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Utilizing Smart Home Technology for the Renovation of Deteriorated Residential Buildings

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Abstract

The field of smart homes stands out as one of the most dynamic domains in advancing information and communication technologies. To deliver enhanced safety, user convenience, and efficient resource use, a smart home should be regarded as an advanced technological setup that integrates automation innovations with up-to-date building practices. Such systems can be incorporated into both newly constructed structures and the upgrading of older ones. This research explores the core concept of a smart home system, justifies the adoption of resource-efficient approaches and solutions, and assesses how these can be combined with the renovation of low-rise housing. The work presents a conceptual design of a smart home configuration tailored to a specific renovation case, along with a mobile-based interface for system management.

Keywords Smart home, Reconstruction of buildings, Mobile application, Low-rise residential buildings

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Introduction

The rise of the Internet of Things (IoT), along with progress in information and communication technologies (ICTs), massive data processing, and artificial intelligence (AI), has begun transforming everyday routines [1]. Computing and software are increasingly embedded seamlessly into the environment and everyday objects, fundamentally reshaping how people live. According to figures from the Swedish analytics firm Berg Insight, approximately 63 million U.S. residences qualify as smart, featuring connected elements ranging from lighting to surveillance cameras that enable continuous remote oversight (with the U.S. having close to 130 million households overall as of 2018) [2]. With the spread of high-speed internet options like Asymmetric Digital Subscriber Line (ADSL), smart home setups have grown by embedding sensors into routine-use items and enabling interaction via portable gadgets. As defined by Kim *et al.* [3], a smart home consists of “a dwelling outfitted with a high-tech network, sensors and devices and functions that can be remotely monitored, managed and provide services that meet its residents’ needs”. A key characteristic is the ability to operate home devices remotely.

At its essence, a smart home is an integrated technological framework that unifies various building engineering components under centralized, programmable, intelligent control, tailored for an optimal user experience [4, 5]. It delivers improved protection, greater ease of use, and better resource management for occupants [6]. Through these setups, all electrical equipment within the structure becomes interconnected, allowing unified oversight via a control interface, automated logic-driven operation, or smartphone commands. Popular platforms such as Smart Life, Smart Living, Tuya Smart, TP-Link Tapo, and similar tools facilitate the management of individual or grouped devices, with automation based

on conditions like temperature, location, or schedules. Integration with voice assistants like Amazon Echo or Google Home supports spoken commands, while features enable sharing access with household members and simulating occupancy through modes like “away from home” [1, 7].

Amid ongoing increases in electricity costs [8], concerns over the electrical reliability of home appliances [9], and the clear priority of energy optimization [10], resource preservation has emerged as a central objective for smart homes.

Energy performance requirements are routinely enforced in new construction projects, frequently as a prerequisite for approvals [11]. In Ukraine, a large share of residents live in low-rise structures, often classified as aging or outdated housing [12]. Upgrading these to meet modern efficiency criteria poses significant challenges and complications [13].

The present study introduces an innovative approach to revitalizing such structures and boosting their energy performance, illustrated through a concrete example of an existing building. Given its practical focus, the research is particularly important for post-conflict urban recovery in Ukraine, where financial constraints will severely limit new housing development. Revitalizing the remaining residential stock must prioritize elevated living standards and substantial energy reductions.

The primary contributions of this paper include:

- Justification for incorporating resource-efficient technologies to realize smart home principles in upgraded structures drawn from aging housing inventories.
- Outline of the key phases involved in modernizing and enhancing energy performance in outdated low-rise buildings.
- Examination of how smart home resource-saving features align with architectural renovation efforts in low-rise residential properties.
- Development of a device placement scheme for smart elements, customized to the layout, purpose, and requirements of individual spaces in the target renovation building;
- Creation of a dedicated mobile application to oversee the smart home setup.

Phases of Upgrading and Boosting Energy Performance in Outdated Low-Rise Housing Stock

Resource conservation serves as a primary indicator of effective building renewal, achievable through multiple strategies:

- Thermal insulation upgrades for walls and floors;
- Installation of contemporary roofs, doors, and windows incorporating heat-recovery ventilation;
- Overhaul of heating infrastructure (including cogeneration systems), metering equipment, and utility networks;
- Deployment of cutting-edge renewable energy solutions (such as photovoltaic panels or small-scale wind turbines);
- Adoption of smart home technologies featuring robust software that optimizes energy utilization.

The focus of this study is the examination of smart home control mechanisms integrated with the renovation of low-rise residential structures, culminating in the development of a mobile device application for system operation.

While extensive research exists on smart homes—predominantly from engineering and technical perspectives—this work approaches the topic through the lens of architectural design and current construction methodologies, using as a case study an example structure from Ukraine’s outdated housing fund situated in Lviv at Videnska Street, 3 (**Figure 1**).



Figure 1. Reconstruction of the facility in L’viv, str. Videnska, 3.

To implement a smart home setup, various intelligent components must be incorporated, including surveillance cameras, window and door security sensors, intelligent temperature regulators, carbon monoxide and smoke detectors, and additional connected home equipment. These elements are linked within a unified network that features a main control unit and AI-driven algorithms for operation [14–16].

Once the system is in place, residents can oversee and operate all connected devices through a single unified interface accessible via a smartphone application. This eliminates the need to switch between multiple apps or physically operate switches, as all functions are consolidated into a single centralized platform.

The setup enables remote management of household functions and additional services using a smartphone, internet connectivity, and compatible tools [17]. It supports secure, unidirectional delivery of security-related data from the residence, among other capabilities, and automates the collection and oversight of readings from water and gas utility meters [18]. Interactive control panels also provide functionality such as smoke and gas leak detection, burglary prevention, emergency response support, and broader residential protection measures [19].

The process of developing a customized engineering solution—specifically focused on upgrading and enhancing energy performance in a particular structure (**Figure 1**) drawn from the category of aging or obsolete residential buildings—can be structured into the following phases:

Stage 1. Facility redesign and overhaul. Since the project involves the comprehensive refurbishment of an already standing residence, improving energy performance demands a holistic, building-wide strategy. This approach accounts for every factor, interaction, and element that influences overall home energy consumption [20].

Figures 2 and 3 illustrate the layout dimensions for the ground level (Figure 2) and upper level (Figure 3) of the examined structure. Meanwhile, Figures 4 and 5 depict the planned spatial configurations and room areas (Figure 5) following the intended redevelopment.

