

## Low-Cost IoT Retrofitting framework for transforming legacy household appliances into smart devices

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*A low-cost IoT retrofitting framework is proposed for transforming conventional household appliances into smart devices without appliance replacement or internal hardware modification. Commercially available smart plugs and infrared controllers are integrated to enable remote control, scheduling, and energy monitoring for legacy devices. Three residential use cases were implemented and tested, an air conditioner, an electric water heater, and an electric heater, covering technical feasibility, installation complexity, economic efficiency, and energy optimization potential. All devices were configured within 5 to 10 minutes using standard Wi-Fi connectivity and smartphone applications, with no professional installation required. Retrofit costs remained below €25 per appliance, achieving savings exceeding 80% compared to smart device replacement. Scheduling and remote-control functions measurably reduced idle operating time across all tested scenarios, demonstrating a practical path for smart home adoption in low-budget residential environments.*

**Keywords:** *Internet of Things, smart home, retrofitting, smart plug, infrared controller, energy monitoring, residential automation, legacy appliances*

### 1 Introduction

The rapid development of the Internet of Things (IoT) has significantly transformed residential environments by enabling intelligent monitoring, automation, and remote control of household devices. Modern smart home systems integrate sensors, communication technologies, and mobile applications to improve user comfort, optimize energy consumption, and increase operational flexibility. As the adoption of smart technologies continues to grow, consumers increasingly expect connected functionalities such as remote access, scheduling, energy monitoring, and automated control from residential appliances.

Despite these advancements, many households still rely on legacy electrical appliances that lack native smart capabilities. Air conditioners, electric water heaters, and electric heaters without smart capabilities are still widely used due to their operational reliability and the high replacement cost associated with

purchasing new smart devices. Replacing fully functional appliances solely to obtain smart functionalities is often economically inefficient and contributes to increased electronic waste generation. Consequently, retrofitting existing devices with low-cost IoT technologies has emerged as an attractive alternative for enabling smart home integration without requiring complete appliance replacement.

IoT retrofitting refers to the process of extending the functionality of conventional devices through external smart components such as smart plugs, infrared (IR) controllers, sensors, and wireless communication modules. Through this approach, legacy appliances can acquire functionalities including remote ON/OFF control, operational scheduling, environmental monitoring, and energy consumption tracking. Compared with traditional smart home installation approaches, retrofitting solutions are simpler to deploy, require minimal technical expertise, and avoid permanent electrical modifications, making them particularly suitable for apartments,

rental properties, and low-budget residential environments.

In addition to improving user convenience, IoT retrofitting also supports residential energy optimization. Heating and cooling appliances represent some of the largest electricity consumers in households, and their inefficient operation often leads to unnecessary energy consumption and increased electricity costs. Smart scheduling and remote-control functionalities allow users to operate appliances only during occupancy periods or according to predefined comfort conditions, potentially reducing idle operating time and improving overall energy efficiency. This paper proposes and experimentally validates a low-cost IoT retrofitting framework for transforming legacy household electrical appliances into smart devices using commercially available smart plugs and IR controllers. The proposed architecture is evaluated through three representative residential use cases involving an air conditioner, an electric water heater, and an electric heater. The study analyzes the technical feasibility, installation complexity, economic benefits, and energy optimization potential of the proposed approach.

The main contributions of this paper are summarized as follows:

- the design of a practical IoT retrofitting architecture for legacy residential appliances;
- the implementation and validation of multiple retrofitting scenarios using commercially available IoT devices;
- a techno-economic evaluation comparing retrofitting and appliance replacement approaches;
- analysis of usability and energy management benefits associated with low-cost residential automation.

The remainder of this paper is organized as follows. Section 2 presents related work in the field of smart homes and IoT retrofitting. Section 3 describes the

proposed methodology and retrofitting architecture. Section 4 presents the implementation scenarios and experimental results. Finally, Section 5 concludes the paper and discusses future research directions.

