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Smart Home System Design and Optimization

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10-13-2023

Table of Contents

List of Figures

List of Tables

Executive Summary

This project aims to investigate the current market landscape of smart home technology, identify typical configurations for different property types, and provide a detailed comparison of smart home products based on their features, performance, installation, and reliability. The goal is to recommend optimized smart home system solutions tailored to the specific needs and preferences of average families residing in houses, units, or apartments, along with detailed instructions for installation.

The research methodology involves conducting a comprehensive literature review, analyzing industry reports, and gathering data from reliable sources to gather information on smart home systems and products. The data will be analyzed, and a detailed comparison matrix will be created to aid in the decision-making process. The project objectives include investigating current smart home systems, identifying typical configurations, conducting a detailed product comparison, providing tailored recommendations, and offering installation instructions.

While this research project has several limitations, such as relying on existing literature and market analysis, the findings and recommendations aim to provide valuable insights and practical guidance for individuals interested in smart home technology. Future research could incorporate user surveys, practical experiments, and consider evolving technologies.

In conclusion, this research project aims to enhance the understanding of smart home systems and products, empower individuals in making informed decisions, and provide practical guidance for the installation and setup of these systems. By achieving these objectives, individuals will be equipped with the knowledge and tools to embrace the benefits of smart home technology and create an optimized living environment based on their specific needs and preferences.

1. Introduction

1.1. Project Aim

The aim of this research project is to investigate the current market landscape of smart home systems and products. The project aims to identify the typical configurations of smart home systems for various property types, including houses, units, and apartments. Furthermore, it seeks to provide a detailed comparison of smart home products, considering their features, performance, installation processes, and reliability. The goal is to recommend an optimized smart home system solution tailored to the specific needs and preferences of an average family residing in a house, unit, or apartment. Additionally, the project aims to provide comprehensive instructions and recommendations for the installation of the recommended smart home products. By achieving these objectives, this research project aims to equip individuals with valuable insights and practical guidance in embracing the benefits of smart home technology.

1.2. Project Objectives

Conduct an extensive investigation of the current smart home systems and products available in the market. This objective involves comprehensive research using scholarly articles and analysis of industry reports, market trends, and consumer feedback to gather a comprehensive understanding of the range of smart home systems and products available.

Identify the typical configurations of smart home systems for different types of properties, including houses, units, and apartments. This objective aims to categorize and analyze the specific setups, components, and integrations commonly found in smart home systems based on property types, providing insights into the optimal configurations for each type of dwelling.

Provide a detailed comparison of smart home products based on their features, performance, installation processes, and reliability. This objective involves systematically evaluating a range of smart home devices and products, considering their key attributes and functionalities. The comparison will focus on factors such as compatibility, ease of use, reliability, cost, security, and overall user satisfaction.

Recommend an optimized smart home system solution for an average family in a house, unit, and apartment based on their specific needs and preferences. This objective aims to synthesize the findings from the previous objectives and formulate tailored recommendations that align with the requirements and preferences of an average family in different property types. The recommendations will consider factors such as budget, lifestyle, security needs, energy efficiency, and convenience.

Provide detailed instructions and recommendations for the installation of the recommended smart home system. This objective involves developing step-by-step instructions and guidelines for the installation of various smart home devices and products. The instructions will cover aspects such as device setup, network connectivity, and integration with other components, ensuring a seamless installation experience for the end user.

By achieving these objectives, this research project aims to enhance the understanding of smart home systems and products, empower individuals in making informed decisions when adopting smart home technology, and provide practical guidance for the installation and setup of these systems.

1.3. Limitations

This research project on smart home systems and products has several limitations that are listed below:

Firstly, the study's scope is limited to the available literature and market analysis and may potentially exclude recent developments and products. The recommendations provided for optimized smart home system solutions are based on general assumptions which have been researched online and may not fully address the unique preferences and requirements of every individual or family.

Another limitation is that this research is a desktop-based exercise and does not involve surveys, practical work, or experimentation. The findings and recommendations rely on existing literature, market analysis, and data from reliable sources. While efforts have been made to ensure the reliability and validity of the information, the absence of direct user surveys or hands-on experimentation may limit capturing real-world nuances and individual user experiences.

Furthermore, the information collected for the analysis and comparison is dependent on the availability and reliability of the sources accessed. Variations in data accuracy or bias in the literature may impact the robustness of the findings. It's important to note that the installation instructions and recommendations provided are general guidelines and may require adaptation to specific circumstances and technical configurations which the author may not necessarily be conversant with.

Despite these limitations, this research project aims to provide valuable insights and practical guidance for individuals interested in smart home technology. The findings should be interpreted within the context of the available literature and market analysis, considering the specific needs and preferences of the users. Future research could focus on incorporating user surveys, conducting practical experiments, and considering the evolving landscape of smart home systems to further enhance the understanding and recommendations in this field.

2. Literature Review

The literature review section of this report provides a comprehensive examination of the existing knowledge and research in the field of smart home technology. It aims to explore various aspects related to smart home systems and products, including their evolution, architecture, devices, user-centric design principles, energy efficiency, security and privacy, market analysis, and real-world deployments.

The first subsection focuses on the evolution and development of smart home technology, providing a historical overview of its progression. Key advancements and milestones in the field will be discussed, along with emerging trends and future directions that shape the trajectory of smart home technology.

Next, the literature review delves into the architecture of smart home systems, outlining the components and infrastructure involved. It explores communication protocols and standards commonly used in smart homes and examines the integration of different devices and platforms within a smart home ecosystem.

The section on smart home devices and products categorizes and explores various types of smart home devices, including smart speakers, thermostats, lighting systems, security systems, and appliances. It highlights the features, functionalities, and capabilities of popular smart home devices and examines advances in sensor technologies and their applications within smart homes.

User-centric design principles for smart home systems and products are also explored, focusing on usability and user satisfaction in smart home environments along with incorporation of health and wellness aspects. Challenges and solutions related to providing intuitive interfaces and seamless interactions with smart home devices are discussed.

Additionally, the literature review addresses the important topics of energy efficiency and sustainability in smart homes. It examines the integration of renewable energy sources and smart grid technologies, as well as the impact of smart home systems on energy consumption patterns and environmental sustainability.

Security and privacy considerations in smart home systems are also analyzed, highlighting the threats, vulnerabilities, and security risks associated with smart home devices. Authentication, encryption, and data protection mechanisms are discussed, along with privacy concerns and ethical considerations in collecting and processing personal data within smart homes.

The review then moves on to market analysis and consumer perspectives, examining the current market trends and adoption rates of smart home technology. It explores consumer preferences, behaviors, and the factors influencing the adoption of smart home systems. Additionally, the economic implications and business models within the smart home industry are discussed.

Finally, the literature review section includes case studies and real-world deployments of smart home systems. It analyzes successful smart home projects and implementations, identifies lessons learned, challenges faced, and best practices for smart home deployments. User feedback and satisfaction in real-world smart home environments are also considered.

2.1. Evolution and Development of Smart Home Technology:

a. **Historical overview of the evolution of smart home technology:** The evolution of smart homes has been a journey marked by significant technological advancements and paradigm shifts. Starting in 1975 with the introduction of X10[29], a pioneering communication protocol, the concept of a connected home transitioned from a futuristic notion into a tangible reality. Some of the key milestones that have shaped the smart home landscape are as per the timeline below which has been sourced from reference [29].
   1975: The inception of smart homes began with the launch of X10, a communication protocol that employed existing electric wiring to control devices. However, X10 faced reliability issues due to interference and was initially limited to one-way communication.

   1984: The term "smart house" was coined by the American Association of Home Builders to advocate for integrating technology into home design.

2005: Insteon introduced a technology that combined electric wiring with wireless signals. This development aimed to address the limitations of X10. Concurrently, protocols like Zigbee and Z-Wave emerged as alternatives.

2007: Smart TVs marked a significant advancement, offering internet-connected services and streaming capabilities.

2011: Nest Labs made a notable entry into the field by releasing the Nest Learning Thermostat, followed by smart smoke detectors and security cameras. The acquisition of Nest by Google in 2015 further solidified its position.

2012: SmartThings gained attention with a successful Kickstarter campaign for its smart home system. Samsung's acquisition of SmartThings in 2014 demonstrated the increasing interest of major players in the smart home market.

2014: A pivotal moment arrived with the introduction of Amazon Echo and its voice assistant Alexa, along with Apple's HomeKit platform, marking a transformative step towards voice-controlled smart devices.

2016-2018: The landscape of smart homes experienced a notable shift as smart speakers like Google Home, Google Nest, Apple Home Pod, and Sonos entered the scene, revolutionizing how users interacted with their smart environments.

Today: The evolution of home automation persists, offering an array of connectivity options and continually evolving features that cater to the increasing demands and expectations of smart homeowners.

b. **Emerging trends and future directions in smart home technology**: Emerging advancements in smart device technology are poised to merge the capabilities of language models with virtual assistants like ChatGPT. Several companies are already leveraging this synergy to create personalized AI assistants, and Amazon is notably engaged in the development of a substantial language model, aimed at enhancing the capabilities of Alexa, its voice-activated assistant [20].

The Internet of Things (IoT) has revolutionized the way individuals experience home life by converting traditional residences into intelligent, interconnected smart homes. Presently, homes incorporate numerous associated devices, but experts project that future smart homes will seamlessly link hundreds, even thousands, of interconnected devices. As consumer demand remains strong, the market consistently introduces inventive home solutions. The integration of IoT-driven home automation not only presents fresh revenue avenues for businesses but also facilitates enhanced customer engagement, enabling companies to deliver heightened value and superior customer support [20].

Domb [23] notes that the incorporation of blockchain into home networks presents a straightforward process with the utilization of Raspberry Pi. A secure blockchain layer can be established between devices and gateways without the need for an extensive overhaul of the existing code framework.

2.2. Smart Home System Architecture:

a. Overview of the components and infrastructure of smart home systems.

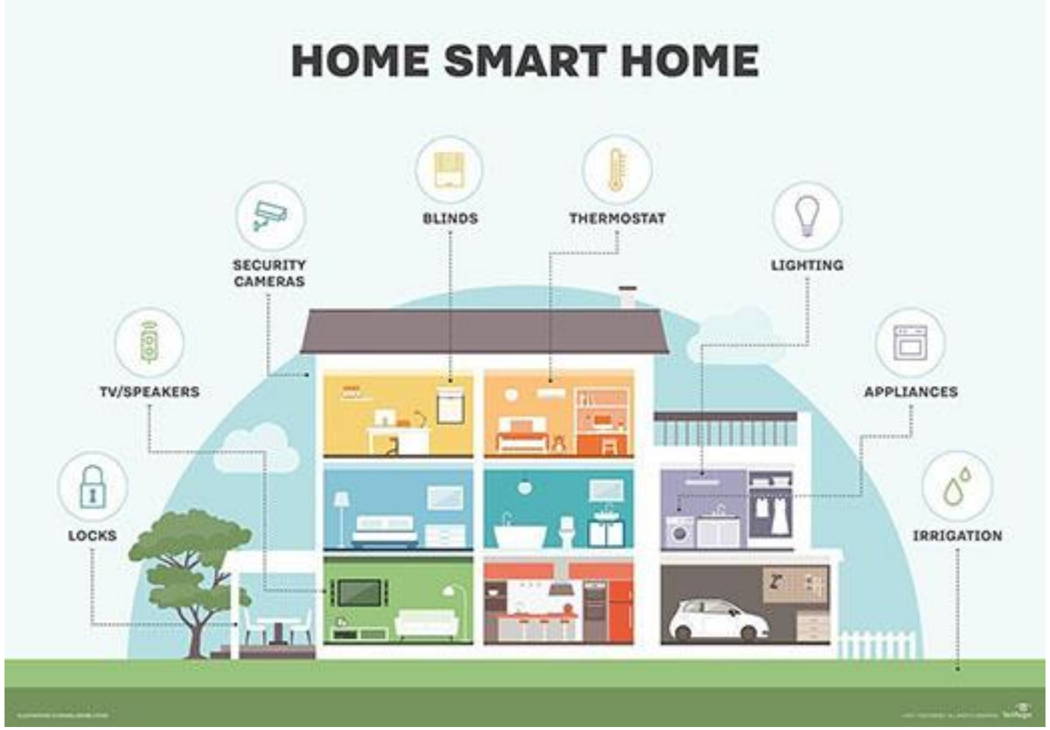


Figure 1 Smart home (Source [33])

Fig 1 above shows the typical components of a Smart home system. Without being exhaustive they comprise access control, security systems, lighting, climate regulation, entertainment systems, and household appliances [33]. They comprise of a myriad number of devices from different manufacturers to obtain the above functionality. Within a smart home system there are generally two kinds of devices. The end devices themselves such as sensors, actuators, and switches which possess the capacity to execute a restricted range of functions. These devices are usually compact and incorporate micro-controller units (MCUs) that are energy-efficient, resource-constrained (including elements like RAM, ROM, and energy), and adept at supporting short-range, low-power communication protocols. The other device is the Gateway [25]. Gateway devices function as a link between the numerous IoT devices within a smart home, as they are equipped to handle a broader array of communication protocols and possess enhanced resources for data collection and processing. Within a smart home framework featuring cloud services, these gateway devices are referred to as edge gateways, as they reside at the intersection of the external Internet and the local Intranet. As a result, these devices boast heightened capabilities and require operating systems that accommodate diverse communication technologies [25].Table 1 below is a comparison chart of various popular IoT operating systems, outlining their minimal resource requirements, programming models, real-time capabilities, supported programming languages, and the licensing terms they are distributed under.