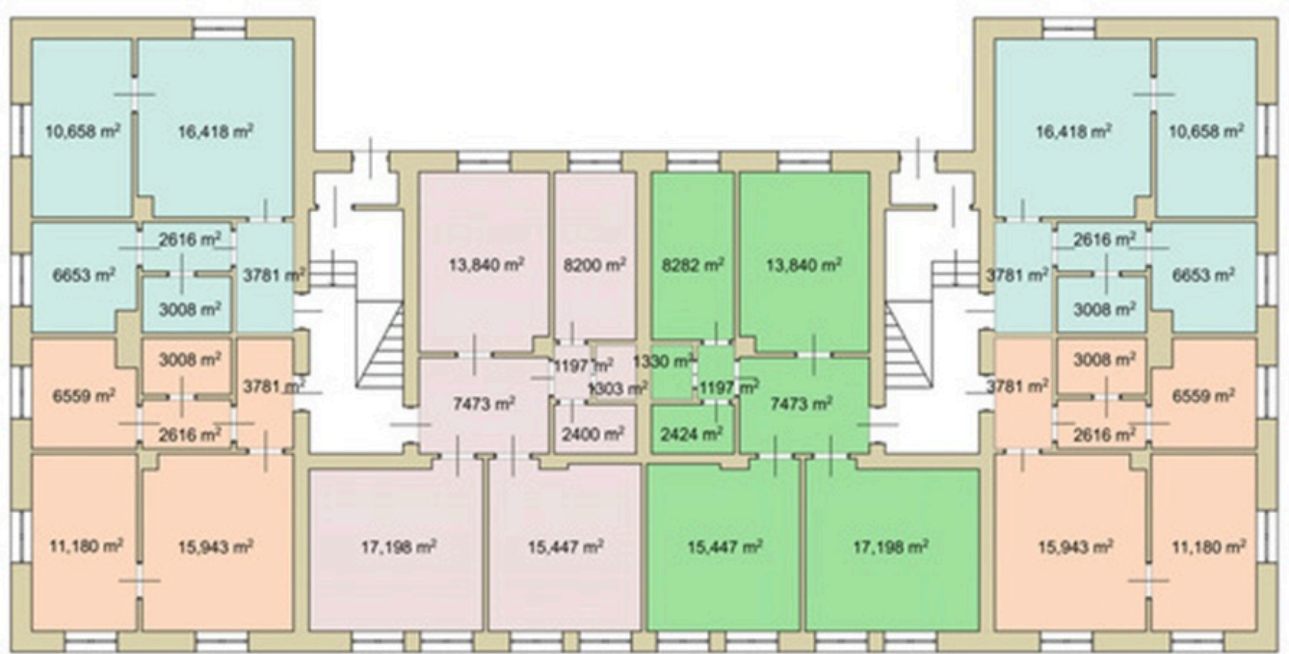


Figure 2. The area of premises on the ground floor.

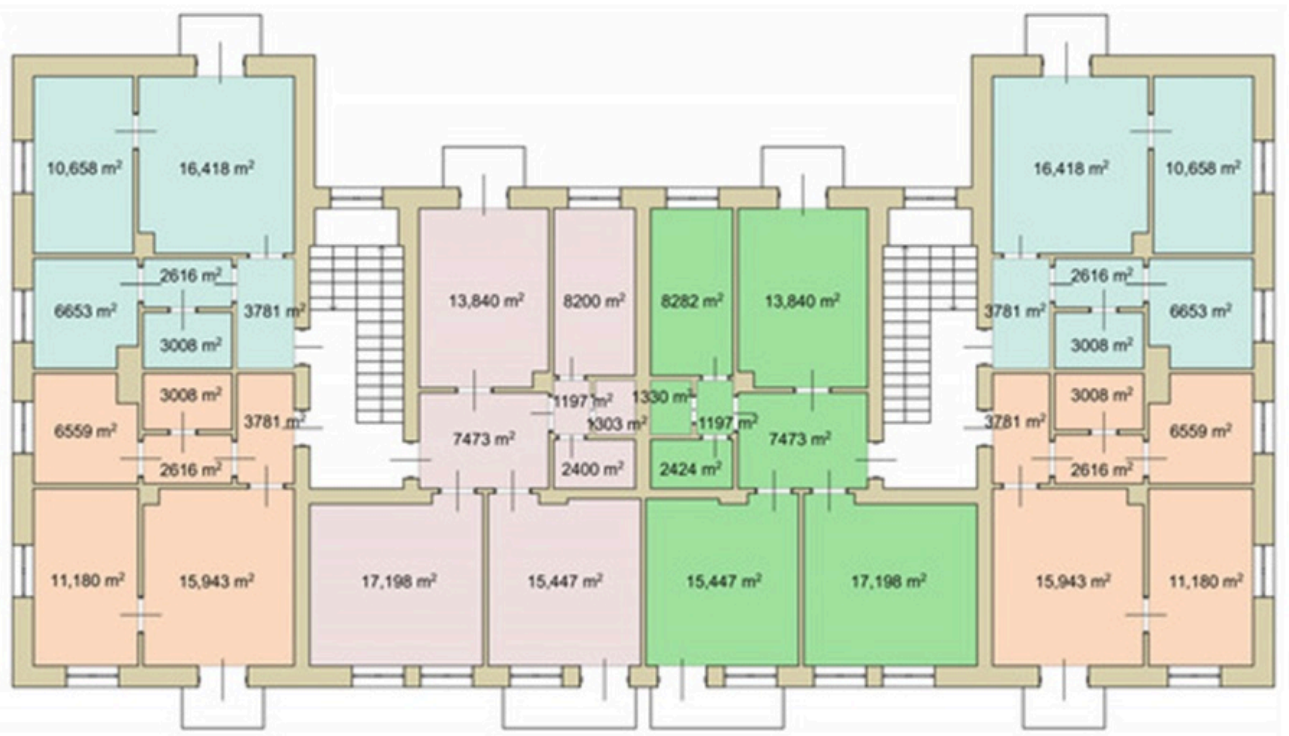


Figure 3. The area of the premises on the first floor.