## **2 Literature Review**

IoT systems integrate sensors, communication technologies, cloud services, and mobile applications to enable intelligent monitoring and control of household devices [5], [10]. The concept of smart homes has evolved significantly over the past decade due to the increasing availability of low-cost embedded devices and wireless communication technologies [11].

Several studies have investigated the role of IoT technologies in residential energy optimization and smart building management. Shah et al. [3] reviewed energy consumption optimization techniques in IoT-based smart buildings and highlighted the importance of appliance scheduling, automated control, and real-time monitoring for reducing electricity consumption. Similarly, Nikpour et al. [2] emphasized the role of intelligent IoT frameworks and machine learning approaches in improving energy efficiency and operational sustainability within smart residential environments.

Research on smart homes has also explored activity recognition, ambient intelligence, and intelligent automation systems. Bouchabou et al. [1] presented a comprehensive survey of human activity recognition in smart homes using IoT sensors and deep learning techniques. Their work demonstrated the increasing importance of low-cost sensing infrastructures and connected residential environments. In addition, Nakip et al. [4] proposed a renewable energy management framework for smart homes based on forecasting and scheduling techniques, showing that optimized appliance operation can contribute to significant energy savings. The integration of wireless sensor networks and IoT infrastructures into residential buildings has been widely studied in recent

years. Ghayvat et al. [7] analyzed IoT-based smart home architectures and their extension toward smart building applications, highlighting the importance of interoperability, communication reliability, and real-time monitoring capabilities. Zanella et al. [8] further discussed the role of IoT systems in smart city environments, including residential applications involving connected appliances, intelligent monitoring, and energy-aware infrastructures.

Energy monitoring has become one of the most important functionalities in residential IoT systems. Context-aware residential systems have also gained attention due to their ability to adapt appliance behavior according to user preferences and environmental conditions [9].

Although considerable progress has been achieved in smart home technologies, most existing studies focus primarily on newly manufactured smart appliances or complex integrated building management systems. Commercial smart home ecosystems generally assume that appliances already support native connectivity, embedded sensors, or dedicated communication interfaces. Consequently, limited attention has been given to the retrofitting legacy household appliances that remain widely used in residential buildings due to their long operational lifetime and high replacement costs.

Retrofitting represents a practical alternative for enabling smart functionalities without replacing existing appliances. Instead of modifying the internal electrical structure of devices, retrofitting approaches rely on external IoT components such as smart plugs, infrared controllers, and wireless sensors. This approach significantly reduces implementation complexity, installation costs, and technical requirements while preserving the functionality of existing equipment.

Commercial IoT devices such as smart plugs and infrared controllers have become increasingly affordable and accessible to residential users. Smart plugs enable remote switching, scheduling, and energy monitoring, while infrared controllers emulate the functionality of traditional remote controls for devices such as air conditioners and televisions. Despite their widespread commercial adoption, relatively few academic studies investigate their integration into unified low-cost retrofitting architectures for legacy appliances.

Existing literature also identifies several challenges associated with residential IoT deployment, including interoperability issues, dependence on cloud services, cybersecurity concerns, communication reliability, and energy-aware scheduling optimization [2], [7]. Furthermore, many advanced smart home systems require professional installation, dedicated gateways, or costly infrastructure, limiting accessibility for low-budget users and renters.

The present study addresses this research gap by proposing a practical and experimentally validated IoT retrofitting framework for legacy household appliances using commercially available low-cost devices. Unlike complex smart building platforms, the proposed approach emphasizes affordability, ease of deployment, reversibility, and accessibility for non-technical residential users. The framework is evaluated through multiple real-world retrofitting scenarios involving air conditioners, electric water heaters, and electric heaters, together with a techno-economic assessment of installation complexity and potential energy optimization benefits.

