids: Mathematical Models and Approaches. *IEEE Trans. Ind. Inform.* **2015**, *11*, 570–582. [CrossRef]
28. Patel, J.; Desai, T. Internet of Things: A platform for implementing smart cities. *Int. J. Inf. Manag.* **2018**, *36*, 496–505.
29. El-Metwally, M. Sunshine and global solar radiation estimation at different sites in Egypt. *J. Atmos. Solar Terr. Phys.* **2005**, *7*, 1331–1342. [CrossRef]