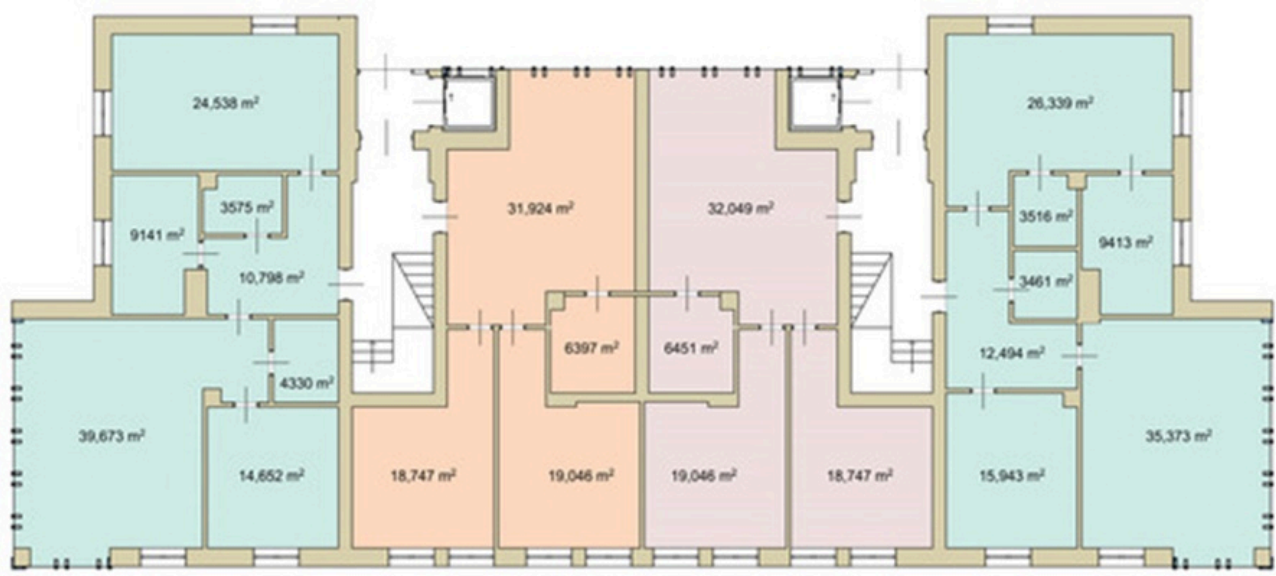


Figure 4. The area of premises on the ground floor after redevelopment.

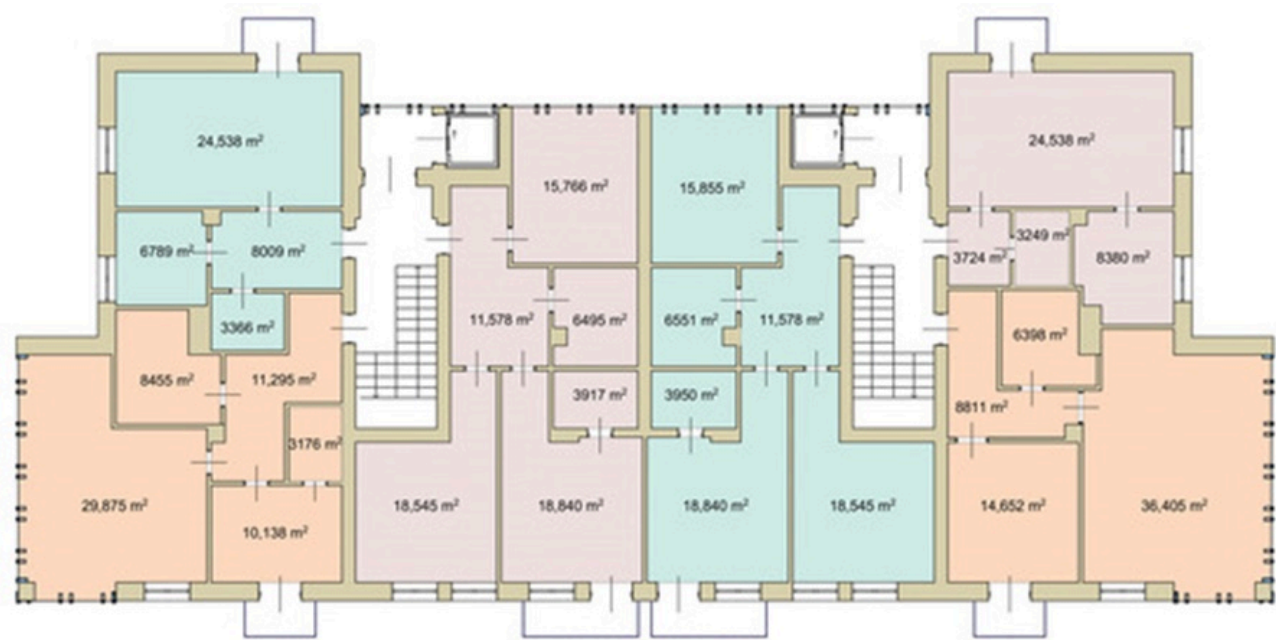


Figure 5. The area of premises on the first floor after redevelopment.

Stage 2: 3D Modeling of the Facility. Following the remodeling plan, a 3D model of the facility (Figures 6 and 7) was created to ensure precise design and development of automation systems.



Figure 6. Facility model: external view.