### 3 Methodology

This study adopts a design-oriented and experimental methodology to evaluate the feasibility of transforming legacy household electrical devices into smart appliances using low-cost IoT components such as smart plugs and IR controller. The

methodology consists of four stages: device selection, IoT retrofitting design, implementation, and evaluation. The

steps of the methodology are illustrated in Figure 1.

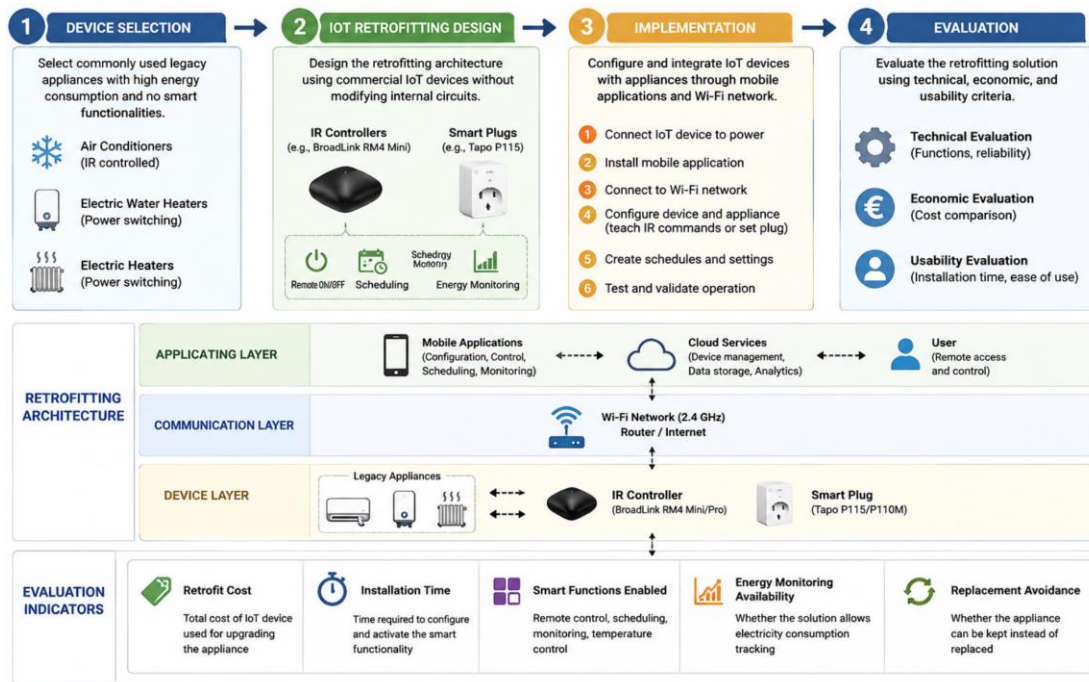


Fig 1. Proposed methodology for retrofitting non-smart appliances

### 3.1 Device selection

Three categories of commonly used household electrical devices are selected: air conditioners, electric water heaters, and electric heaters. These devices were chosen because they are widely used in residential buildings, often have high electricity consumption, and are frequently operated manually. Moreover, many existing units lack native connectivity, remote control, or energy monitoring functions.

The selected devices represent two technical control categories. The first category includes appliances controlled by IR signals, such as air conditioners. The second category includes appliances controlled through power supply switching, such as electric water heaters and electric heaters.

### 3.2 IoT retrofitting architecture

The proposed retrofitting architecture uses commercially available IoT devices to add smart functionality to existing appliances without replacing them or

modifying their internal electrical circuits. For air conditioners, an infrared controller is used to emulate the commands of the original remote control. The controller learns or retrieves the infrared command set and enables users to control the appliance through a mobile application. For electric water heaters and electric heaters, smart plugs are used as intermediary control devices between the wall socket and the appliance. These plugs enable remote ON/OFF switching, scheduling, and energy consumption monitoring.