OS name	Min RAM	Min ROM	Program. model	Realtime	Language	License
Contiki	10KB	30KB	Proto-threads	Partial	C	Open-src
TinyOS	1KB	4KB	Event-driven	No	NesC	Open-src
RIOT	1.5KB	5KB	Threads	Yes	C, C++	Open-src
Mantis	14KB	50KB	Threads	Partial	C	Open-src
FreeRTOS	1KB	10KB	Threads	Yes	C	Open-src
Nano-RK	2KB	18KB	Threads	Yes	C	Open-src
LiteOS	4KB	128KB	Threads/ Events	Yes	LiteC++	Open-src
Apache Mynewt	16KB	128KB	Threads	Yes	Assembly, C, Go	Open-src
Zephyr OS	8KB	128KB	Threads	Yes	Multiple	Open-src
Ubuntu Core Snappy	128MB	350MB	Threads	No	Multiple	Open-src
Android Things	512MB	4GB	Threads	No	C, Java, Kotlin	Open-src
Windows 10 IoT	256MB	200MB	Threads	Partial	Multiple	Propriet.
WindRiver VxWorks	1MB	128KB	Processes	Yes	C, C++	Propriet.
Micrium μC/OS	1KB	6KB	Threads, Tasks	Yes	C	Propriet.
MicroEJ OS	32KB	128KB	Threads	Yes	C, C++, Java	Propriet.
Express Logic ThreadX	1KB	2KB	Threads	Yes	C	Royalty-Free
Nucleus RTOS	2KB	12KB	Threads	Yes	C, C++	Propriet.

Table 1 Operating systems for IOT devices (Source [25])

When dealing with Smart home there is sometimes confusion about the terms Gateway, Bridge and Hub.

Hub: A smart home hub operates as the nucleus of the Wi-Fi network, acting as the central point of coordination. It is what the end devices send to and receive messages from either a smart phone or a tablet-controlled app. The role of hubs is to consolidate all the smart home devices and systems and offering the user the capability to control and communicate with them. Some typical examples of smart hubs currently in the market are the smart speakers available from Amazon (Amazon Echo), Google (Home devices) and Apple (Home Pods). There are specific Hubs from Samsung (SmartThings)and Aeotec (Smart Home Hub) that serve as a dedicated connection device rather than having a dual function as a speaker. Hubs are not routers as they themselves must connect to the Wi-Fi Router within the home [31].

Gateway: Communication among smart home devices takes place through wireless protocols, and there is a range of options available for these internet-connected products and appliances to employ. In addition to various Wi-Fi networks, notable examples encompass Z-Wave and Zigbee. A gateway serves as an interpreter, translating messages from devices that utilize different languages into a universal language that enables seamless communication among them. Hubs establish connections among devices of similar types within a shared network, while gateways facilitate connections among devices of diverse types that operate on separate networks. Nowadays a lot of the Hubs themselves come with gateways built in so there is no requirement to get a second gateway device [31].

Bridge: Sometimes there are specific kinds of devices like smart window blinds or shades that cannot directly communicate with the Wi-Fi network due to a low power wireless communication protocol. In this instance a specific kind of device called a bridge would be used to enable this communication between the device and the gateway or router [31].

b. Communication protocols and standards used in smart home systems.

Smart homes represent a highly promising domain within the Internet of Things (IoT) landscape. Nonetheless, the acceptance and implementation of smart home technology remain limited, despite considerable research efforts focused on this area in recent times. A significant obstacle arises from the technological fragmentation present within the smart home ecosystem. At present, the multitude of protocols utilized within connected homes contributes to consumer confusion when selecting products for their residences [32]

In the context of devices in smart homes, there are a variety of commonly used Network protocols used to communicate with these devices or between themselves. A comparison of some of the most widely used protocols is provided in the figures and tables below.

Figure 2 below shows the network protocols and their relative usage in the Smart home industry.

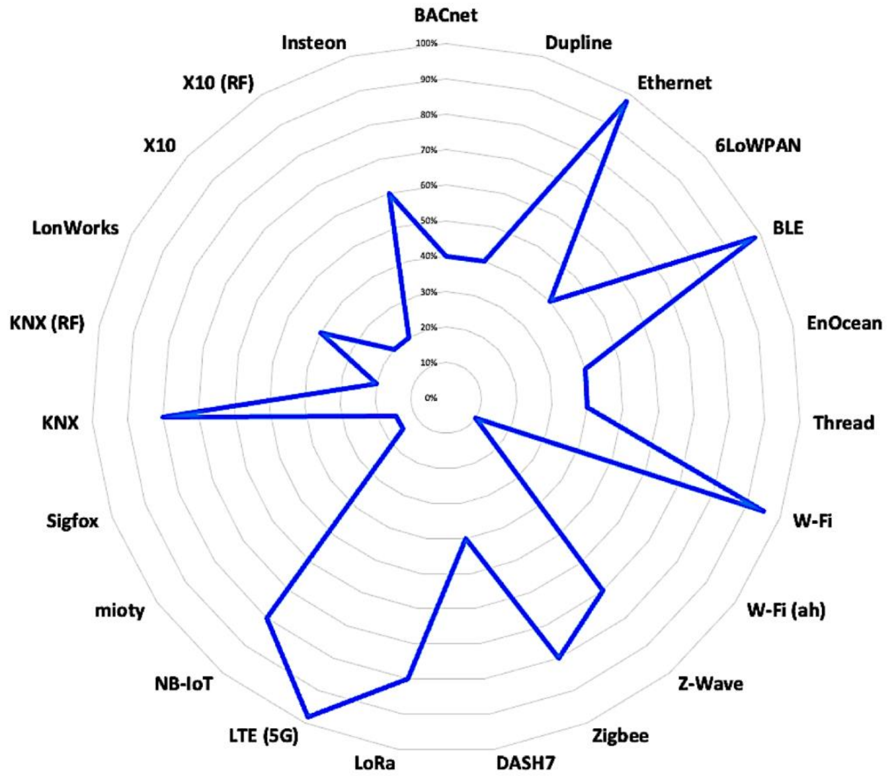


Figure 2.Protocol usage (Source Orfanos et al. (2023))

Figure 3 below shows the usage distance of the protocols.

Figure 3 Usage distance (Source Orfanos et al. (2023))

The tables below outline the technical characteristics of these protocols.

Home Automation Technologies	BACnet	Dupline	ethernet alliance
Released	1995	2003	1980
Primary Markets	Home Automation	Home Automation	Computer networks, Home automation
Adoption	Medium	Medium	Extremely High
Commercial devices	Medium	Medium	Extremely High
Open source	YES	Proprietary	NO
APIs available	YES	YES	YES
Platforms	Windows/MAC/Linux /IOS/Android	Windows	Windows/MAC/Linux IOS/Android
Connection type	Wired	Wired	Wired
Standard	ASHRAE/ANSI Standard 135, ISO 16484-5:2003	Proprietary	802.3
Multimedia apps	NO	NO	YES

Home Automation Technologies	BACnet	Dupline	ethernet alliance
Network Size	65,534	128	unlimited
Range (m)	1000	10,000	100–40,000
Connection Medium	T.P, PL	P, PL	T.P, Optical Fiber
Message type	Telegram, TCP/IP, LonTalk	Telegram	TCP/IP
Packet length (Bytes)	Ethernet: 1515, ARCNET: 501 MS/TP: 501 LonTank:228	1.5	1522
Data Rate	Ethernet: 10–1000 Mbps, ARCNET: 0.156–19 Mbps MS/TP: 9.6–78.4 Kbps LonTalk: 4.8–1250 Kbps	9.6 Kbps	~100 Gbps (TP), ~1.6 Tbps (FO)
Gateway	YES	YES	YES
Topology	Star/P2P	Star/P2P	Star/P2P/mesh *
Mesh Enrollment	-	-	YES *
Heterogeneity	Ethernet, LonWorks, EnOcean	Ethernet, LonWorks, LTE	With almost all wired and wireless protocols
SoC Solution	YES	YES	YES
CPU architecture	32-bit	N/A	32-bit–64-bit

* It can be achieved with extra hardware implementation.

Table 2 Wired Home automation Technology (Source Orfanos et al. (2023))

Home Automation Technologies	6LoWPAN	Bluetooth	enocean	THREAD	WiFi	Z-WAVE	zigbee
Released	2007	2002	2008	2014	1997	2001	2004
Primary Markets	H. A.	H. A.	Building Automation	H. A.	H. A.	H. A.	H. A.
Adoption	Medium	Extremely High	Medium	Medium	Extremely High	Widely adopted	Widely adopted
Commercial devices	Medium	Extremely High	Medium	Medium	Extremely High	High	Very High
Open source	YES	YES	Licensed	Licensed, OpenThread	YES	Licensed	YES
APIs available	YES	YES	YES	YES	YES	YES	YES
Platforms	Windows/MAC/ IOS/Android	Windows/MAC/ Linux/IOS/Android	Windows/MAC/ Linux/IOS/Android	Windows/MAC	Windows/MAC/ Linux/IOS/Android	Windows/MAC/ IOS/Android	Windows/MAC/ IOS/Android
Connection type	Wireless	Wireless	Wireless	Wireless	Wireless	Wireless	Wireless
Standard	802.15.4	802.15.1	ISO/IEC 14543-3-1	802.15.4	802.11a/b/g/n/ac/ah	Proprietary	802.15.4
Multimedia apps	NO	YES	NO	NO	YES	NO	NO

Home Automation-Technologies	6LoWPAN	Bluetooth	enocean	THREAD	WiFi	ZWAVE	zigbee
Network Size	64,000	9	64,000	250	50/8191 (ah)	232	64,000
Range (m)	10–100	100	30 (in)/ 300 (out)	100	100, 2000–4000 (1 Mbps)	30 (in)/ 100 (out)	100–100
Frequency (MHz)	868 (EU), 915 (US), 2400	2400	868	868 (EU), 915 (US), 2400	900 (ah), 2400 5000 6000	868 (EU), 908 (US), 2400	868 (EU), 915 (US) 2400
RF Channels	16 (2.4 GHz), 10 (915 MHz), 1 (868 MHz)	40	1	16 (2.4 GHz), 10 (915 MHz), 1 (868 MHz)	14 (2.4 GHz), 8 (5 GHz), 4 (900 MHz)	2	16 (2.4 GHz), 10 (915 MHz), 1 (868 MHz)
Modulation	BPSK/BPSK, O-QPSK	GFSK	ASK	BPSK/BPSK, O-QPSK	B/QPSK, COFDM, QAM	FSK/GFSK	BPSK/BPSK, O-QPSK
Spreading	DSSS	FHSS	No	DSSS	DSSS, CCK, OFDM	No	DSSS
Message type	MQTT, TCP/IP	Frames, TCP/IP, CoAP	Telegrams	MQTT, D.V.R., TCP/IP	MQTT, TCP/IP	Network identifiers	Frames
Packet length (Bytes)	100	8–47	4	100	2304/100 (ah)	32	100
Data Rate	20/40/250 Kbps	1 Mbps	125 Kbps	20/40/250 Kbps	1 Gbps/1 Mbps (ah)	9.6/40/200 Kbps	20/40/250 Kbps
Gateway	NO	YES	YES	YES	NO	YES	YES
Topology	Star/P2P/mesh	Star/P2P/Mesh	Star/P2P/Mesh	Star/P2P/mesh	Star/P2P/Mesh	Star/P2P/mesh	Star/P2P/mesh
Mesh Enrollment	Procedural	Procedural	Procedural	Procedural	Procedural	Procedural	Procedural
Heterogeneity	Bluetooth, Thread, Wi-Fi, Zigbee	Wi-FI, 6LoWPAN EnOcean Sigfox	BACnet, BLE, Ethernet, KNX, Wi-Fi, Zigbee	Wi-Fi Zigbee	Most technologies	Wi-Fi	EnOcean, Ethernet, Wi-Fi, Thread
SoC Solution	YES	YES	YES	YES	YES	YES	YES
CPU architecture	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit

Table 3 WPAN and WLAN home automation Technology (Source Orfanos et al. (2023))

Home Automation Technologies	DASH7	LoRa	lte 5G	NB-IoT	mioty	sigfox
Released	2011	2015	2012 (5G)	2014	2016	2009
Primary Markets	Sensors H. A.	Building Automation, and Security, Agriculture	Communications, Multimedia	Smart cities, Smart buildings Agriculture Smart metering	Agriculture, Smart metering	Building Automation, and Security, Agriculture
Adoption	Medium	High	Widely adopted	High	Low	Medium
Commercial devices	Medium	Medium	Very High	High	Low	Low
Open source	YES	YES	Proprietary	YES	Proprietary	Proprietary
APIs available	YES	YES	YES	YES	YES	YES
Platforms	Windows/MAC/ Linux	Windows/MAC Linux/IOS/Android	Windows/MAC Linux/IOS/Android	Windows/MAC Linux/IOS/Android	Windows/Linux	Windows/MAC Linux/IOS/Android
Connection type	Wireless	Wireless	Wireless	Wireless	Wireless	Wireless
Standard	ISO/IEC 18000-7	Proprietary	3GPP-R14	3GPP-R13	ETSI TS 103 357	ETSI EN 300 220-1, EN 300 220-2
Multimedia apps	NO	NO	YES	NO	NO	NO

Home Automation Technologies	DASH7	LoRa	lte 5G	NB-IoT	mioty	sigfox
Network Size	Unlimited	>10,000	50,000–100,000	>50,000	10,000	>10,000
Range (m)	2000	20,000	5000	5000–15,000	5000–15,000	15,000
Frequency (MHz)	433, 868 (EU), 916 (US)	169, 433, 868 (EU), 915 (US)	700–900, 1700–1900, 2000–4000, 24,000–40,000	450–3500	433, 868 (EU), 916 (US)	868 (EU), 902z (US)
RF Channels	8	8 (915 MHz), 10 (868 MHz),	6 (2U + 3D)	6 (2U + 4D)	N/A	360 + 40 reserved
Modulation	FSK/GFSK	CSS	GFSK/BPSK	QPSK/BPSK	GMSK (UNB)	DBPSK (U) GFSK (DL)
Spreading	CSMA/CA	FHSS	OFDMA/SC-FDMA	OFDM, SC-FDMA	TSMA	DSSS
Message type	OpenTag, TCP/IP	LoraWAN	TCP/IP	Frames	Telegrams	Frames
Packet length (Bytes)	256	255	Network Deployment Driven	Network Deployment Driven	10–192	U: 12 D: 8
Data Rate	200 kbps	0.3–50 kbps	1 Mbps (CAT-M), 10 Gbps (CAT-0)	U: 204.8 kbps D: 234.7 kbps	512 kbps	U: 100 bps D: 600 bps
Gateway	YES	YES	YES	YES	YES	YES
Topology	Star/P2P/mesh	Star/mesh *	Star	Star	Star	Star
Mesh Enrollment	Procedural	-	-	-	-	-
Heterogeneity	Wi-Fi	Ethernet, Wi-Fi	NB-IoT, Wi-Fi	LTE	Ethernet	Wi-Fi, BLE
SoC Solution	YES	YES	YES	YES	YES	YES
CPU architecture	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	32 bit–64 bit	8-bit