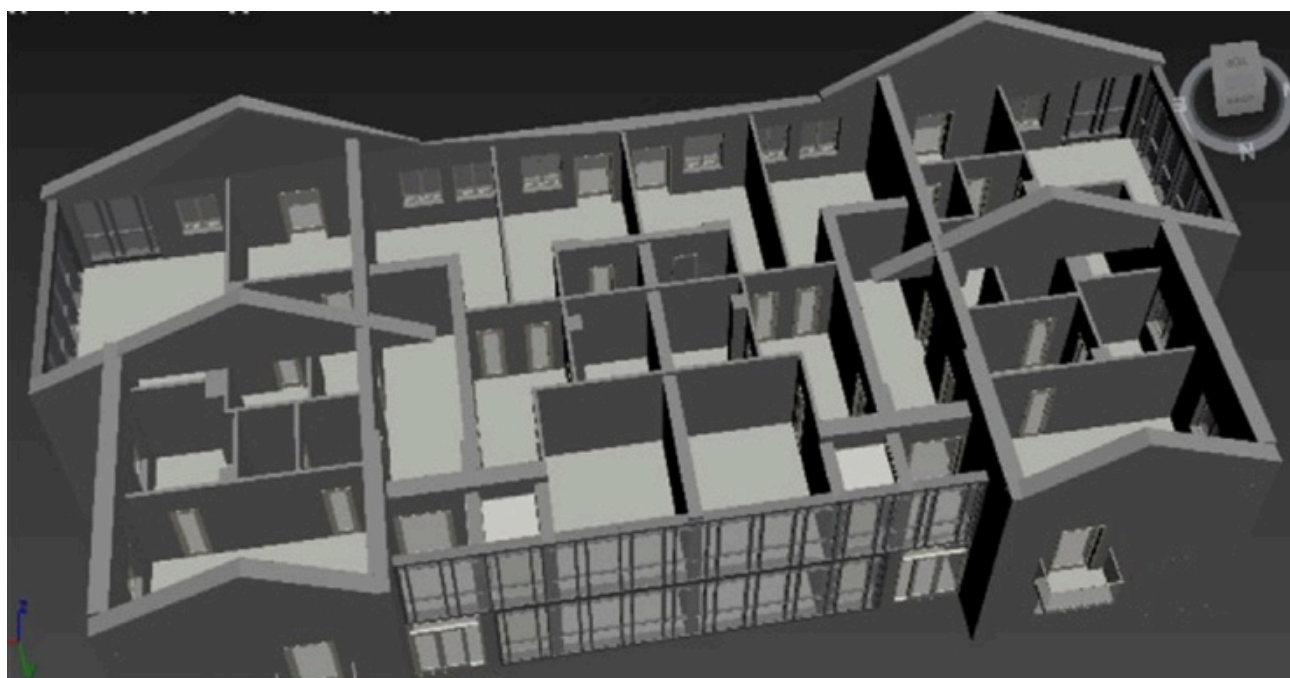


Figure 7. Facility model: internal view.

Stage 3. Design of automation systems. To develop an effective layout for positioning smart devices throughout the residence, the primary subsystems and their intended usage patterns were carefully reviewed.

Stage 3.1. Lighting system.

Lighting remains the electrical feature most frequently used by residents in any home [21]. Within a smart home installation, every type of lighting fixture can be operated in on/off mode or with adjustable dimming levels, utilizing preferred control methods such as standard wall switches, handheld remotes, smartphone applications, or similar interfaces. Users can define and store personalized lighting arrangements (for example, the first fixture set to 80% brightness, the second to 60%, and the third to 40%) along with scheduled intensity changes over specific durations (such as one hour at 80%, followed by 30 minutes at 20%, then 10 minutes at 10%).

Stage 3.2. Heating system.

In regions with cold seasons, a reliable heating system is essential for residential comfort [22]. For buildings with central heating distribution, thermostatic radiator valves can be installed and integrated with the smart home platform, permitting independent temperature settings in each zone. In standalone houses or townhouses, an advanced alternative is an underfloor hydronic heating system equipped with a manifold and multiple-zone actuators linked to the automation network.

These setups allow you to regulate temperatures room by room directly from a mobile phone. A major additional benefit is the potential for significant energy cost savings, as heat is supplied only to occupied rooms and only when needed.

Stage 3.3. Scenes (scenarios).

The term “scene” refers to a preconfigured collection of simultaneous commands. In a smart residence, pressing a single button or issuing a single instruction can trigger an entire sequence of actions through automated scripts. For instance, the “Nobody is there” scenario can turn off all lights, shut water valves, set the climate control to an energy-saving profile, and arm the security system—all at once. Scenarios tailored to individual daily routines make home living noticeably more convenient.

Stage 3.4. Anti-burglary system.

A substantial number of smart home manufacturers incorporate security functions as a standard component, ranging from basic packages (sirens combined with presence/motion sensors) to comprehensive solutions (direct connection to police departments or private security companies).

A noteworthy feature is the presence simulation. The system can capture typical occupant behavior throughout a normal day—for example, the precise timing of lights being turned on and off in different rooms, the raising and lowering of blinds, variations in room lighting, and other routine activities. Before departing for an extended period (such as a vacation), the homeowner can activate the presence simulation mode. The automation will then automatically reproduce the recorded patterns, making it appear that someone is still present in the house.

Stage 3.5. Security system.

Protecting the home is a critical requirement in today’s world. Smart home sensors continuously observe a variety of indoor conditions—including temperature levels, heating operation, lighting status, ventilation performance, and more—processing all information in real time. The system immediately notifies residents of any detected irregularities. Additionally, every event is automatically recorded in a database for later examination and analysis whenever required.

A properly implemented smart home ensures rapid and coordinated interaction among various safety mechanisms [23]. The alarm infrastructure can connect to the electrical system and support a wide range of sensors, including motion detectors, smoke detectors, CO2 detectors, water-leak detectors, open-door/window contacts, and monitors for unusual electricity consumption. These components help prevent property damage and reduce the impact of unexpected incidents.

Stage 3.6. Remote control of the house.

All devices and functions inside the residence can be managed using conventional switches, dedicated buttons, touchscreen panels, or voice commands. The vast majority of contemporary smart home platforms place strong emphasis on remote access capabilities, most often delivered through a secure web interface or dedicated application that allows full monitoring and control of every system and device from any location [24].

Consequently, a detailed plan for the placement of smart devices was prepared (Figures 8 and 9), taking full account of the specific characteristics and functional requirements of each area within the home.