The architecture includes three layers:

1. Device layer – legacy appliances, smart plugs, and IR controllers.
2. Communication layer – Wi-Fi connection between IoT devices, router, and cloud/mobile services.
3. Application layer – smartphone applications used for configuration, control, scheduling, and monitoring.

### 3.3 Implementation procedure

The implementation is carried out separately for each appliance type. For the air

conditioner, the IR controller is connected to the home Wi-Fi network and configured using the dedicated mobile application. The original remote control is used to teach the required commands, including ON/OFF, temperature adjustment, and operating mode selection. After configuration, the air conditioner can be controlled remotely and scheduled through the application.

For the water heater, the smart plug is connected to a wall outlet, and the appliance is connected through the plug. A heating schedule is created in the mobile application to activate the device only during predefined time intervals. The energy monitoring function is used to record electricity consumption.

For the electric heater, a similar procedure is followed. The heater is connected to the smart plug, and operating schedules are configured according to occupancy and comfort needs.

For heaters with built-in thermostats, the smart plug provides time-based control, while temperature regulation remained managed by the appliance thermostat.

### 3.4 Evaluation Criteria

The proposed retrofitting approach is evaluated using technical, economic, and usability criteria.

The technical evaluation considered whether each appliance can successfully perform smart functions such as remote control, scheduling, and energy monitoring. The economic evaluation compares the approximate cost of retrofitting with the estimated cost of replacing the appliance with a new smart alternative. The usability evaluation considers installation time, need for technical expertise, and ease of configuration.

The main evaluation indicators are:

Indicator	Description
Retrofit cost	Total cost of the IoT device used for upgrading the appliance
Installation time	Time required to configure and activate the smart functionality
Smart functions enabled	Remote control, scheduling, monitoring, temperature control
Energy monitoring availability	Whether the solution allows electricity consumption tracking
Replacement avoidance	Whether the appliance can be kept instead of replaced

## 4. Simulation and results

### 4.1 Sample retrofitting scenarios

To validate the applicability of the proposed IoT retrofitting framework, three representative residential appliance scenarios were implemented: an air conditioner, an electric water heater, and an electric heater. The selected appliances represent common legacy household devices that typically operate without connectivity, automation, or energy monitoring functionalities. All devices are integrated without requiring electrical rewiring, internal hardware modification, or professional installation. The average installation time ranged between 5 and 10 minutes per device, depending on the configuration procedure. Before installation, each appliance was checked for compatibility with the selected IoT device. For smart plugs, the appliance power rating was compared with the maximum supported load of the plug. For IR-controlled appliances, the IR controller was positioned within line of sight of the target device.

Only certified IoT devices were considered, and no internal modification of appliances or electrical rewiring was performed. This ensured that the retrofitting process remained simple, reversible, and suitable for non-technical users.

### Air Conditioner Retrofitting

The air conditioner is retrofitted using a BroadLink RM4 Mini<sup>1</sup> infrared controller together with the appliance's original remote control. The implementation process consisted of connecting the IR controller to a power source, installing the dedicated mobile application, configuring the device within the local Wi-Fi network, and registering the infrared commands from the original remote control. After the learning phase using the original remote control, the system successfully reproduced all essential commands, including: i) power ON/OFF; ii) temperature adjustment; iii) mode selection; iv) scheduled activation. The command recognition rate during repeated testing reached 100% under direct line-of-sight conditions. Remote operation through the mobile application was stable during all test sessions.

Once the configuration procedure was completed, the air conditioner could be remotely controlled directly from a smartphone application. The implemented functionalities included device activation and deactivation, temperature adjustment, operating mode selection, and scheduled operation. The proposed approach eliminates the need for electrical rewiring, additional cabling, or professional installation services, making the solution suitable for apartments and rented residential spaces.