Table 4 WNAN and WWAN home automation Technology (Source Orfanos et al. (2023))

Home Automation Technologies	KNX	LonWorks	X10	INSTEON
Released	1990	1991	1975	2005
Primary Markets	Home Automation	Home Automation	Home Automation	Home Automation
Adoption	Widely Adopted	High	Low	High
Commercial devices	Very High	High in US	Low	High US
Open source	Proprietary	Proprietary	YES	Proprietary
APIs available	YES	YES	YES	YES
Platforms	Windows/MAC/ Linux/IOS/Android	Widows/MAC/ Linux/IOS/Android	Widows/MAC/ Linux/IOS/Android	Windows/MAC/Linux
Connection type	Wired/Wireless	Wired/Wireless	Wired/Wireless	Wired/Wireless
Standard	ISO/IEC 1454-3	ISO/IEC 14908	Open	Proprietary
Multimedia apps	YES	NO	NO	NO

Home Automation Technologies	KNX	LonWorks	X10	INSTEON
Network Size	32,768	4096	256	Unlimited
Range (m)	350 wired, 100 wireless	2700 wired	30 wired	120 wired 45 wireless
Connection Medium	Twisted pair, Powerline	Twisted pair, Powerline, Fiber optics	Power Line	Powerline
Frequency	868 MHz	120 KHz (PL) 432 MHz	132 KHz (pl) 310 MHz (US), 433.92 (EU)	132 KHz (pl), 869.5 (EU), 915 MHz (US), 921 (AU)
RF Channels	5	1	1	34
Modulation	2-FSK	N/A	NO	FSK
Spreading	OFDMA/SC-FDMA	NO	NO	NO
Message type	Telegrams, TCP/IP	LonTalk, Telegrams	Frames	Frames
Packet length (Bytes)	16	228	4	10–24
Data Rate Wired	9.6 Kbps (pl) 100 Gbps (ethernet)	1.25 Mbps	60 bps	13,165 bps
Data Rate Wireless	38.4 Kbps	N/A	N/A	38.4 Kbps
Gateway	YES	YES	YES	YES
Topology	Star/P2P/mesh *	Star/P2P	Star/P2P	P2P/mesh
Mesh Enrollment	YES *	-	-	Automatic
Heterogeneity	Ethernet, Wi-Fi, Zigbee, EnOcean	BACnet, Ethernet, KNX	No	X10, Ethernet
SoC Solution	YES	YES	YES	YES
CPU architecture	16 bit, 32 bit	8-bit, 16-bi, 48 bit	8-bit	8-bit

* It can be achieved via the collaboration with protocols such as Zigbee or EnOcean.

Table 5 Dual-mode home automation technology (Source Orfanos et al. (2023))

2.3. Smart Home Devices and Products:

This section provides an overview of some of the smart devices currently available in the market.

- **Smart Speakers:** Smart speakers typically come equipped with Wi-Fi capabilities and integrated voice assistants such as Amazon Alexa, Google Assistant, and Siri. These devices allow the user to manage them through vocal commands [44]. These Smart speakers have taken over the functionality of smart Hubs and are able to control end devices using voice commands. These devices have an advantage over smart hubs as they connect directly to the internet and in turn can access more services and upgrades. Hubs are limited in certain respects as the manufacturer (e.g., Samsung Smart Things) needs to include the required design within the hub to connect to a device whereas in the case of smart speakers it is the other way around. As an example, devices manufacturers will tend to build in functionality within their devices to connect to the assistants of smart speakers like Apple Echo's Alexa and Google Home's Google assistant. These are easily achieved as Apple and Google provide API's that easily allow even novice engineers to create smart home devices and connect to them. These speakers are backed by a cloud AI system which ensures interaction are more logical and creative [45].

Figure 4 Smart Speakers (Source [44])

- **Smart Lighting:** Smart lighting systems are used within smart homes which are connected to the internet. The key feature of this system is that the smart lights can be controlled using voice activated personal assistants like Alexa or Siri or can be operated using IFTTT (If This Then that) condition-based technology [46].Smart lights can be made to follow schedules as well as make their own decisions based on Artificial Intelligence [47].

The details below on smart lighting are sourced from [46].

The key benefits of Smart lighting are savings on energy, user convenience, user customization and remote controlled. There are key types of Smart Lighting Systems that are available in the market for Smart home usage.

- Smart Light bulbs: These lights connect to a standard light holder and are operated remotely using the local wi-fi network after pairing them. These bulbs can be controlled using voice activated personal assistants like Alexa or Siri or can be operated using IFTTT.

Figure 5 Smart Bulb

- Smart lights connected with the hub. These lights require a HUB to work with and will need to be operated using the same communication technology.

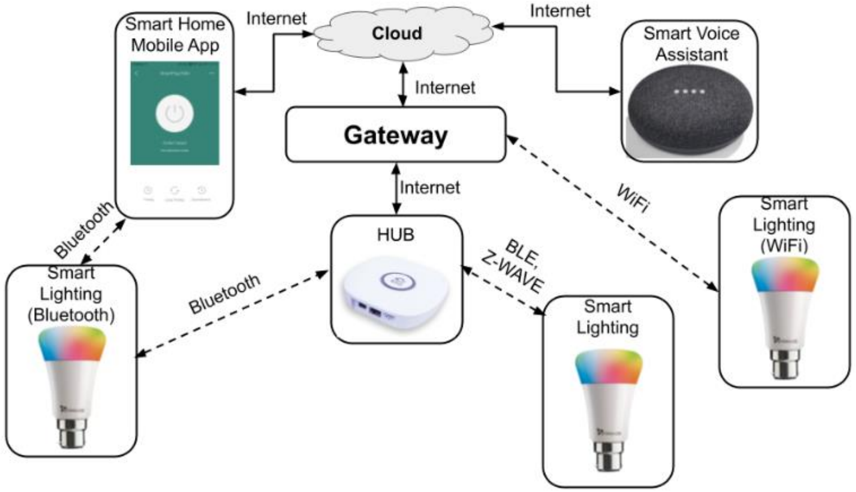


Figure 6 Smart lights connected to the Hub and operated via Mobile Apps/Voice Assistant

- IFTTT controlled Smart Lights: Smart lights are controlled through IFTTT which is a condition-based technology.

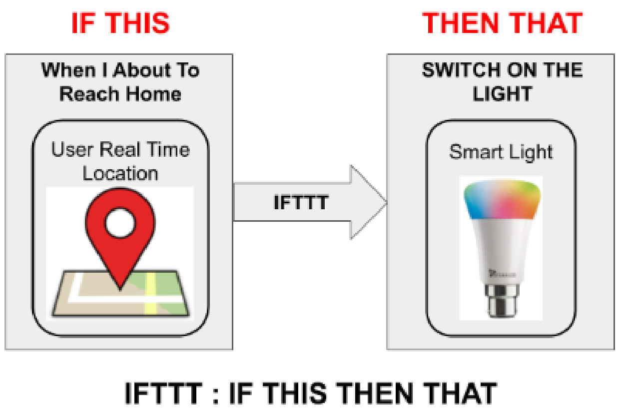


Figure 7 IFTTT based operation of Smart bulb.

- Motion sensing lights: Smart lights are controlled through motion sensors which can operate the bulb either through the HUB or through a direct wireless signal.

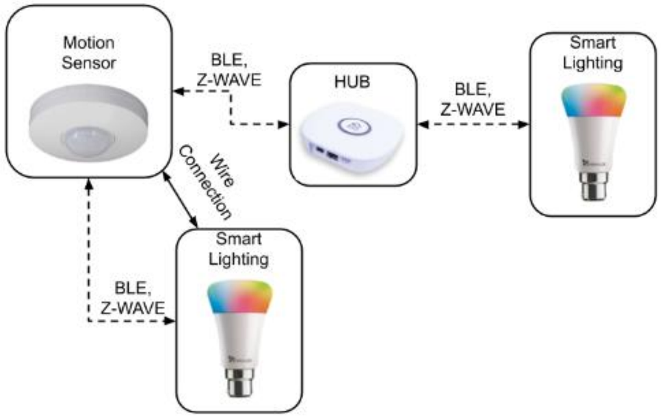


Figure 8 Motion Sensing smart lights

- **Smart Thermostats:** The details below on smart thermostats are sourced from [48].

  A smart thermostat represents a smart home innovation utilized in home automation, permitting remote temperature control of a residence via a smart device. Basic scheduling and programming options are available in some systems, whereas others, designed for complex multi-stage systems, can oversee heating, cooling, dehumidification, and ventilation. As with most smart home devices, the cost varies depending on the extent of features and functionalities. Smart thermostats offer various features for home comfort and energy savings. Basic models are affordable and have Wi-Fi connectivity for remote control via mobile devices or web browsers. They allow temperature adjustments, schedule creation, and override options. The Nest Learning Thermostat goes further, adapting schedules based on the user's presence and preferences.

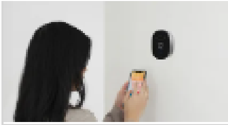
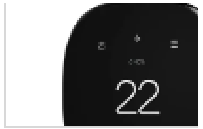
  More expensive models often include colourful touch displays, motion sensors, and additional features like humidity sensors and weather forecasts. Some, like the Eco bee Smart Thermostat with Voice Control, use remote room sensors to maintain uniform temperatures throughout the house.

  Models supporting geofencing technology, like the Nest Thermostat, can automatically adjust temperatures depending on when the user leaves or returns home based on the user's phone's location. Usage reporting provides historical data on system operation and outside temperatures. Other useful features include maintenance reminders, vacation scheduling, and alerts for system issues.

  Using a Nest thermostat as an example it easily connects to other Nest products and a wide array of third-party devices, including smart switches, fans, and lighting systems.

  Numerous modern smart thermostats offer compatibility with Amazon Alexa, Apple Siri, and Google Assistant voice instructions. The user can adjust temperature settings and inquire about the present temperature through simple verbal commands. Some of the most advanced smart thermostats come equipped with integrated Alexa voice control, granting them capabilities akin to those of a smart speaker. The user can initiate tasks such as playing music, obtaining the latest news and sports updates, checking the weather forecast, altering temperature settings, and a host of other functions. The Smart Thermostats are typically hardwired to the HVAC in the residence to ensure it is always powered [49] and the thermostat itself is controlled either through mobile devices or smart assistants.

  Some notable thermostats available in the market are provided below with their pros and cons listed:

	 Ecobee Smart Thermostat Premium	 Nest Learning Thermostat (3rd Generation)	 Nest Thermostat	 Wyze Thermostat	 Amazon Smart Thermostat	 Ecobee Smart Thermostat Enhanc
Smart Home Integration	Amazon Alexa, Apple HomeKit, Google Assistant, IFTTT, SmartThings	IFTTT, Nest	None	Amazon Alexa, Google Assistant	Amazon Alexa	Amazon Alexa, Apple HomeKit, Google Assista IFTTT
Sensors	✓		✓			✓
Self-Install	✓	✓	✓	✓	✓	✓
Multiple Zones	✓	✓			✓	✓
Motion Activation	✓	✓	✓			✓
Geofencing	✓	✓	✓	✓		✓
Compatibility	2 Stage	Multi-stage	Multi-stage	Multi-stage	Multi-stage	2 Stage
C-Wire	✓	✓		✓	✓	✓

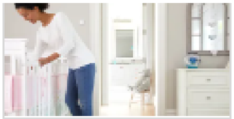
	 Amazon Smart Thermostat	 Ecobee Smart Thermostat Enhanced	 Honeywell Home T9 Smart Thermostat With Sensor	 Sensi Smart Thermostat ST55	 Sinope TH1123WF Smart Wi-Fi Thermostat	 Bosch Connected Control BCC100 Thermostat
Smart Home Integration	azon Alexa	Amazon Alexa, Apple HomeKit, Google Assistant, IFTTT	IFTTT, Apple HomeKit	Apple HomeKit	Apple HomeKit, SmartThings	None
Sensors		✓	✓			
Self-Install	✓	✓	✓	✓	✓	✓
Multiple Zones	✓	✓				
Motion Activation		✓				
Geofencing		✓	✓	✓	✓	
Compatibility	Multi-stage	2 Stage	2 Stage	Multi-stage	Multi-stage	Multi-stage
C-Wire	✓	✓	✓	✓		✓

Table 6 Notable thermostats in the market (Source [48])

- **Smart Security Systems:** The details below on smart security systems are sourced from [50].

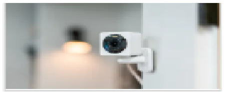
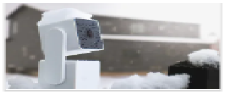
A smart home security system connects to the Wi-Fi network, allowing the user to manage security devices through a mobile app. These systems vary in price and components.

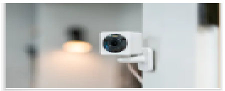
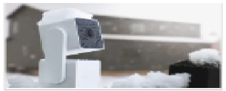
Basic systems include door/window sensors, motion detectors, and a hub using wireless protocols like Wi-Fi, Z-Wave, Zigbee, or proprietary mesh networks. These can be further expanded by adding more sensors and devices, such as door locks, garage openers, cameras, lights, sirens, detectors (smoke, CO, water), and more.