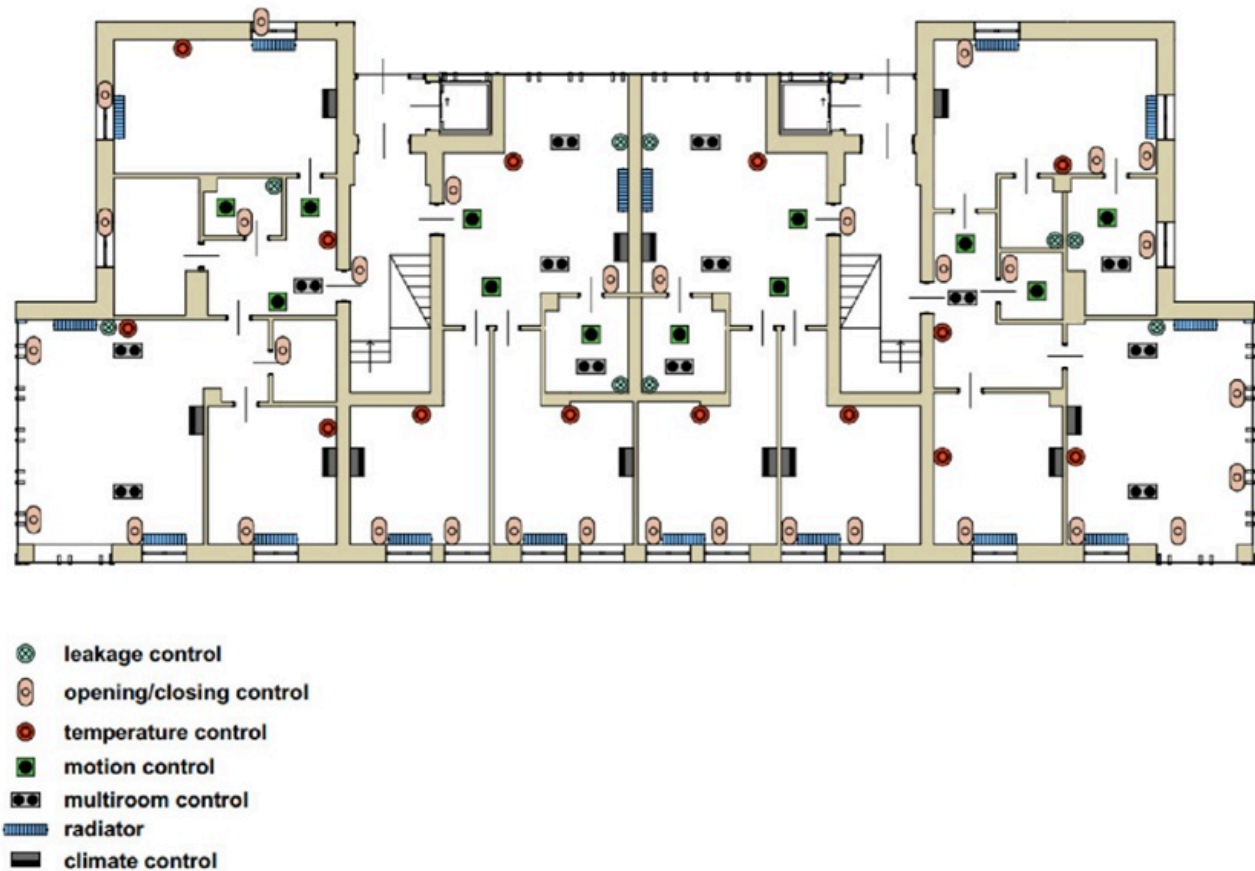


Figure 8. The project of placing smart devices on the ground floor.

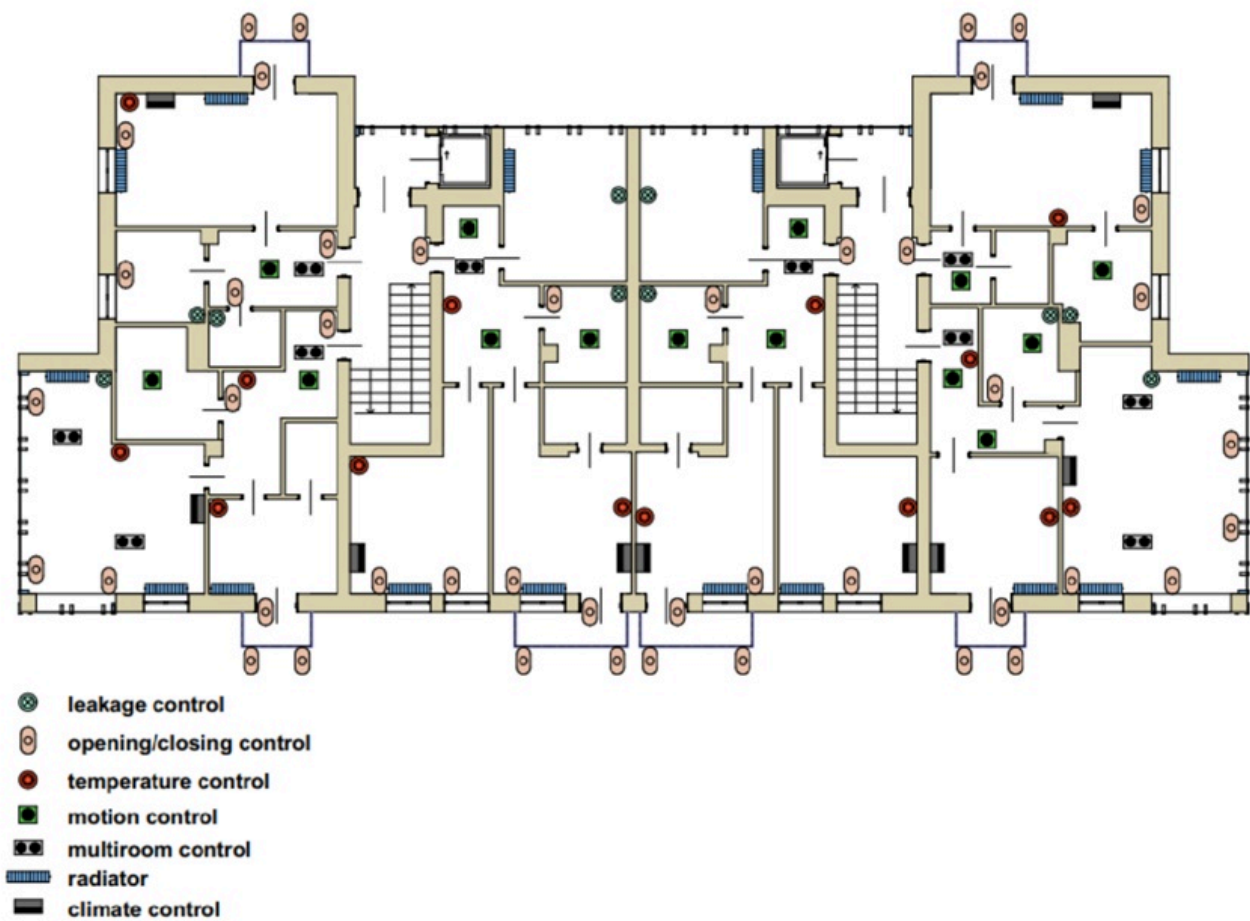


Figure 9. The project of placing smart devices on the first floor.

An evaluation of the energy performance in a 42 m² apartment was conducted. Simulation results indicated that implementing the home automation system led to daily electricity savings of 6.4%. Over the course of a month, this translated into a reduction in overall consumption ranging from 7% to 8%, resulting in an approximate annual saving of around 8%.

Overall, the adoption of smart home technologies enables reductions exceeding 40% in both financial expenditures and energy consumption required for household maintenance.