#### SET UP AN OLD AC DEVICE



Fig 2. Set up an old AC unit

<sup>1</sup> <https://www.ibroadlink.com/>

### Water Heater Retrofitting

The water heater is retrofitted using a TP-Link Tapo P115<sup>2</sup> smart plug. After connecting the smart plug to the local Wi-Fi network through the Tapo mobile application, operating schedules were configured to activate the water heater only during predefined intervals, such as morning and evening periods.

The implemented solution enabled remote ON/OFF switching, scheduled operation, and electricity consumption monitoring through the mobile application. By reducing unnecessary heating periods, the retrofitting approach contributes to lowering electricity consumption and improving overall energy efficiency. In addition, the system offers improved operational safety compared to manual switching by enabling controlled and automated operation.

Before deployment, the electrical specifications of the appliance were verified to ensure that the power consumption remained within the maximum supported load of the smart plug.

#### SET UP THE WATER HEATER

##### What you need

- TP-Link Tapo smart plug

##### Step-by-Step

1. Connect the smart plug to a wall outlet
2. Download and install the Tapo app on your smartphone
3. Plug in the water heater to the smart plug
4. Use the app to create a heating schedule (e.g., start at 10:00 and 16:00)

##### Advantages

- ✓ Warm water ready before you arrive
- ✓ Avoid unnecessary heating and reduce electricity costs

⚠ Ensure the heater's power rating does not exceed the smart plug's maximum capacity (e.g., Maximum Load 16A, 3680W).

Fig 3. Set up an old water heater

### Electric Heater Retrofitting

The electric heater retrofitting scenario is implemented using the same smart plug architecture. For heaters equipped with integrated thermostats, the smart plug is used to manage scheduled power delivery,

<sup>2</sup> <https://www.tp-link.com/ro/home-networking/smart-plug/tapo-p115/>

while temperature regulation continued to be controlled internally by the heater thermostat.

For electric heaters without integrated thermostatic control, an additional temperature sensor integrated into the IR controller ecosystem can be used to automate switching cycles according to ambient room temperature.

The implemented solution provided remote control, operating schedules, and automated heating management while maintaining low installation complexity and minimal hardware cost. The heater operated correctly under all scheduled intervals, and no connectivity interruptions were observed during testing.

**SET UP AN ELECTRIC HEATER**

**What you need**

- TP-Link Tapo smart plug

**Step-by-Step**

1. Plug the smart plug into a power outlet
2. Download and set up the Tapo app on your smartphone
3. Connect the heater to the smart plug
4. Use the app to set a heating schedule (e.g., between 10:00–12:00 and 14:00–16:00). The heater will control the temperature automatically through its thermostat

**Advantages**

- ✓ Room is warm upon your arrival
- ✓ Prevents unnecessary heating, saving on electricity
- ✓ Same comfort as a modern smart heaters

⚠ This applies only to heaters with thermostats. For heaters without thermostat, set shorter heating periods (no longer than 30 minutes) or consider purchasing a thermostat to control it.



<https://www.tp-link.com/ro/home-networking/smart-plug/tapo-p115/>

**Fig 4.** Set up an electric heater with thermostat

**4.2 Evaluation of the techno-economic benefits and optimization potential**

One of the main objectives of this paper is to evaluate whether retrofitting provides an economically viable alternative to replacing existing appliances.

Table 1 presents the cost comparison between the retrofitting and replacement options.

**Table 1.** Retrofit Cost versus Replacement Cost

Appliance	Retrofit solution	Retrofit cost (€)	Estimated replacement cost (€)	Cost reduction
Air conditioner	IR Controller	20	400–700	>95%
Water heater	Smart Plug	25	250–500	>90%
Electric heater	Smart Plug	25	150–300	>80%

The results show that the proposed retrofitting approach reduces upgrade costs by more than 80% compared with replacing appliances with smart alternatives.

To evaluate usability, installation complexity is assessed based on setup time, required tools, and technical expertise (Table 2).