Again, different devices often use various wireless standards, like Z-Wave and Zigbee for small sensors and Wi-Fi for high-bandwidth devices like cameras. Hubs control Z-Wave and Zigbee devices, while the user manages Wi-Fi devices through an app.

Security cameras to monitor indoor and outdoor activities would make up one of the components of a home security system. Cameras can come with features to provide alerts when sounds and motion is detected. They can provide facial recognition as well as local storage capabilities. Storing videos in the cloud simplifies access, yet the expense can reach hundreds of dollars annually, contingent on the subscription. Certain systems combine cloud and local storage, while others provide a dedicated storage drive, equipping the user with DVR capabilities like time-lapse recording, facilitating the quick retrieval of specific video events. Practically all modern DIY and premium home security systems now provide compatibility with voice control through Amazon Alexa, Google Assistant, and occasionally, Siri.

The table below shows some of the cameras available in the market as well as a comparison of features.

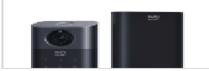
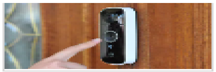
	 Arlo Pro 4 Spotlight Camera	 Eufy Indoor Cam E220	 Wyze Cam OG	 Wyze Cam Pan V3	 Ring Stick Up Cam Battery	 Arlo Essential Indoc Security Camera
Two-Way Audio	✓	✓	✓	✓	✓	✓
Storage	Cloud	Cloud, Local	Cloud, Local	Cloud, Local	Cloud	Cloud
Resolution	2K	2K	1080p	1080p	1080p	1080p
Notifications					Push	
Night Vision	✓	✓	✓	✓	✓	✓
Mechanical Pan/Tilt		✓		✓		
Integrations	Amazon Alexa, Google Assistant, Apple HomeKit, IFTTT, Samsung SmartThings	Amazon Alexa, Apple HomeKit, Google Assistant	Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Google Assistant, IFTTT		Amazon Alexa, Google Assistant, IFTTT
Integration					IFTTT	
Field of View	160	125	121	120	115	130
Connectivity	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi
Color Temperature	6,500K					
Brightness	N/A					
Alarm Volume	80dB					
Alarm	✓	✓	✓	✓	✓	✓

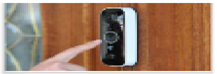
	 Wyze Cam OG	 Wyze Cam Pan V3	 Ring Stick Up Cam Battery	 Arlo Essential Indoor Security Camera	 Eufy Solo IndoorCam C24	 Google Nest Cam (Outdoor or Indoor, Battery)
Two-Way Audio	✓	✓	✓	✓	✓	✓
Storage	Cloud, Local	Cloud, Local	Cloud	Cloud	Cloud, Local	Cloud
Resolution	1080p	1080p	1080p	1080p	2K	1080p
Notifications			Push			
Night Vision	✓	✓	✓	✓	✓	✓
Mechanical Pan/Tilt		✓				
Integrations	Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Google Assistant, IFTTT		Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Apple HomeKit, Google Assistant	Google Assistant
Integration			IFTTT			
Field of View	121	120	115	130	105	130
Connectivity	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Bluetooth, Wi-Fi
Color Temperature						
Brightness						
Alarm Volume						
Alarm	✓	✓	✓	✓	✓	

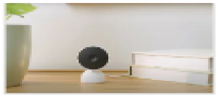
Video doorbells provide a convenient way to identify individuals at the front doorstep without the need to open the door or approach it closely. These devices connect to the Wi-Fi network and issue an alert when someone approaches the entryway. They record video when the doorbell is pressed or when motion is detected, typically offering two-way audio communication for remote conversations with the visitor via the user's mobile phone. While most video doorbells utilize existing doorbell wiring (two low-voltage wires) and are relatively simple to install, battery-powered models can be installed within minutes. Some are compatible with other smart devices such as door locks and sirens, and they also support Alexa voice commands and IFTTT integration.

Figure 9 Video doorbell (Source [50])

The table below shows some of the doorbells available in the market as well as a comparison of features

	 Ezviz DB1C Wi-Fi Video Doorbell	 Eufy Video Smart Lock	 Toucan Wireless Video Doorbell	 Arlo Video Doorbell	 Eufy S330 Video Doorbell	 Arlo Essential Vide Doorbell Wire-Fre
Voice Activation		✓				
Two-Way Audio	✓		✓	✓	✓	✓
Touchpad		✓				
Tamper Alarm		✓				
Storage	Cloud, Local		Cloud	Cloud	Local	Cloud
Resolution	1536p		1080p	1,536 by 1,536	2K	1,536 by 1,536
Notifications				Call, Push		
Night Vision	✓		✓	✓	✓	✓
Mechanical Pan/Tilt				✗		
Integrations	Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Google Assistant	Amazon Alexa, Google Assistant		Amazon Alexa, Google Assistant	Amazon Alexa, Google Assistant, IFTTT, Samsung SmartThings
Integration				Google Assistant, IFTTT, Amazon Alexa		
Installation		Exterior Escutcheon, Interior Escutcheon				
Guest Access		✓				
Geofencing/Location Services		✓				
Field of View	170		180	180	160	180
Connectivity	Wi-Fi	Bluetooth, Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi
App		Mobile				
Alarm			✓	✓	✓	

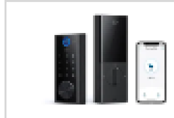
	 Toucan Wireless Video Doorbell	 Arlo Video Doorbell	 Eufy S330 Video Doorbell	 Arlo Essential Video Doorbell Wire-Free	 Ring Video Doorbell Pro 2 (2021)	 Nest Doorbell (Battery
Voice Activation						
Two-Way Audio	✓	✓	✓	✓	✓	✓
Touchpad						
Tamper Alarm						
Storage	Cloud	Cloud	Local	Cloud	Cloud	Cloud
Resolution	1080p	1,536 by 1,536	2K	1,536 by 1,536	1536p	1,280 by 960
Notifications		Call, Push				
Night Vision	✓	✓	✓	✓	✓	✓
Mechanical Pan/Tilt		✗				
Integrations	Amazon Alexa, Google Assistant		Amazon Alexa, Google Assistant	Amazon Alexa, Google Assistant, IFTTT, Samsung SmartThings	Amazon Alexa, IFTTT	Google Assistant
Integration		Google Assistant, IFTTT, Amazon Alexa				
Installation						
Guest Access						
Geofencing/Location Services						
Field of View	180	180	160	180	150	145
Connectivity	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi	Bluetooth, Wi-Fi
App						
Alarm	✓	✓	✓			

	 Ring Stick Up Cam Battery	 Arlo Essential Indoor Security Camera	 Eufy Solo IndoorCam C24	 Google Nest Cam (Outdoor or Indoor,	 Nest Cam (Indoor, Wired)	 TP-Link Kasa Spot Pan Tilt 24/7 Recording
Two-Way Audio	✓	✓	✓	✓	✓	✓
Storage	Cloud	Cloud	Cloud, Local	Cloud	Cloud	Cloud, Local
Resolution	1080p	1080p	2K	1080p	1080p	2K
Notifications	Push					
Night Vision	✓	✓	✓	✓	✓	✓
Mechanical Pan/Tilt						✓
Integrations		Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Apple HomeKit, Google Assistant	Google Assistant	Google Assistant	Amazon Alexa, Google Assistant, IFTTT
Integration	IFTTT					
Field of View	115	130	105	130	135	360
Connectivity	Wi-Fi	Wi-Fi	Wi-Fi	Bluetooth, Wi-Fi	Wi-Fi	Wi-Fi
Color Temperature						
Brightness						
Alarm Volume						
Alarm	✓	✓	✓			

A **smart lock** is another component of a comprehensive smart home security system. Utilizing a home automation hub makes it easy to incorporate a Z-Wave or Zigbee smart lock into the system. Alternatively, a Wi-Fi or Bluetooth lock that includes a mobile app can be used. Smart locks provide the ability to remotely open or close doors through a mobile app, and most models offer notifications when someone locks or unlocks a door. Many smart locks even enable the establishment of permanent and temporary access schedules for family members and friends based on specific times and days. Notable features may include geofencing (which utilizes the user's phone's location services for automatic locking and unlocking), voice control compatibility (with Alexa, Google Assistant, or Siri), support for IFTTT, and integration capabilities with other smart home devices.

A wide array of smart lock models is accessible, encompassing keyless touchless locks, touchscreen-enabled locks, combination keyed and touchpad locks, as well as locks that can be activated through a biometric fingerprint reader.

The table below shows some of the smart lock models available in the market as well as a comparison of features.

	 Ultraloq U-Bolt Pro WiFi Smart Deadbolt	 August Wi-Fi Smart Lock	 Eufy Video Smart Lock	 Kwikset Halo Touch Fingerprint Smart Lock	 Yale Assure Lock 2	 Eufy Smart Lock Tou & Wi-Fi
Voice Activation	✓	✓	✓	✓	✓	✓
Touchpad	✓		✓		✓	✓
Tamper Alarm	✓		✓			
Integrations	Amazon Alexa, Google Assistant, IFTTT	Apple HomeKit, Amazon Alexa, Google Assistant, IFTTT	Amazon Alexa, Google Assistant	Amazon Alexa, Google Assistant	Amazon Alexa, Apple HomeKit, Google Assistant	Amazon Alexa, Google Assistant
Installation	Exterior Escutcheon, Interior Escutcheon	Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Interior Escutcheon	Exterior Escutcheon, Inter Escutcheon
Guest Access	✓	✓	✓	✓	✓	✓
Geofencing/Location Services	✓	✓	✓		✓	
Connectivity	Bluetooth, Wi-Fi	Bluetooth, Wi-Fi	Bluetooth, Wi-Fi	Bluetooth, Wi-Fi	Bluetooth, Wi-Fi, Z-Wave, RF Radio	Bluetooth, Wi-Fi
App	Mobile	Mobile	Mobile	Mobile	Mobile	Mobile

Water and leak sensors: Some of the other sensors that can be found within smart homes are water and leak sensors. As an example, the D-Link Water Leak Sensor Kit (DCH-S1621KT) is designed to notify the user about leaks and are effective in mitigating potential damage to walls, floors, and cabinets. The Flo by Moen Smart Water Detector, goes a step further by offering the capability to shut off the home's water supply when combined with the Flo by Moen Smart Water Shutoff valve, thereby preventing additional damage.

Figure 10 Water leak sensor (Source [50])

- Home Automation and Hubs: A smart home platform (SHP) refers to a software system designed to oversee and coordinate various devices made by different manufacturers which often accessible through a mobile app on a smartphone or tablet. Many SHPs also incorporate hardware components like hubs and smart speakers or displays. Whilst it is not necessary to have a SHP to smart devices it becomes very cumbersome to use different apps to control each device. This is where a SHP comes in handy. It can be used to manage all devices within one app. SHPs are also key to enable home automation wherein devices can be grouped and scheduled to operate as determined by the user [51].

Some of the major SHPs that are available in the market are listed below. The details have been sourced from [52]

- Smart Things- The SmartThings application comes pre-installed on all Samsung Galaxy smartphones and is available for download on the Google Play store for Android users, as well as on the App Store for Apple users. By using Wi-Fi, Zigbee, and Z-Wave protocols within the Aeotec hub, users can access a wide range of brands and an impressive collection of more than 5,000 smart devices. Smart Things being a product of Samsung, integrates with other smart Samsung devices within the user's automation ecosystem.

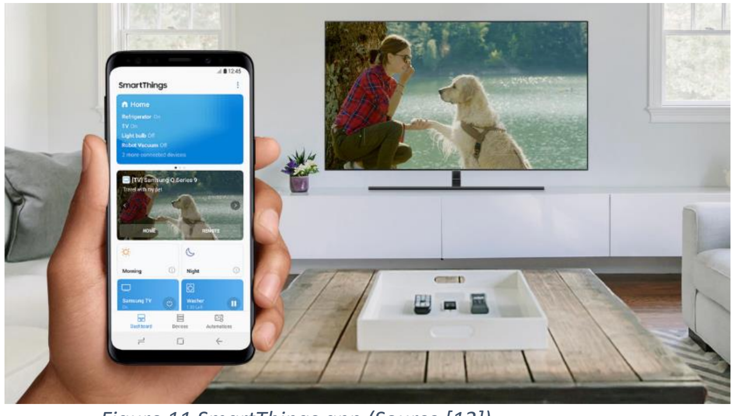


Figure 11 SmartThings app (Source [12])

This integration enables users to monitor household appliances and exercise control over smart lighting, including adjustments for brightness, colour, and temperature, all through a unified application. SmartThings extends its functionality by offering voice control capabilities, facilitating the integration of popular voice (like assistants Google Assistant and Amazon Alexa directly within the app.

- Home Assistant- Home Assistant is an open-source smart home platform that offers intuitive control, notable for its hub-free operation. It can be deployed on various operating systems, including Windows, MacOS, Linux, ODROID, Asus Tinker board, and Raspberry Pi. One of its key strengths its local processing, minimizing cloud reliance, resulting in faster, more responsive, and more secure performance compared to other systems. Home Assistant has extensive integration capabilities, supporting over 1000 different APIs.

Figure 12 Home Assistant (Source [52])

It functions locally, via the cloud, and is compatible with Zigbee, Z-Wave, Bluetooth, and is soon expected to support Matter. Home Assistant allows integration with Amazon Alexa and Google Assistant, enabling voice commands for the smart home.

- HomeKit- HomeKit, Apple's smart home automation system, offers an integrated solution for Apple users. It utilizes devices like the Home Pod Mini or Apple TV 4K as hubs, providing dual functionality in a single device. The HomeKit mobile app presents devices as cards, with quick access to favourite accessories and camera feeds. Shortcuts at the top of the app facilitate easy access to the security system, device status, and unresponsive accessories. It also supports control through iPhone, iPad, and Apple Watch.