Development of a Smartphone Application for Managing the Smart Home System

Existing IoT platforms can serve as effective tools for overseeing a smart home setup. Among the leading options is the Samsung SmartThings application, recognized as a comprehensive all-in-one solution that simplifies the control of various connected devices. The Google Home app is another highly regarded choice for managing smart home ecosystems. It supports Google Nest products, Google Wi-Fi, Google Home speakers, Chromecast devices, and a wide array of compatible items from brands such as Nest, Philips Hue, and others. The interface is designed to be straightforward and user-friendly, facilitating easy setup, configuration, and monitoring of linked devices. Additionally, the Apple Home app provides exclusive management for HomeKit-compatible accessories. Given the wide range of HomeKit-compatible smart home products, users can rely on Siri voice commands to execute a variety of instructions.

In summary, smart home system control can rely on either pre-existing IoT platforms or a purpose-built management application. Off-the-shelf solutions accelerate deployment, demand fewer development resources, and enable rapid implementation; however, they may constrain customization and offer limited adaptability to specific user preferences. For this reason, many individuals favor bespoke applications, as they deliver precisely tailored functionality without the overhead of unused features.

Several primary methods exist for implementing automation control in a smart home environment:

- Wall-mounted terminal installation: This approach provides centralized access to all connected devices via a single interface, though it limits the range of compatible equipment.
- Smartphone-based control: The home network links to cloud services, smart devices connect via Wi-Fi to the local network, and users interact with them through a dedicated mobile application.
- Voice assistant integration: These systems manage smart devices, handle reminders, and can retrieve information from online sources.
- GSM gateway utilization: This compact module, equipped with a SIM card, enables remote management of in-home smart devices from any telephone, tablet, or computer, regardless of location [25-27].

In this study, a profile of the operational management of a smart home system via a custom-developed mobile application is presented.

For the purpose of developing this mobile application, the climate control system was selected, as it plays a key role in enhancing both occupant comfort and energy conservation [28]. Unified microclimate regulation in a smart residence coordinates the functioning of ventilation, air conditioning, and heating components. This integration enables maintaining optimal levels of temperature, humidity, and fresh air supply, tailored to human well-being.

The Smart Thermo mobile application was developed specifically for Android. Android Studio was chosen as the development environment due to its robust toolkit for creating applications compatible with a broad spectrum of Android devices. To improve usability, features such as graphical data visualization (charts) and multi-language localization were incorporated, ensuring users benefit from an intuitive, visually clear, and accessible interface for system management.

Device communication within the microclimate control framework follows a centralized server-based architecture (Figure 10). Under this model, all commands issued from the mobile application are first directed to a processing queue on the central server. Only after processing are they converted into appropriate instructions and forwarded to the respective microcontrollers.

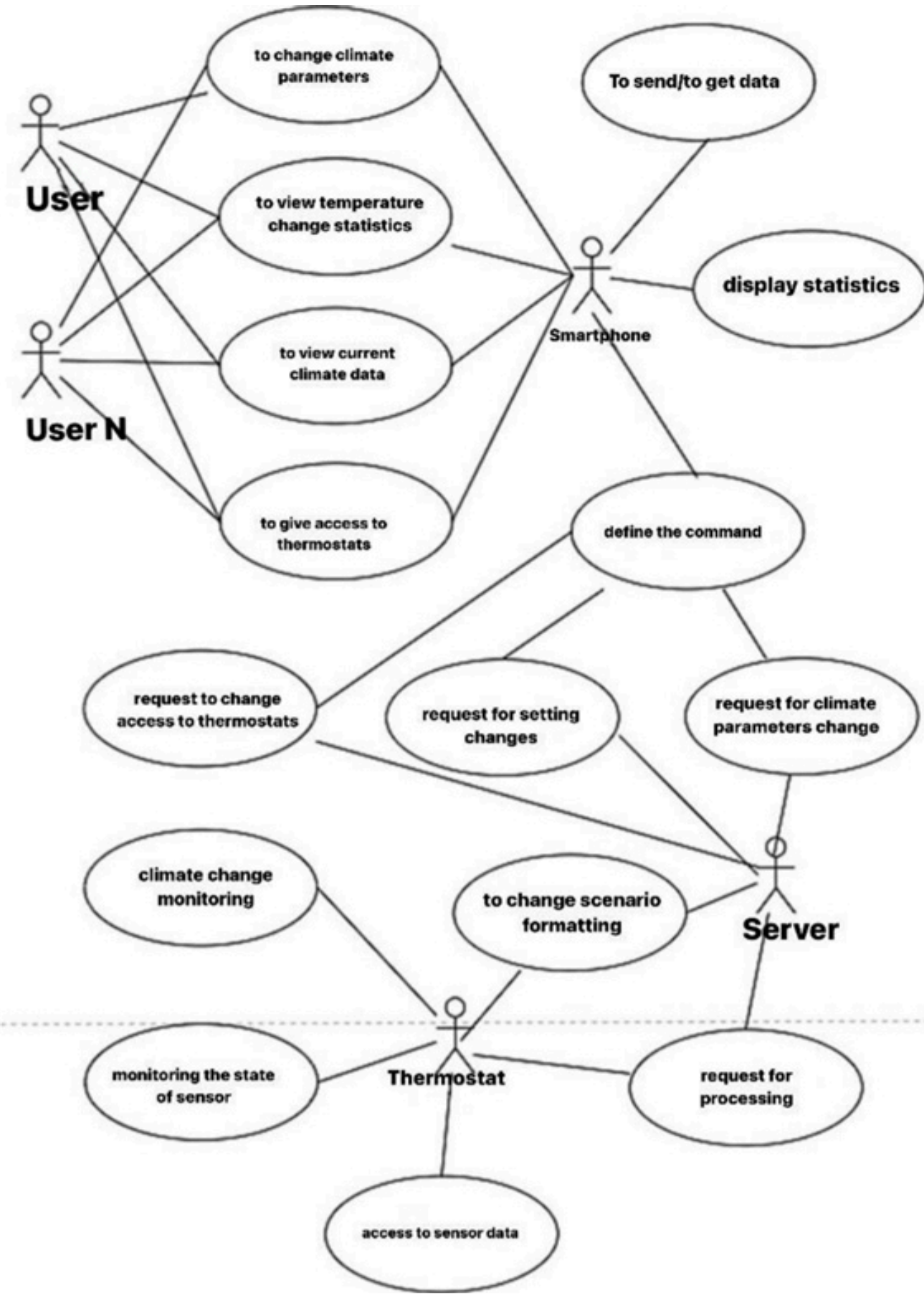


Figure 10. Use case diagram of climate control change.