**Table 2.** Installation Evaluation

Appliance	Installation Time	Tools Required	Professional Installation
Air conditioner	8 min	None	No
Water heater	5 min	None	No
Electric heater	5 min	None	No

The results demonstrate that the proposed solution is accessible even for non-technical users, including renters and apartment residents. Smart functionality assessment is summarized in Table 3.

**Table 3.** Enabled Smart Functions

Functionality	AC	Water Heater	Electric Heater
Remote ON/OFF	Yes	Yes	Yes
Scheduling	Yes	Yes	Yes
Energy Monitoring	No	Yes	Yes
Temperature Control	Yes	No*	Thermostat-based

\* Temperature is indirectly controlled through operating schedules.

The results indicate that the retrofitting architecture successfully enabled core smart-home functionalities across all tested appliances.

Scheduled operation reduced unnecessary appliance runtime, particularly for heating devices. For example, water heating can be scheduled only before occupancy periods, electric heating can be activated only during predefined comfort intervals and air conditioning can be started remotely before user arrival.

These operational changes reduced idle operating periods and improved energy management. Although long-term consumption analysis is outside the scope of this initial implementation, preliminary observations indicate clear potential for electricity savings in residential environments.



**Fig 5.** The consumption of the electric heater in correlation with the indoor temperature

## 5. Conclusions

This paper proposed and validated a low-cost IoT retrofitting framework designed to transform legacy household electrical appliances into smart devices without requiring appliance replacement, electrical rewiring, or professional installation. The proposed approach integrates commercially available smart plugs and IR controllers to provide remote control, scheduling, monitoring, and automation capabilities for conventional residential appliances. The methodology is experimentally validated through three representative use cases involving an air conditioner, an electric water heater, and an electric heater.

The experimental results demonstrate that the proposed retrofitting architecture can successfully extend the functionality of existing appliances while maintaining low implementation complexity and

## Monitoring

Data is collected from mobile applications associated with the IoT devices. For smart plugs, the main collected data consisted of operating status, scheduled activation periods, and electricity consumption. For the IR controller, the collected information included command execution, configured schedules, and temperature or humidity readings when supported by the device.

The collected data is used to assess whether the retrofitting solution enabled smart operation and whether scheduled control could reduce unnecessary appliance usage.

Figure 5 illustrates a sample utilization of the electric heater scheduled to operate between 15:30 and 18:30, switched-off from the smart plug in case the indoor temperature measured by IR sensors exceeds 22°C.

affordability. All tested devices were integrated within a short installation time of approximately 5–10 minutes, using only smartphone-based configuration procedures and standard Wi-Fi connectivity. The results confirm that the proposed framework is accessible even for non-technical users, making it particularly suitable for apartments, rented properties, and residential environments where major electrical modifications are impractical or economically unjustified.

From an economic perspective, the retrofitting approach achieved high cost reductions compared with replacing appliances with new smart alternatives. Depending on the appliance category, retrofit costs remained below €25 per device, while estimated replacement costs ranged from €150 to €700. The obtained results indicate potential investment savings exceeding 80–95%, highlighting the

feasibility of low-budget smart home adoption using existing household infrastructure.

The study also demonstrated the potential of scheduled operation and IR control functionalities to improve residential energy management. By enabling appliances to operate only during predefined occupancy periods or temperature conditions, the proposed solution reduces unnecessary operating intervals and contributes to minimizing electricity waste. Although long-term quantitative energy savings were not extensively analyzed within the scope of this work, preliminary observations indicate significant potential for improving residential energy efficiency through low-cost automation strategies.

In addition, the proposed framework supports sustainability objectives by extending the operational lifetime of existing appliances and reducing the need for premature equipment replacement. This approach contributes to lowering electronic waste generation while facilitating the transition toward smarter and more energy-aware residential environments.

Future research directions include the integration of local edge computing solutions to reduce cloud dependency, the incorporation of machine learning techniques for predictive appliance scheduling, and the development of advanced energy optimization algorithms based on occupancy patterns and electricity tariffs.

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