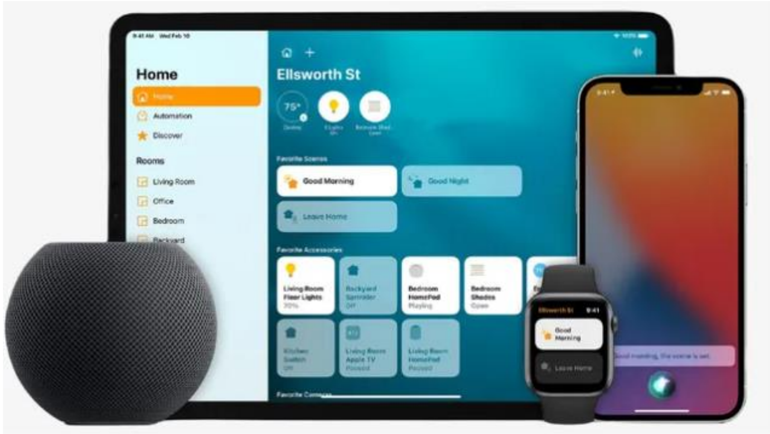


Figure 13 Apple Home Kit (Source [52])

HomeKit provides automation features which enables users to craft customized automations triggered by various events, including arrivals, departures, specific times, accessory interactions, or sensor activations. Due to HomeKit's stringent data security and privacy policies, it exclusively supports devices certified for HomeKit compatibility. Users must verify compatibility by confirming the label on their chosen devices.

- Amazon Alexa- Voice control is a pivotal aspect of home automation and the Amazon Alexa app centred around the Alexa voice assistant allows easy device integration and home customization. Alexa is accessible through various Amazon devices, including Echo speakers and Fire TV devices, employing Wi-Fi, Bluetooth, Zigbee (on specific Echo models), and more recently, Matter for connectivity.

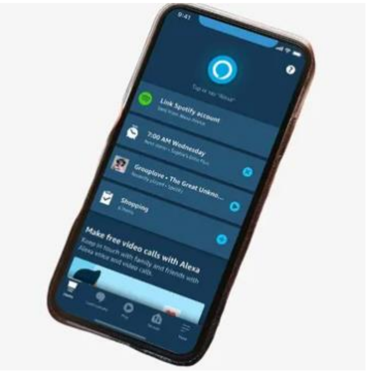


Figure 14 Amazon Alexa (Source [52])

The Alexa app offers automation capabilities through voice commands. Echo devices provide access to a vast array of skills and routines, enabling creative use cases like soothing pets with music or automatically turning off lights when snoring is detected.

- Google Home-A substantial portion of smart home users have adopted the Google ecosystem for home automation, driven by the success of the Nest Thermostat. Google expanded its Nest brand into a diverse line of smart home products, making it convenient for users with Nest thermostats to integrate other Nest devices. The Google Home app serves as the central control hub, offering easy navigation and comprehensive device management.

Figure 15 Google Home (Source [43])

Automation setup within the Google Home ecosystem is straightforward, with customizable triggers and actions. While historically somewhat exclusive, Google's ecosystem is poised for greater compatibility with the introduction of the Matter connectivity standard, backed by industry giants like Google, Amazon, and Apple. This development is expected to open doors to a wider range of compatible devices, enhancing the ecosystem's flexibility and appeal.

- IFTTT- IFTTT, built upon the "If this, then that" programming concept, has gained popularity among smart home users. It doesn't require a hub; instead, the user needs to download it on an Apple or Android device and create an account. IFTTT combines various services into applets or automations, offering a selection from their library.

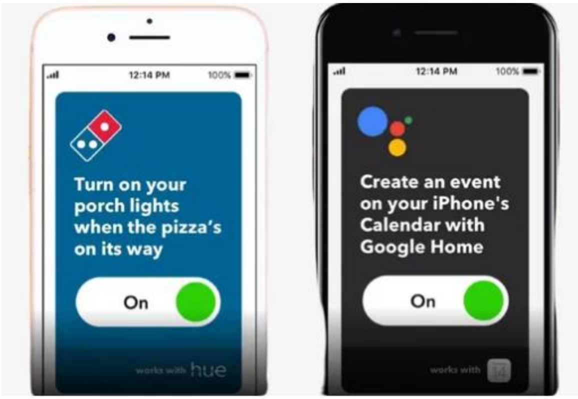


Figure 16 IFTTT (Source [43])

While commonly used for making mobile apps and accounts communicate for automations, IFTTT also extends its utility to smart home devices. For users seeking more automation possibilities for their smart home devices, IFTTT proves beneficial. It allows users to establish both basic automations like illuminating lights at sunset and more advanced ones such as triggering push notifications upon departing from home. IFTTT is a subscription-based service.

2.4. Energy Efficiency and Sustainability:

The consumption of energy is progressively mounting daily, resulting in a continuous surge in energy costs. The ability to forecast forthcoming energy consumption patterns and devise efficient energy management solutions for smart homes has emerged as a pivotal objective for many industry stakeholders seeking to address the challenge of energy wastage. In this context, machine learning has exhibited significant advancements in optimizing energy management systems. The ultimate objective of an energy management system in a smart home is to reduce energy expenses and consumption while concurrently enhancing user comfort. To attain this optimal outcome, essential elements and operations must be collectively addressed. These encompass identifying user behaviours and appliance types, monitoring user-appliance interactions, predicting future usage patterns and associated costs, devising optimal appliance schedules that uphold user comfort, and formulating control guidelines for managing and overseeing smart home devices [63]. The basic principles of saving energy in buildings rely on high-tech solutions that can be expensive and complicated. These are mainly used in places like hotels or wealthy neighbourhoods. However, in places with limited resources like homes these energy-saving technologies need to be more affordable to install. This has resulted in the emergence of budget-friendly open-source options and do-it-yourself (DIY) solutions [64].

The details below on smart energy systems are sourced from [65].

Smart meters: often referred to as advanced metering infrastructure (AMI), possess a range of functionalities that distinguish them from conventional accumulation and interval meters. Although these capabilities may not always be fully harnessed by energy providers, smart meters have the potential to furnish homeowners with real-time data on their electricity consumption, accessible through web portals or in-home displays. Furthermore, they enable the adoption of adaptable pricing structures, transmit energy usage data directly to utilities, obviating the need for manual meter readings, and can execute commands such as disconnecting services for relocating customers. Moreover, smart meters serve as vigilant monitors of power supply, automatically alerting utilities to faults or anomalies. They also serve as pivotal communication hubs for critical information, such as pricing adjustments and emergency notifications, and facilitate a bidirectional interface with customers' appliances through a home energy network [65].

Figure 17 Smart meter (source [65])

Sub-metering devices are connected to a home's circuit board to enhance the understanding of energy consumption. This data can be transmitted wirelessly to an in-home display, accessed online or via a smartphone, or sent directly to an automation controller. Such monitoring offers real-time insights into energy usage, dynamic benchmarking considering factors like weather and occupancy, the detection of emerging issues, user feedback, management of on-site energy generation and storage, and active participation in the grid through demand response and time-of-use pricing. Some devices can even measure renewable energy production from sources like photovoltaic systems or wind generators, showcasing the electricity exported to the grid and consumed on-site [65].

In-home displays (IHDs): are devices that provide visual insights into a home's energy usage and associated costs in real-time. They receive data from smart meters or submeters and present it in a comprehensible manner. Typically, homeowners do not interact with their electricity meters, making it challenging to gauge consumption patterns and costs. IHDs address this issue by showing current power consumption, tariff rates, energy usage over specific periods, total costs, and even comparisons with previous timeframes. They are especially useful for households on time-of-use tariffs, helping them track price periods accurately. More advanced IHDs can also reveal insights like the impact of individual appliances on energy consumption, critical peak pricing alerts, and real-time updates from energy suppliers, enabling users to make informed decisions about their electricity usage. These devices facilitate a better understanding of energy consumption and empower users to manage their electricity efficiently, often through wireless communication with meters or the internet, and are accessible through various user-friendly interfaces [65].

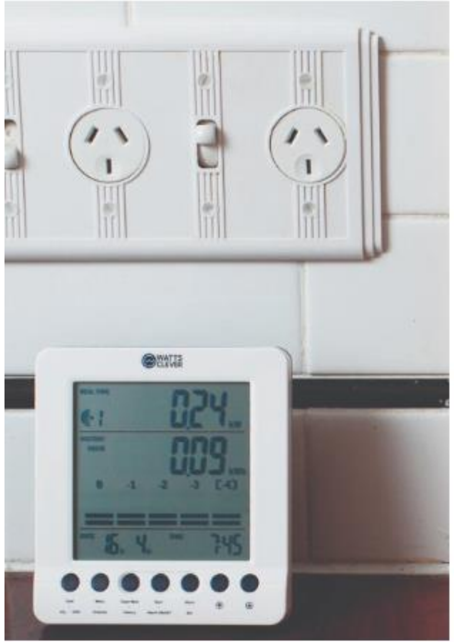


Figure 18 In House display (source [55])

Connected devices: offer the flexibility to oversee a diverse spectrum of internet-enabled equipment, with a specific focus on energy-related functions such as regulating heating and cooling, managing hot water systems, controlling lighting, and operating household appliances. Once integrated, these devices empower users to remotely activate or deactivate equipment, fine-tune settings, and create predefined schedules. Appliances can be manually configured using built-in controls, specialized interfaces, or remote management through mobile applications. Additionally, they can autonomously adapt to environmental fluctuations or be voice-operated through virtual assistants [65].

Energy use for heating and cooling constitutes 40% of the total in an average Australian home. Leveraging smart-enabled heaters, air conditioners, and advanced controls like smart thermostats or Wi-Fi controllers is instrumental in ensuring that heating and cooling equipment is employed precisely as required, thereby enhancing energy efficiency. Additionally, smart-enabled heating and cooling systems may offer added functionalities like remote diagnostics to detect faults in advance and the capability to be 'DRED-enabled,' allowing electricity utilities to remotely activate equipment in customers' homes and businesses through demand response signals. **Demand response** offers automated or user-initiated control of electrical equipment, including air-conditioners, smart controls, pool pumps, electric water heaters, electric vehicle chargers, energy storage systems, and potentially photovoltaic systems through grid interactive inverters. Automated demand response involves signals from program providers that prompt equipment adjustments. To participate, equipment must meet Australian Standard AS/NZS 4755 and connect to a demand response enabling device (DRED), which can be integrated or standalone. High-priority needs, like medical equipment, can have dedicated circuits with separate circuit breakers to ensure uninterrupted use. Allowing energy providers to manage loads, even briefly, can yield financial benefits, either as savings on time-of-use tariffs or incentives for connecting smart appliances [65].

As noted earlier **Smart thermostats** have a significant part in controlling the heating and cooling energy management within a house. The scheduling capabilities of smart heating and cooling controls enable the management of a comfortable indoor temperature while simultaneously achieving energy efficiency. These controls can also enhance passive solar heating and cooling by regulating elements like blinds, awnings, windows, vents, and fans [65].

Connected hot water systems provide the flexibility of being turned on or off based on specific requirements, such as deactivation during holidays and reactivation before returning home. Heat pump and electric-boosted solar hot water systems can be scheduled to operate during periods of anticipated solar photovoltaic electricity generation or during times when local energy prices are at their lowest [65].

The integration of smart appliances and the utilization of data acquired through diverse sensors and smart metering enable a smart home to effectively regulate its electricity demand from the grid, both in terms of volume and timing. This strategic approach is geared toward minimizing electricity costs and, in scenarios where surplus electricity is sent back to the grid from on-site generation, could result in net profits [69].

2.5. Security and Privacy in Smart Home Systems:

a. **The threats, vulnerabilities, and security risks associated with smart home devices**.

Since a smart home is equipped with a range of smart devices which are wirelessly connected internally as well as to the external world through the it introduces fresh vulnerabilities that pose threats to the security and privacy of the individuals inhabiting the smart home [69]. According to [73] as households have seen a proliferation of smart devices in their home networks, this has resulted in an overall increase in the attack surface of organizational IT networks.

Security as defined in this context relates to the security of the user's data as well as privacy. The typical approach for safeguarding data involves the application of both symmetric and asymmetric key cryptography techniques [69].

The security of a smart home can be compromised by two distinct threat classifications: internal threats and external threats. Internal attacks become feasible when a cybercriminal is in close physical proximity to the dwelling, while external threats can occur through an internet connection.

Some of the more common methods by which the security of a home system could be compromised are eavesdropping, impersonation, software exploitation, denial of service (DoS) attacks, and ransomware. Eavesdropping can compromise privacy by intercepting traffic or sensor data, potentially leading to further active attacks. Impersonation involves attackers acting on behalf of legitimate users through credential theft or man-in-the-middle attacks. Software exploitation results from neglecting security measures, like changing default passwords or not updating software, allowing cybercriminals to gain control of devices. DoS attacks disrupt device operations by overwhelming them with requests or corrupted messages, impacting Internet connectivity. Ransomware attackers encrypt data and demand a ransom for decryption keys [69].

[68] notes that a significant portion of the household IoT devices currently available for purchase possesses vulnerabilities, including some that are of critical nature. Hence, it becomes imperative to explore future research avenues aimed at enhancing the security of IoT and guiding consumers away from exposed products. One viable approach could involve the implementation of cybersecurity certifications for household IoT and similar devices.

b. **Authentication, encryption, and data protection mechanisms in smart home systems**.

Since security is such a critical aspect of Smart homes some of the steps recommended [70] to ensure protection are as listed below

Router Setup: Change the default router name to prevent potential access via default login credentials. Choose a unique and unrelated name. Set a strong, complex password for the router, incorporating letters, numbers, and symbols. Ensure the highest level of encryption, like WPA2, to bolster router security.

Utilize Secure Passwords: generate distinct credentials for each IoT device's account and its respective app.

Establish an Isolated Wi-Fi Network for IoT Devices: Modern routers often offer the option to configure a guest or secondary network. Designating a distinct network exclusively for the user’s IoT devices helps fortify the primary network against potential IoT-related security risks.

Deactivate Unused Features: Numerous IoT devices offer remote control capabilities, permitting users to manage them from anywhere globally. If it is being used only within the home's Wi-Fi network, then disabling remote access can be deactivated. Similarly, some smart devices, like smart speakers, come equipped with both Bluetooth and Wi-Fi connectivity. The option not being utilized should be disabled to enhance protection.