The design of the mobile application represents a critical element in the overall development process. It is highly recommended to adhere to Material Design guidelines, which provide well-established standards for visual aesthetics and navigation patterns, as well as for ensuring high quality, broad device compatibility, optimal performance, and robust security.

In alignment with these core principles, the application's structural architecture (Figure 11) and its complete graphical user interface were carefully developed and finalized.

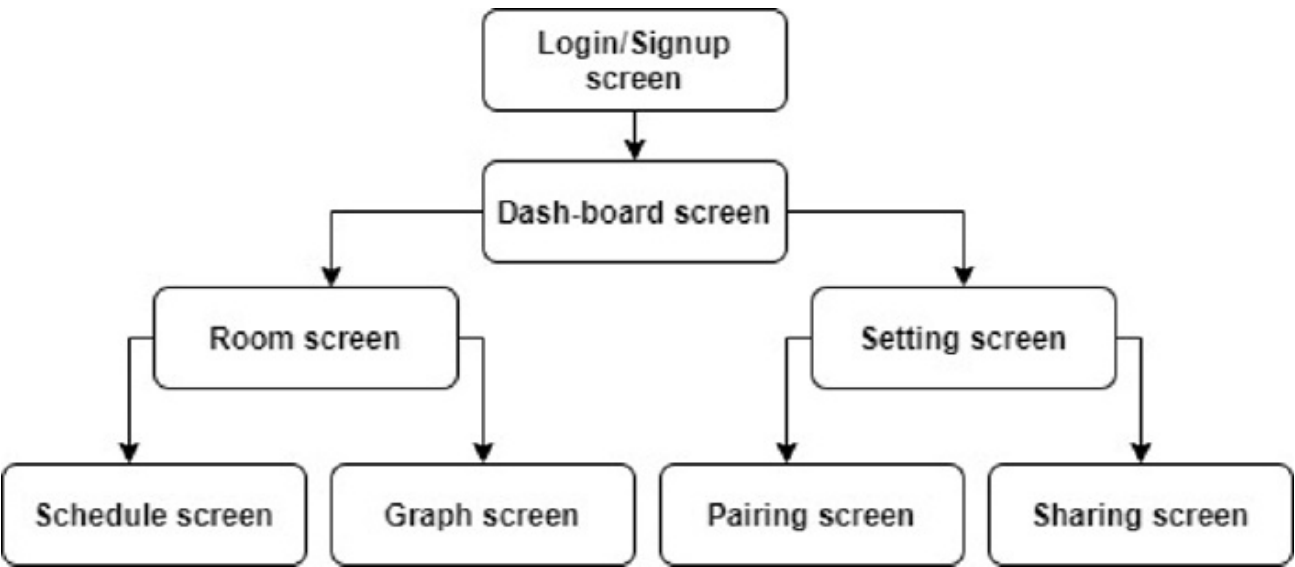


Figure 11. Structure diagram of panels of application Smart Thermo.

On the main dashboard screen (Figure 12a), two large buttons let you quickly turn all devices on or off. The rooms are shown as rectangular cards, each displaying the room name, the current temperature, the desired/target temperature, and an individual on/off button for that room.

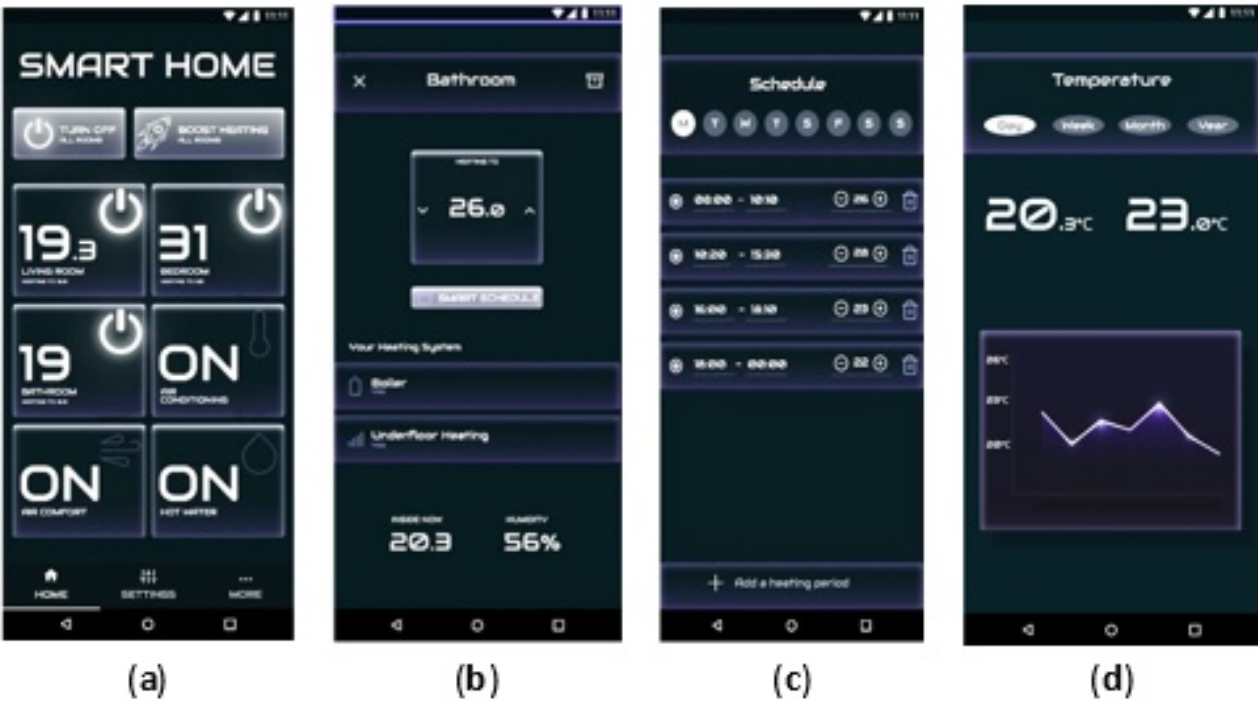


Figure 12. Application interface panels: (a) main interface, (b) room settings panel, (c) heating schedule panel, and (d) statistics panel.

The room settings panel (Figure 12b) allows users to view the current temperature and humidity while setting the desired target temperature for the room. Additionally, users can select which heating system to use. By clicking the ‘Smart Schedule’ button, users are directed to the heating schedule settings panel. From there, they can access the temperature statistics for the chosen room by clicking the graph icon.