Multi-Factor Authentication: Multi-factor authentication, usually consisting of two factors (2FA), adds an extra layer of security beyond a basic password. Most smart devices come with multi-factor authentication as a default feature, but there are exceptions. In these instances, the user can activate 2FA using third-party applications like Google Authenticator.

Next-Generation Firewall (NGFW): While a router includes a built-in firewall, it might not be sufficient. Traditional firewalls lack essential security features like intrusion prevention systems (IPS), malware protection, content filtering, SSL/SSH interception, quality of service (QoS) management, and virtual private networks (VPNs). A next-generation firewall (NGFW) serves as an integrated network platform, combining a traditional firewall with these security functionalities. An NGFW retains all the capabilities of a traditional firewall while excelling at detecting and safeguarding against cyberattacks.

c. Privacy concerns and ethical considerations in collecting and processing personal data within smart homes.

Smart homes generate a vast volume of data, posing both an opportunity and a challenge. The effective transmission, storage, analysis, and application of this data in real-time or offline have significant implications for society's economy, health, and safety. Extracting valuable insights from this data can lead to tangible benefits, such as manufacturers using IoT data to create equipment maintenance plans and promptly replace faulty devices, showcasing the potential of data analytics to summarize smart home occupants' behaviour patterns and improve daily life's convenience and efficiency [77]. However, this also leads to concerns that this data could be potentially misused either by corporations or hackers who could sell this on to interested parties.

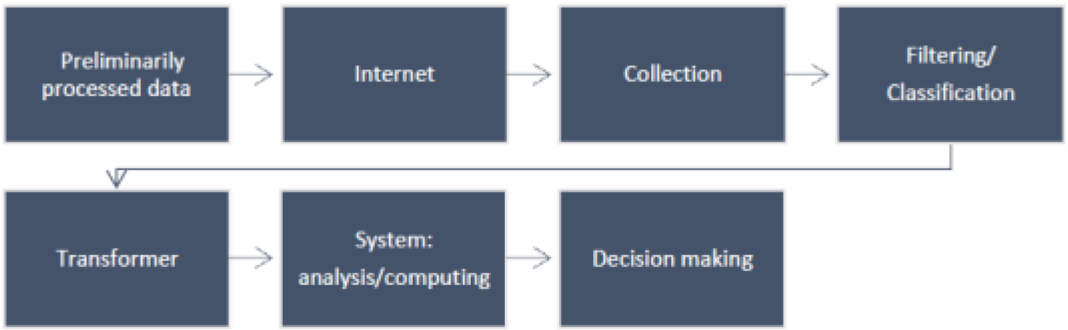


Figure 19 IOT based big data analysis process (Source [77])

Corporations by collecting and analysing this data can target user susceptibilities to ensure they are able to profit from it. Secondly companies which are more adept at managing data have an unfair advantage over others who do not. To secure ongoing consumer usage of their products, certain smart home enterprises intentionally develop elaborate IoT ecosystems that solely cater to their product range. This compels consumers to opt for the company's offerings when they seek to integrate new smart home devices and may involve intricate contractual arrangements that hinder users from transitioning to alternative IoT systems.

2.6. Market Analysis and Consumer Perspectives:

Smart home adoption isn't yet commonplace due to cost, complexity, and a lack of awareness among the public. To boost market demand, it's essential to conduct usability studies and implement targeted information strategies, in addition to ongoing innovation efforts. Ensuring smart homes become a standard choice necessitates straightforward and efficient designs. Challenges like device interoperability, the complexity of setting up smart home networks, and the absence of unified device management interfaces must be addressed. Major industry players should work together to establish technology standards, simplifying the array of devices available for consumers. Everyday homeowners seek simplicity and convenience in enhancing their homes for efficiency and enjoyment, without grappling with technical details. Recent developments like software-defined smart homes hold promise in alleviating flexibility and interoperability issues [69]. Mashal et al [75] suggest that manufacturers connect various smart home devices to create comprehensive solutions. This approach enhances compatibility and reduces technical issues associated with different brands. Furthermore, they recommend creating personalized smart home applications and services to cater to specific customer clusters, like the elderly or those with special needs, aligning with their unique needs and preferences.

Shin et al [76] note that consumers already possess numerous home appliances, which reduces their motivation to acquire new smart home products unless these products offer distinctive value. Therefore, operators must go beyond basic internet connectivity to create additional value. Their findings emphasize that the key factors influencing purchasing decisions include compatibility, perceived ease of use, and perceived usefulness. Their research reveals that older consumers are more inclined to embrace smart homes compared to younger ones. The study concludes that a strategy targeting younger consumers is essential to boost market demand. This issue is closely linked to how smart homes fulfill promises of enhancing comfort, convenience, security, and leisure while managing energy effectively.

3. Project Methodology

The project methodology section outlines the systematic approach that will be utilised to investigate the current smart home systems available in the market and provide an optimized solution for an average family in a house, unit, and apartment based on their specific needs and preferences. The methodology has been chosen to ensure that a comprehensive and well implemented strategy is utilised to deliver the most practical and optimal solution for the needs of the user.

3.1. Research Design:

a. Conduct a comprehensive literature review to gather information on current smart home systems and products in the market.
b. Analyse industry reports and consumer reviews to gain insights into the latest advancements and popular smart home systems and products.

3.2. Data Collection:

a. Gather data on smart home systems using online research from USQ library, Google scholar, IEEE articles and other scholarly reputed publications and data bases.
b. Gather data on smart home systems and products from product catalogues, manufacturer websites and reputed technology publications.
c. Gather data on typical configurations of smart home systems for different property type including houses, units, and apartments.
d. Gather data on technology used and security vulnerabilities.
e. Gather data on the specific needs and preferences of an average family in a house, unit, or apartment through online research.

3.3. Data Analysis:

a. Analyse the data collected to identify common features, performance metrics, installation processes, security features, reliability factors and costs of different smart home systems and products.
b. Compare and evaluate the identified based on the identified characteristics.
c. Summarize the findings in a detailed comparison matrix that would help in the final decision-making process to provide an optimized solution.

3.4. Recommendations for an optimized smart home solution:

a. Utilise the findings to recommend an optimized smart home solution for a house, unit, or apartment based on user needs and preferences.
b. Provide justification for the recommended solutions by highlighting the key features, performance, installation considerations and reliability of the utilised products.

3.5. Installation Instructions:

a. Develop detailed installation instructions for the installation of the recommended smart home products, considering the specific installation requirements, processes, and wiring rules.
b. Provide detailed operation instructions for each product category including smart speakers, lighting systems, thermostats, security systems and other devices which constitute the smart home system.

3.6. Conclusion and Reporting

a. Summarize the key findings, recommendations, and installation instructions within the final report.
b. Present the report in a clear and organized manner with the appropriate figures, tables, and charts.
c. Conclude the report with an emphasis on the significance of smart homes, the benefits as well as limitations of the optimized solution and the necessity of a choice based on the needs of the client.

4. Results and Evaluations

4.1. Smart Home Platform

With a multitude of options flooding the market, users will often find themselves overwhelmed by the sheer diversity and features offered by various platforms. This selection process can be particularly perplexing, given the wide range of devices, ecosystems, and compatibility factors to consider. It would be prudent to align with the established market leaders, such as Samsung, Apple, Google, and Amazon as they serve as prominent players in the industry and endorse Matter, an emerging smart home standard that facilitates seamless collaboration between devices from various brands. These companies maintain an extensive and diverse selection of compatible devices and accessories, often sourced from third-party manufacturers. Their offerings include user-friendly and convenient applications, as well as voice assistants, which greatly simplify the management of smart home devices.

It is important to note that choosing the right platform needs to be an informed decision as it is a long-term commitment that the user will be using on an everyday basis.

A few key points that may be considered to help in making these decisions are [51]:

- User’s current smartphone -The more gadgets that the user has in a specific group, like smartwatches, tablets, laptops, and things for music or watching videos, the better that group works. If the family uses different types of smartphones, then there will be a requirement to pick a system that works with all the gadgets in the home.
- Devices the user already owns-If the user already has a smart speaker or platform from any of the main players them that platform would form a good foundation to build the smart home on. Similarly, if the user already has some smart lights, a smart lock, or maybe a smart security system, it would be worthwhile to check the compatibility of these devices before picking the platform. However as listed in the previous tables many smart devices work across multiple ecosystems.
- Voice assistant preference-The three main voice assistants are Amazon’s Alexa, Apple’s Siri, and Google Assistant, each of which has a distinct character. The user's preference is the deciding factor in platform selection. Samsung SmartThings offers compatibility with both Alexa and Google Assistant.
- Features required by the user-Defining the desired functions for the user's smart home will guide the choice of the most suitable platform. This is due to the performance characteristics which each platform may be superior at.

  A few examples would be:

  Within Apple Home, the HomeKit Secure Video feature ensures the safe use of connected cameras by processing data locally on an Apple TV or HomePod before securely storing it in your iCloud account.

Samsung's SmartThings Energy plays a role as an energy management system, overseeing the monitoring of home energy consumption via compatible devices, primarily Samsung appliances. Furthermore, it offers proactive suggestions for saving energy.

Amazon's Alexa Hunches has a feature that utilizes Artificial intelligence. It can analyse the user's daily patterns and propose beneficial actions, like reminders to complete certain actions before retiring for the night.

Google Home includes features for presence sensing. It can automatically adapt the user's home settings based on whether it detects occupancy.

In conclusion, the selection of a smart home platform hinges largely on the user's preferences and specific needs

4.2. Configurations for a home or unit or apartment

Wired and Wireless: Choosing between wired and wireless smart home devices is influenced by variables like cost, ease of use, and installation preferences, all aimed at enhancing the overall convenience and user-friendliness of a smart home. Crafting an ideal smart home configuration often entails a blend of wired and wireless components to maximize their unique advantages. Ultimately, the decision-making process revolves around assessing factors such as affordability, user-friendliness, and preferred installation methods.

In a research study conducted [40]using "wired" (KNX) or "wireless" (EnOcean) systems the authors made a comparison using:

"A one-room studio apartment (450 sq. ft.) with a total of 33 or 42 products (basic or full equipment), a two-bedroom apartment (900 sq. ft.) and a total of 70 or 89 products, a single-family house (2300 sq. ft.) and a total of 162 or 186 products"

Some of their findings were that:

- the wired home required 30% more initial costs when compared to the wireless option.
- the installation costs of the wireless version were a third of the cost of the wired option.
- wireless options scored higher in terms of flexibility and environment.
- The radian exposure levels were significantly lower (700 times lesser) when compared to WLAN and Bluetooth as well as 1.6 million times lesser than a smartphone.

According to [37] a comparison of various optimization algorithms with multiple Home Energy Management constraints was made to achieve the minimum electricity cost and user comfort (with and without Renewable Energy Sources).The wireless communication protocols (Zig-Bee & Wi-Fi) are preferred mostly because of their reliability and low cost of use in Home Area Networks on both wired and wireless networks. Zigbee is the most appropriate technology used for data transmission between individual appliances and smart meters. Wi-Fi is a suitable technology for controlling and monitoring appliances because of its high data rate.

Wired smart home devices can be categorized into two main types: Ethernet and hardwired connections. Ethernet involves connecting devices to the home network via an Ethernet cable that plugs into the router. In contrast, some smart home hubs utilize direct connections to mitigate any potential problems arising from weak Wi-Fi signals. Other wired devices are hardwired into the home. For instance, the Nest Protect smoke and carbon monoxide detector wires directly into the ceiling versus using a battery [38].

Some of the pros and cons of wired networks are.

Smart devices are powered all the time and there is no requirement to change or recharge batteries. Having a hardwired ethernet connection implies there is minimal dropouts due to Wi-Fi fluctuations as well as improved security [39].

The installation of wired automation systems can be challenging, requiring the connection of sensors through low-voltage wires concealed within walls, which necessitates drilling holes. Removing wired automation system equipment can also be cumbersome as it's not possible to detach the wires [38].

Some of the pros and cons with wireless systems are as below:

Wireless smart home devices bring flexibility regarding their positioning within the Wi-Fi coverage area, enabling their adaptability to different home configurations. They also provide present a wider array of device choices as well as easy setup options [38].

Blind spots are common, meaning the wireless signal might not reach every corner of the house. When metal sheeting is used it can obstruct wireless reception, especially when combined with materials like plasterboard, insulation, or underfloor heating [42].

Home, unit, or apartment configurations: Despite a thorough online review of articles there was no clear delineation between smart home configurations between the three dwellings. The setup and architecture of smart devices and automations was similar across all three. The only items of note from the material researched was the increased use of wireless options in an apartment which tended to favour renters. This was to enable them to make these devices mobile in case of moving homes.

The other was to ensure integration with property management software, which automates tasks and synchronizes resident data seamlessly. It would need to facilitate the job functions of property managers efficiently while ensuring reliability and issue identification. The platform should enable staff to manage thermostat and lighting schedules for vacant units and common areas from a centralized dashboard. It should provide timely alerts to staff regarding battery or connectivity issues that could impact device monitoring. There should be options for removal of residents from the system to ensure a hassle-free transition when moving in or out [42].

4.3. Optimised Smart Home Solution

To provide an optimised solution as an example case, we could assume that the user based on his preferences and needs has chosen to utilise the Apple HomeKit platform as he is an Apple enthusiast and currently owns an iPhone, iWatch, iPad and Apple TV.

The requirements for a smart home can be exhaustive based on user needs, however, to demonstrate a solution some typical requirements would be:

- Open Garage automatically when the car arrives.
- Operate blinds through voice control.
- Operate lights through voice control.

This first place to start off would be to check for compatible devices on the Apple HomeKit site(https://www.apple.com/home-app/accessories).

The table below shows a comparison of the three Apple HomeKit compatible products required to fulfill the three requirements above.

Garage Door	Manufacturer	Comments	Smart control Devices required	Cost	Product	Price	Website	Review rating stars
	Entrematic		Entrematic Hub+Tilt sensor				Simulator – Entrematic (entrematic-smartconnect.com)	
	ismartgate		1 x ismartgate LITE + 1 x Sensor TWS	$199.00			Best Smart Garage Door Opener | Remote Controls for Garage Door -	5 /1 reviewer
	Meross		Smart Wi-Fi Roller Shutter Timer MSG100	$ 85.00			Meross Smart Garage Door Opener Remote Control - MSG100	4.6/3514 reviews
	Remootio		Remootio 3 + Sensor + Power Adapter Multipack	$186.00			https://www.remootio.com/	4.8/1272 reviews
Blinds	Eve MotionBlinds	not available						
	IKEA		DIRIGERA hub	$ 99.00	Block-out roller blind, smart wireless/battery-operated grey, 140x195 cm each	$ 299.00	Smart blinds - IKEA	4.0/265reviews
	Kirsch	unable to get pricing with appointment					Automated Window Blinds & Shades | Kirsch	
	Hunter douglas	unable to get pricing online	PowerView Gateway				Use Legacy PowerView Home Automation | Hunter Douglas Help & Support	
	mobilus c-mr bt	unable to get pricing						
	Automate		Automate Pulse 2 Hub	$269.00	LOW VOLTAGE MOTORS Automate DC Zero Series		Apple HomeKit - Automate Australia (automateshades.com) , https://www.automateshades.com/au/	no reviews found
Lights	IKEA		DIRIGERA hub	$160.00	TRÅDFRI LED bulb B22 1055 lumen, smart wireless dimmable/white spectrum globe each	$ 20.00	https://www.ikea.com/au/en/customer-service/product-support/app-gateway/ , https://www.ikea.com/au/en/p/tradfri-led-bulb-b22-1055-lumen-smart-wireless-dimmable-white-spectrum-	no reviews found
	PHILIPS		Hue Bridge	$100.00	A60 - E27 / ES smart bulb - 1100 lumens , each	$ 35.00	https://www.philips-hue.com/en-au/p/hue-bridge/8719514342569#faq	4.4/38 reviews

The three devices chosen: Garage –Meross, Blinds-IKEA, Lights-IKEA

were based on consumer reviews, cost as well as functionality. Using the IKEA for blinds and lights makes it more cost effective as only one hub is required, and the lights are reasonably priced. With the Meross, it has an inbuilt Hub so there is no additional cost involved. The device is quite popular as well based on consumer reviews.

5. Conclusion

The benefits of smart homes are manifold, presenting users with a convenient and efficient means of managing their living spaces. While the vast array of options in the market can be overwhelming, aligning with established industry leaders like Samsung, Apple, Google, and Amazon, who endorse the emerging Matter standard for seamless device collaboration, can simplify the decision-making process. These companies offer a wide range of compatible devices, user-friendly applications, and voice assistants that significantly enhance the smart home experience.

Choosing the right platform requires an informed decision, considering various factors, including the user's existing devices, compatibility, voice assistant preferences, and desired features. Furthermore, the choice between wired and wireless smart home devices depends on considerations like affordability, ease of installation, and individual preferences. A blend of both wired and wireless components can optimize benefits, with wireless options often offering flexibility and cost-effectiveness in installation. On the other hand, wired devices provide uninterrupted power and enhanced security but may entail more complex installation and removal processes.

Regardless of whether one resides in a home, unit, or apartment, smart home configurations can be tailored to suit individual needs. In essence, smart homes offer a multitude of advantages, and making the right choices for your specific needs is a long-term commitment that significantly enhances daily living.

6. Risk Assessment

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Smart Home System, Design and Optimisation	Assessment Date:	26/05/2023
Workplace (Division/Faculty/Section):	ENG4111/BENG/Electrical and Electronics	Review Date:(5 Years Max)	26/06/2024
Context			
Description:			
What is the task/event/purchase/project/procedure?	Investigate Smart homes systems		
Why is it being conducted?	As a part of Dissertation for ENG 4111/4112		
Where is it being conducted?	At Home -Online task		
Course code (if applicable)	ENG 4111/4112	Chemical name (if applicable)	
What other nominal conditions?			
Personnel involved	Jude Asirvatham (student at USQ)		
[No Title] nent	Online task using a computer		
Environment	At Home -Online task		
Other	N/A		
Briefly explain the procedure/process	Research task		
Assessment Team - who is conducting the assessment?			
Assessor(s)	Paul Wen		
Others consulted:	John Leis		

Eg 1. Enter Consequence

Eg 2. Enter Probability

Probability	Consequence				
	Insignificant No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Eg 3. Find Action

Recommended Action Guide
E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Working in a seated posi [No Title]	Muscle strain	Moderate	Ergonomic Chair ,Proper seating posture	Unlikely	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Working long hours	Stress	Moderate	Ensure appropriate breaks	Unlikely	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
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			Click here to enter a date.
			Click here to enter a date.

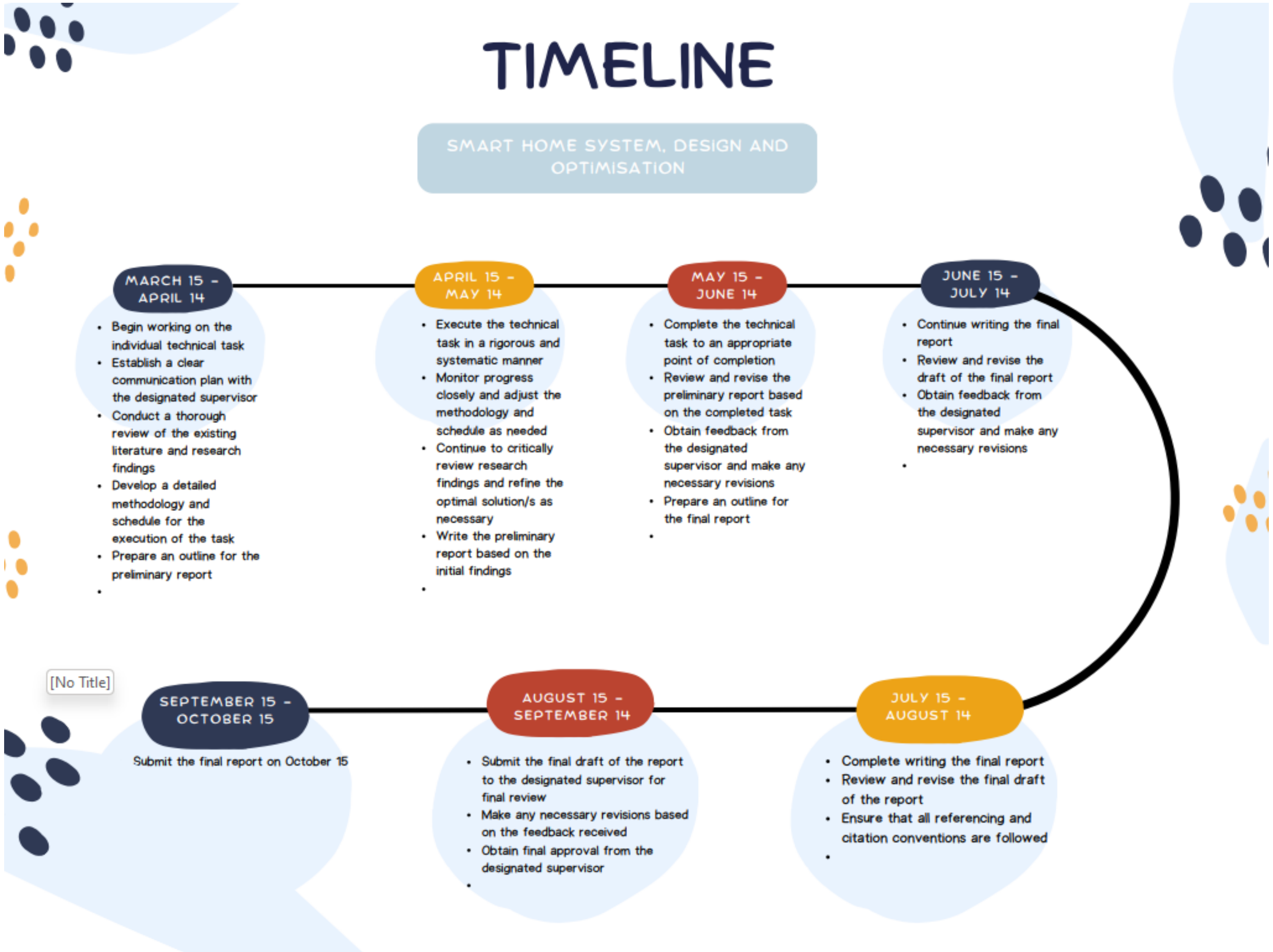
[No Title]

Step 6 - Approval			
Drafter's name:	Jude Asirvatham	Draft date:	26/05/2023
Drafter's comments:	As this is a desktop exercise the risk level is very low with controls in place		
Approver's name:		Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.

7. Consequences and Ethics

In line with University of Southern Queensland's human ethics clearance policy, there is no requirement to obtain clearance for this project as it falls under the exempted category of research, utilizing statistical data, or utilizing non-identifiable archival data.

8. Timeline


TIMELINE
SMART HOME SYSTEM, DESIGN AND OPTIMISATION
MARCH 15 - APRIL 14
• Begin working on the individual technical task
• Establish a clear communication plan with the designated supervisor
• Conduct a thorough review of the existing literature and research findings
• Develop a detailed methodology and schedule for the execution of the task
• Prepare an outline for the preliminary report
APRIL 15 - MAY 14
• Execute the technical task in a rigorous and systematic manner
• Monitor progress closely and adjust the methodology and schedule as needed
• Continue to critically review research findings and refine the optimal solution/s as necessary
• Write the preliminary report based on the initial findings
MAY 15 - JUNE 14
• Complete the technical task to an appropriate point of completion
• Review and revise the preliminary report based on the completed task
• Obtain feedback from the designated supervisor and make any necessary revisions
• Prepare an outline for the final report
JUNE 15 - JULY 14
• Continue writing the final report
• Review and revise the draft of the final report
• Obtain feedback from the designated supervisor and make any necessary revisions
[No Title]
SEPTEMBER 15 - OCTOBER 15
Submit the final report on October 15
AUGUST 15 - SEPTEMBER 14
• Submit the final draft of the report to the designated supervisor for final review
• Make any necessary revisions based on the feedback received
• Obtain final approval from the designated supervisor
JULY 15 - AUGUST 14
• Complete writing the final report
• Review and revise the final draft of the report
• Ensure that all referencing and citation conventions are followed

References

1. RSE Home Automation (no date) 'Make your home a smart home.' Available at: https://rsehomeautomation.com.au/?gclid=EAIaIQobChMIgoaNqYCJ_wIVEbuWCh2nYwEeEAAYASAAEgI--fD_BwE (Accessed: 27 May 2023).
2. Google (no date) 'A home that knows how to help.' Available at: https://home.google.com/intl/en_au/welcome/ (Accessed: 27 May 2023).
3. Control4 Smart Homes (no date) 'Live life brilliantly.' Available at: https://www.control4.com/ (Accessed: 27 May 2023).
4. Legrand (no date) 'Smart home.' Available at: https://www.legrand.com.au/node/264 (Accessed: 27 May 2023).
5. Clipsal by Schneider Electric (no date) 'Create your perfect smart home.' Available at: https://www.clipsal.com/smarthome (Accessed: 27 May 2023).
6. Philips (no date) 'Philips dynalite overview page.' Available at: https://www.lighting.philips.com/main/products/lighting-controls/dynalite (Accessed: 27 May 2023).
7. PIXIE PLUS (2023) 'Home Automation Systems Australia - smart home systems Australia.' Available at: https://pixieplus.com.au/ (Accessed: 27 May 2023).
8. Apple (Australia) (no date) 'Home app - accessories.' Available at: https://www.apple.com/au/home-app/accessories/ (Accessed: 27 May 2023).
9. LG Australia (no date) 'LG THINQ: The new way of living.' Available at: https://www.lg.com/au/lg-thinq (Accessed: 27 May 2023).
10. Amazon.com (no date) 'Echo smart speakers & displays: Amazon devices.' Available at: https://www.amazon.com/smart-home-devices/b?node=9818047011 (Accessed: 27 May 2023).
11. Amazon.com (no date) 'Echo smart speakers & displays: Amazon devices.' Available at: https://www.amazon.com/smart-home-devices/b?node=9818047011 (Accessed: 27 May 2023).
12. Samsung Electronics America (no date) 'Samsung SmartThings hub SmartThings - F-Hub-US-2.' Available at: https://www.samsung.com/us/smart-home/smartthings/hubs/samsung-smartthings-hub-f-hub-us-2/ (Accessed: 27 May 2023).
13. ABB (no date) 'Building solutions: Commercial, residential, industrial.' Available at: https://new.abb.com/buildings (Accessed: 27 May 2023).
14. Savant (no date) 'Savant Home Page.' Available at: https://www.savant.com/ (Accessed: 27 May 2023).
15. Canary (no date) Available at: https://canary.is/global (Accessed: 27 May 2023).
16. August Home (no date) '$100 off Pro Keypad Bundle.' Available at: https://august.com/ (Accessed: 27 May 2023).
17. HomeSeer Smart Home Systems (2023) 'Smart Home Systems for every need & budget.' Available at: https://homeseer.com/ (Accessed: 27 May 2023).
18. Siemens (no date) 'Home Automation with logo!' Available at: https://www.siemens.com/global/en/products/automation/systems/industrial/plc/logo/home-automation.html (Accessed: 27 May 2023).