The heating schedule settings panel (Figure 12c) enables users to choose specific weekdays and configure (or remove) heating schedules with designated target temperatures.

The statistics panel (Figure 12d) displays a detailed graph that shows temperature variations over a selected period in the chosen room.

Figure 13a depicts the interface for adding new smart thermostats, allowing users to seamlessly integrate devices into the system, which will then appear on the main screen. Figure 13b illustrates the page where users can be invited and granted shared access to the thermostat system.



Figure 13. The various screens of the application: (a) the interface for registering new devices, (b) the screen for creating new user accounts, (c) the primary settings screen, and (d) the supplementary information screen.

The primary settings screen (Figure 13c) displays user details (such as profile picture and name) along with options for several operations: registering an additional thermostat, reviewing responses to common questions, logging out, updating the password, and distributing thermostat access to other users.

The supplementary information screen (Figure 13d) provides details about the application itself and includes a feature for submitting user feedback.

The typical user journey in the application unfolds as follows:

- The individual either signs up to establish a fresh account or logs in with existing credentials. Upon successful completion, the home screen becomes visible.
- From the settings menu, the user can incorporate new thermostat(s), which then appear as distinct rooms on the main interface. Alternatively, upon login, rooms may already be present if the account previously received shared access to certain thermostat(s).
- In settings, the user can grant thermostat access to selected individuals.
- Quick controls allow the user to activate 'Boost Heating' or completely deactivate the heating system with a single tap.
- By selecting a specific room, the user can adjust the desired temperature and configure the heating system for that room.
- Choosing a specific room enables the user to define a personalized heating schedule.
- Selecting a room also grants access to temperature history visualizations in graph form for a chosen period.

Application navigation approach

The Jetpack Navigation component, an official API and visual editor integrated into Android Studio, greatly simplifies the building and maintenance of navigation paths in mobile apps. Before adopting this component, developers had to hand-code navigation logic — for instance, by triggering explicit Intents to launch new Activities or by swapping Fragments, while attaching click listeners to every relevant interface element.

This component consists of three core elements:

- **Navigation Graph:** An XML file that consolidates all navigation-related details, defining every screen (known as destinations) and the allowable transitions between them.
- **NavHost:** A placeholder view responsible for rendering the selected destinations. The standard implementation, `NavHostFragment`, is used specifically for fragment-based destinations.
- **NavController:** The central manager that directs navigation within the `NavHost`, replacing displayed content as the user moves through the app.

To move between screens, developers define routes in the navigation graph or directly indicate target destinations, after which the `NavController` updates the `NavHost` accordingly.

Key benefits offered by this navigation system include:

- Automated management of fragment transactions.
- Built-in, consistent handling of Up and Back button behavior.
- Standardized support for enter/exit animations and transitions.
- Built-in deep linking capabilities.
- Ready-to-use patterns for elements like bottom navigation bars and navigation drawers that require minimal extra setup.
- The Safe Args Gradle plugin promotes type-safe argument passing between destinations.
- Compatibility with ViewModel scoping tied to navigation graphs, facilitating data sharing across related screens.

Consequently, the Smart Thermo app was built leveraging this modern navigation framework.

App localization strategy

Supporting multiple languages requires translating the interface and content appropriately.

A critical early choice in Android localization involves identifying priority markets, as adapting an application for every possible language can become prohibitively expensive. Not all languages require the same effort or cost for proper adaptation.

Designing layouts with localization in mind

Translated phrases often differ significantly in length. Consider these examples of the same concept rendered in various languages:

- Ukrainian: Мобільна система керування розумним будинком
- German: Ein mobiles Smart Home Management System
- Chinese: 基于移动的智能家居管理系统

Evidently, text length fluctuates across languages, so interface design must account for both expansion and contraction. A widely accepted guideline recommends allocating roughly 30% extra space in UI components to handle longer translations comfortably.

Three fundamental design guidelines stand out:

- Avoid hard-coded, fixed dimensions (width/height) for elements such as buttons, text fields, labels, or images, as this can lead to clipped text or awkward gaps during translation.
- Position components using relative constraints rather than absolute values, and validate layouts against target languages.
- Use flexible containers that dynamically resize based on their contents.

Handling string resources

Embedding text strings directly into source code severely hinders localization efforts. The Android framework addresses this through the resource system, which manages strings, layouts, drawables, audio files, and other static assets.

An application can define multiple resource variants tailored to different configurations (such as language or screen size), and the system automatically selects the best match at runtime.

In line with these best practices, the Smart Thermo application stores all textual content in the `strings.xml` resource file (with provisions for additional language-specific files), making future translations straightforward.

Graph display guidelines

A large portion of users process information more effectively through visuals — diagrams, charts, images, and graphs tend to convey data far more clearly than plain text or raw figures. As a result, modern mobile interfaces frequently incorporate vivid, intuitive charts.

While building custom graphics for charts can demand considerable development time and increase expenses, leveraging established open-source libraries offers an efficient alternative. For this reason, the Smart Thermo application employs the `MPAndroidChart` library, originally developed by Phil Jay.

This popular open-source tool enables rapid creation of diverse, highly customizable charts — complete with animations and extensive configuration options.

Key highlights of `MPAndroidChart` include its ease of integration for adding charts to Android projects, broad compatibility starting from API level 8 (though animations require API 11+), and overall developer-friendliness.

In Smart Thermo, a line chart (**Figure 14**) displays detailed temperature trends for the selected timeframe in the chosen room.



Figure 14. Line chart display.

Conclusion

Smart home research spans multiple disciplines. The design of a smart home is influenced by factors such as technology, space, and services. The integration of these diverse areas has driven continuous improvement and increased demand for smart homes. Although research on smart homes primarily falls under technological sciences and engineering, it has attracted interest from experts in fields such as architecture, healthcare, services, economics, and energy. This study emphasizes the importance of knowledge exchange and collaboration across these domains. It explores integrating energy-efficient systems into smart homes and the architectural renovation of low-rise residential buildings.

As part of this work, floor plans, layouts, and visual models for the renovation of low-rise residential buildings were developed. A project was also designed to map out the placement of each smart home device in these new buildings. Achieving optimal energy efficiency in homes requires a holistic systems approach that considers all components, details, and interactions that influence energy consumption. Such technologies can result in savings of over 40% in both energy and maintenance costs.

The Smart Thermo mobile app for Android was developed to provide users with a practical and user-friendly interface for controlling the system. Additionally, the app includes localization features to offer content in multiple languages, as well as graphing capabilities to enhance the visual presentation of data.

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Conflict of interest

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