19. WIR elektronik (no date) 'Smarthome der Wir elektronik – automationslösungen für ihr Zuhause.' Available at: https://wir-elektronik.de/Smarthome/ (Accessed: 27 May 2023).
20. Alshaikhli, M. et al. (2022) 'Evolution of internet of things from Blockchain to Iota: A Survey', IEEE Access, 10, pp. 844–866. doi:10.1109/access.2021.3138353.
21. Koskela, T. and Väänänen-Vainio-Mattila, K. (2004) 'Evolution towards smart home environments: Empirical evaluation of three user interfaces', Personal and Ubiquitous Computing, 8(3–4). doi:10.1007/s00779-004-0283-x.
22. Chetty, M., Sung, J.-Y. and Grinter, R.E. (no date) 'How smart homes learn: The evolution of the networked home and household', UbiComp 2007: Ubiquitous Computing, pp. 127–144. doi:10.1007/978-3-540-74853-3_8.
23. Domb, M. (2019) 'Smart Home Systems based on internet of things', IntechOpen. Available at: https://www.intechopen.com/chapters/65877 (Accessed: 29 August 2023).
24. OO, Z.L., LAI, T.W. and MOE, A. (2022) 'IOT based home automation system using a REST API architecture', European Journal of Technic [Preprint]. doi:10.36222/ejt.1018131.
25. Mocrii, D., Chen, Y. and Musilek, P. (2018) 'IOT-based Smart Homes: A Review of System Architecture, software, communications, Privacy and Security', Internet of Things, 1–2, pp. 81–98. doi:10.1016/j.iot.2018.08.009.
26. Li, M. et al. (2018) 'Smart home: Architecture, technologies and systems', Procedia Computer Science, 131, pp. 393–400. doi:10.1016/j.procs.2018.04.219.
27. Wang, L., Peng, D. and Zhang, T. (2015) 'Design of smart home system based on WIFI Smart Plug', International Journal of Smart Home, 9(6), pp. 173–182. doi:10.14257/ijsh.2015.9.6.19.
28. Orfanos VA, Kaminaris SD, Papageorgas P, Piromalis D, Kandris D. 'A Comprehensive Review of IoT Networking Technologies for Smart Home Automation Applications', Journal of Sensor and Actuator Networks. 2023; 12(2):30. https://doi.org/10.3390/jsan12020030.
29. Yasar, K. and Shea, S. (2023) 'What is a smart home? everything you need to know: Definition from TechTarget', IoT Agenda. Available at: https://www.techtarget.com/iotagenda/definition/smart-home-or-building (Accessed: 27 August 2023).
30. 'I've been working with computers for ages' (2021) 'What is a smart home hub (and do you need one)?', PCMag Australia. Available at: https://au.pcmag.com/home-automation-hubs/24370/what-is-a-smart-home-hub-and-do-you-need-one (Accessed: 30 August 2023).
31. Dellinger, A. (no date) 'Smart Hub, bridge or gateway: Which is right for your home', Bankrate. Available at: https://www.bankrate.com/homeownership/difference-between-smart-hub-bridge-gateway-for-smart-home/ (Accessed: 30 August 2023).
32. Phan L-A, Kim T. 'Breaking Down the Compatibility Problem in Smart Homes: A Dynamically Updatable Gateway Platform', Sensors. 2020; 20(10):2783. https://doi.org/10.3390/s20102783.

33. 'Smart Homes explained' (2021) Nanotechnology. Available at: https://www.nanowerk.com/smart/smart-homes-explained.php (Accessed: 30 August 2023).
34. 'Smart Home Network topology' (no date) Thread in Homes. Available at: https://www.threadgroup.org/BUILT-FOR-IOT/Smart-Home (Accessed: 07 September 2023).
35. 'IOT' (2023) CSA. Available at: https://csa-iot.org/ (Accessed: 07 September 2023).
36. Tuohy, J.P. (2021) 'What matters about matter, the new smart home standard', The Verge. Available at: https://www.theverge.com/22832127/matter-smart-home-products-thread-wifi-explainer (Accessed: 07 September 2023).
37. Ramalingam, S.P. and Shanmugam, P.K. (2022) 'A comprehensive review on wired and wireless communication technologies and challenges in smart residential buildings', Recent Advances in Computer Science and Communications, 15(9), pp. 1140–1167. doi:10.2174/2666255814666210119142742.
38. Crystal Crowder (2023) 'Wired or Wireless Smart Home Devices: Which is best?', Make Tech Easier. Available at: https://www.maketecheasier.com/smart-home/wired-or-wireless-smart-home-devices/ (Accessed: 09 September 2023).
39. Peach, H. (2021) 'Wired or wireless - which system is right for your smart home?' Available at: https://www.atamate.com/atamate-news/wired-or-wireless-which-system-is-right-for-your-smart-home (Accessed: 09 September 2023).
40. 'There is no getting around the smart home wired or ... - Enocean Alliance' (no date) Available at: https://www.enocean-alliance.org/wp-content/uploads/2021/08/Wired-vs-Wireless-Smart-Home.pdf (Accessed: 09 September 2023).
41. 'Wired vs wireless automation: Which one's best for you?' (2020) Avenue Sound. Available at: https://avenuesound.in/wired-vs-wireless-home-automation/ (Accessed: 09 September 2023).
42. Stahlman, J. (2022) 'Installing Smart Home Technology For Apartments: ZegoTM', Zego. Available at: https://www.gozego.com/articles/smart-home-technology-apartments/#:~:text=But%20now%2C%20more%20and%20more,to%20consider%20adding%20these%20conveniences. (Accessed: 09 September 2023).
43. Reig, S. et al. (2021) 'Smart Home Agents and devices of today and tomorrow: Surveying use and desires', Proceedings of the 9th International Conference on Human-Agent Interaction [Preprint]. doi:10.1145/3472307.3484664.
44. Fischer, B. (2023) 'The 7 best smart speakers - summer 2023: Reviews', RTINGS.com. Available at: https://www.rtings.com/speaker/reviews/best/smart (Accessed: 30 August 2023).
45. Admin (2023) 'Smart hubs vs. smart speakers - how to Control Your Home Automation System', DIY Smart Home Solutions. Available at: https://www.diysmarthomesolutions.com/smart-hubs-smart-speakers-home-automation/ (Accessed: 31 August 2023).
46. Admin (2021) 'What is smart lighting technology it's types and how does it work?', SMLease Design. Available at: https://www.smlease.com/entries/automation/what-is-smart-lighting-technology/ (Accessed: 31 August 2023).

47. Wodecki, B. (2023) 'Powered Smart Lights unveiled at CES 2023', AI. Available at: https://aibusiness.com/verticals/ai-powered-smart-lights-unveiled-at-ces-2023 (Accessed: 31 August 2023).
48. 'The best smart thermostats for 2023' (2023) PCMag Australia. Available at: https://au.pcmag.com/thermostats/50336/the-best-smart-thermostats (Accessed: 01 September 2023).
49. Blank, E. (2022) 'What is a C wire? and why’s it so important for your smart thermostat?', The Smart Cave. Available at: https://thesmartcave.com/thermostat-c-wire-common/ (Accessed: 01 September 2023).
50. 'The best smart home security systems for 2023' (2023a) PCMag Australia. Available at: https://au.pcmag.com/home-security/41818/the-best-smart-home-security-systems (Accessed: 02 September 2023).
51. Tuohy, J.P. (2023a) 'How to pick a smart home platform', The Verge. Available at: https://www.theverge.com/23751295/smart-home-platform-google-amazon-apple-samsung (Accessed: 07 September 2023).
52. 'The Best Home Automation Systems of 2023' (no date) ZDNET. Available at: https://www.zdnet.com/home-and-office/smart-home/best-home-automation-system/ (Accessed: 07 September 2023).
53. Ali, Z., Muhammad, G. and Alhamid, M.F. (2017) ‘An automatic health monitoring system for patients suffering from voice complications in Smart Cities’, IEEE Access, 5, pp. 3900–3908. doi:10.1109/access.2017.2680467.
54. Berrezueta-Guzman, J. et al. (2021) ‘Assessment of a robotic assistant for supporting homework activities of children with ADHD’, IEEE Access, 9, pp. 93450–93465. doi:10.1109/access.2021.3093233.
55. Yuanbing, W., Wanrong, L. and Bin, L. (2021) ‘An improved authentication protocol for Smart Healthcare System Using Wireless Medical Sensor Network’, IEEE Access, 9, pp. 105101–105117. doi:10.1109/access.2021.3099299.
56. Luperto, M. et al. (2023) ‘Seeking at-home long-term autonomy of assistive mobile robots through the integration with an IOT-based monitoring system’, Robotics and Autonomous Systems, 161, p. 104346. doi:10.1016/j.robot.2022.104346.
57. Obaid, A.J. (2021) ‘Assessment of Smart Home assistants as an IOT’, International Journal of Computations, Information and Manufacturing (IJCIM), 1(1). doi:10.54489/ijcim.v1i1.34.
58. Tejani, D., Al-Kuwari, A.M. and Potdar, V. (2011) ‘Energy conservation in a smart home’, 5th IEEE International Conference on Digital Ecosystems and Technologies (IEEE DEST 2011) [Preprint]. doi:10.1109/dest.2011.5936632.
59. Kazmi, S. et al. (2019) ‘Towards optimization of metaheuristic algorithms for IOT enabled smart homes targeting balanced demand and supply of Energy’, IEEE Access, 7, pp. 24267–24281. doi:10.1109/access.2017.2763624.
60. Andrade, S.H. et al. (2021) ‘A smart home architecture for smart energy consumption in a residence with multiple users’, IEEE Access, 9, pp. 16807–16824. doi:10.1109/access.2021.3051937.

61. Iqbal, M.J. et al. (2021) 'Smart Home Automation Using Intelligent Electricity Dispatch', IEEE Access, 9, pp. 118077–118086. doi:10.1109/access.2021.3106541.
62. Khajeh, H., Laaksonen, H. and Simões, M.G. (2023) 'A fuzzy logic control of a smart home with energy storage providing active and reactive power flexibility services', Electric Power Systems Research, 216, p. 109067. doi:10.1016/j.epsr.2022.109067.
63. Shafqat, W., Lee, K.-T. and Kim, D.-H. (2022) 'A comprehensive predictive-learning framework for optimal scheduling and control of smart home appliances based on user and appliance classification', Sensors, 23(1), p. 127. doi:10.3390/s23010127.
64. 'Towards energy smart homes' (no date) SpringerLink. Available at: https://link.springer.com/book/10.1007/978-3-030-76477-7 (Accessed: 04 September 2023).
65. 'Connected Home' (no date) YourHome. Available at: https://www.yourhome.gov.au/energy/connected-home (Accessed: 04 September 2023).
66. Jose, A.C., Malekian, R. and Ye, N. (2016) 'Improving home automation security; integrating device fingerprinting into Smart Home', IEEE Access, 4, pp. 5776–5787. doi:10.1109/access.2016.2606478.
67. Shukla, S., Gupta, V., Pandey, A. K., Sharma, R., Pal, Y., Gupta, B. K., & Agrawal, A. (2023). 'Managing IoT–Cloud-based Security.' Computational Intelligent Security in Wireless Communications, 63.
68. Heiding, F. et al. (2023) 'Penetration testing of connected households', Computers & Security, 126, p. 103067. doi:10.1016/j.cose.2022.103067.
69. Dragos Mocrii, Yuxiang Chen, Petr Musilek, 'IoT-based smart homes: A review of system architecture, software, communications, privacy and security', Internet of Things, Volumes 1–2,2018, Pages 81-98, ISSN 2542-6605, https://doi.org/10.1016/j.iot.2018.08.009.
70. Anderson, M. (2023) '7 actionable tips to secure your smart home and IOT devices', IEEE Computer Society. Available at: https://www.computer.org/publications/tech-news/trends/7-actionable-tips-to-secure-your-smart-home-and-iot-devices (Accessed: 04 September 2023).
71. Ferreira, L., Oliveira, T. and Neves, C. (2023) 'Consumer's intention to use and recommend Smart Home Technologies: The role of environmental awareness', Energy, 263, p. 125814. doi:10.1016/j.energy.2022.125814.
72. Eo E, Yang W. 'Evaluating Smart Home Services and Items: A Living Lab User Experience Study.' Buildings. 2023; 13(1):263. https://doi.org/10.3390/buildings13010263
73. Philip, S.J., Luu, T. (Jack) and Carte, T. (2023) 'There's no place like home: Understanding users' intentions toward securing internet-of-things (IOT) smart home networks', Computers in Human Behavior, 139, p. 107551. doi:10.1016/j.chb.2022.107551.
74. Becks, E. et al. (2023) 'Complexity of Smart Home Setups: A qualitative user study on Smart Home Assistance and implications on technical requirements', Technologies, 11(1), p. 9. doi:10.3390/technologies11010009.
75. Mashal, Ibrahim; Shuhaiber, Ahmed; and Al-Khatib, Ayman Wael (2023) 'User acceptance and adoption of smart homes: A decade long systematic literature review'. All Works. 5814. https://zuscholars.zu.ac.ae/works/5814

76. Jungwoo Shin, Yuri Park, Daeho Lee, 'Who will be smart home users? An analysis of adoption and diffusion of smart homes', Technological Forecasting and Social Change, Volume 134,2018, Pages 246-253, ISSN 0040-1625, https://doi.org/10.1016/j.techfore.2018.06.029.
77. Chang, V., Wang, Z., Xu, Q., Golightly, L., Liu, B. and Arami, M. 'Smart Home based on Internet of Things and Ethical Issues'. DOI: 10.5220/0010178100570064.
78. Khoa, T. A., Nhu, L. M. B., Son, H. H., Trong, N. M., Phuc, C. H., Phuong, N. T. H., ... & Duc, D. N. M. (2020). 'Designing efficient smart home management with IoT smart lighting: a case study.' Wireless communications and mobile computing, 2020, 1-18.
79. Simeoni, E. et al. (2021) 'A secure and Scalable Smart Home Gateway to bridge technology fragmentation', Sensors, 21(11), p. 3587. doi:10.3390/s21113587.
80. Pal, D. et al. (2020) 'Analyzing the adoption and diffusion of voice-enabled smart-home systems: Empirical evidence from Thailand', Universal Access in the Information Society, 20(4), pp. 797–815. doi:10.1007/s10209-020-00754-3.