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Empowering residential building occupants: Highlighting the drivers and barriers to the acceptance and adoption of Smart Energy Technologies

PhD dissertation

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Executive Summary

Climate change is considered one of the most alarming issues of our time. Burning fossil fuels to generate energy, for instance, is a major contributor to this problem. Buildings including residential, commercial, and industrial are large energy consumers and significantly contribute to greenhouse gas emissions. Although residential building units consume less energy than commercial and industrial buildings, the combined energy consumption from residential buildings can still be substantial. Because of that, this dissertation focuses on residential buildings.

Residential building occupants can play a vital role in mitigating climate change through the adoption of smart energy technologies. Smart Energy Technologies (SETs) such as smart HVAC systems, solar PV, smart lighting, smart thermostat, smart home appliances, Home Energy Management system (HEMs), Building Automation Systems (BAS), smart meters, electric vehicles (EVs) can help reduce energy consumption and improve energy efficiency in residential buildings. However, despite the proven effectiveness of SETs, studies indicate that the uptake of smart energy technologies in residential buildings remains low.

The successful integration of Smart Energy Technologies (SETs) in residential buildings depends on the acceptance of residents and communities. Consequently, this dissertation aims to explore the overall situation and patterns related to how residential building occupants in Denmark are adopting SETs into their everyday lives. To fulfil this aim, this Ph.D. dissertation proposes three research questions.

Research question 1: What factors influence the acceptance and adoption of SET?

Research question 2: Are residential building occupants willing to adopt SETs?

Research question 3: Why do residential building occupants decide to adopt or reject SETs, and how do they make these choices?

To address the research questions, four papers were developed and included in the dissertation. Research question 1 consists of two journal articles 1: 1) *A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption* and 2) *Influential Factors to residential building occupants' Acceptance and Adoption of Smart Energy Technologies in Denmark.* Article 3 addressed research question 2 entitled 3) *Examining the path to Smart Energy Technology adoption in residential buildings.* While Article 4 answers research question 3 entitled 4) *Why Do Some Embrace and Others Resist? Understanding the Drivers and Barriers to the Adoption of Smart Energy Technologies in Residential buildings*

The dissertation employed both quantitative and qualitative methods known as an explanatory sequential mixed methods design to provide a deeper understanding and interpretation of the research topic. Explanatory sequential mixed methods design involves two phases: it begins with a quantitative study to collect numerical insights, followed by a qualitative study to explain the quantitative results. Moreover, this project is an interdisciplinary approach that integrates insights from energy engineering, business, and social science, resulting in a comprehensive understanding of SET acceptance and adoption relevant to a variety of stakeholders.

The first journal article (*A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption)* looked to answer Research Question 1 (What factors influence the acceptance and adoption of smart energy technologies?) by providing an overview and general understanding of the factors influencing technology acceptance. A literature review of 54 empirical studies on technology acceptance and adoption that have applied the Technology Acceptance Model (TAM), extended TAM, and UTAUT. In this study, the development of the TAM was presented to establish a strong theoretical foundation for the dissertation. Even though TAM is a widely known model with numerous advantages and adapted across different technological domains, evaluating its suitability for the research objectives and context is essential. Findings reveal the 10 most influential factors in technology acceptance and adoption: knowledge, awareness, policy, social influence, demographics, self-efficacy, trust, enjoyment, perceived risk, and compatibility.

The second journal article (*Influential Factors to residential building occupants' Acceptance and Adoption of Smart Energy Technologies in Denmark)* also looked to answer Research Question 1 **(**What factors influence the acceptance and adoption of smart energy technologies?). The successful acceptance and adoption of smart energy technologies depend on various factors. Therefore, this study aimed to identify the influential factors in technology acceptance and adoption of smart energy technologies in residential buildings. An online survey was conducted on more than 3,000 residential building occupants in Denmark. The Technology Acceptance Model (TAM) and other elements from other models (TAM2, Unified Theory of Acceptance and Use of Technology) were applied to predict the influential factors affecting the acceptance and adoption of Smart Energy Technologies (SETs). Findings show that TAM constructs such as Perceived Ease of Use (PEOU) and Attitudes have significant influence while Perceived Usefulness (PU) does not influence the residential building occupant's willingness to accept Smart Energy Technologies (SETs). Meanwhile, knowledge, awareness, policy (program and subsidy), social influence, and trust have significant effects on residential building occupants' intention to use Smart Energy Technologies.

The third journal article *(Examining the path to smart energy technology adoption in residential buildings)* looks into Question 2 (Are residential building occupants willing to adopt SETs?). The findings revealed a limited willingness to adopt smart energy technologies (SETs) among residential building occupants. The study also examined the SETs owned by residential building occupants and the reasons for the limited uptake of SETs to get a better understanding of the residential building occupants' needs and motivations when it comes to adopting SETs. Meanwhile, the association between knowledge and awareness of SETs, and the residential building occupants' willingness to adopt SETs, as well as the association between demographic factors (income and types of dwelling) and willingness to adopt SETs were examined.

The fourth journal article *(Why Do Some Embrace and Others Resist? Understanding the Drivers and Barriers to Adoption of Smart Energy Technologies)* provides an answer to Research Question 3 (*Why do residential building occupants decide to adopt or reject smart energy technologies, and how do they make these choices?*) by exploring the factors that influence residential building occupants' decisions to adopt or not to adopt SETs. The semi-structured interviews were participated by 21 residential building occupants who installed smart energy technologies at home. In this study, familiarity with SETs, sources of information about SETs, and the types of smart energy technologies installed in residential building occupants were identified. In addition, based on findings presented in journal article 2, the study examined how Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitudes, knowledge, awareness, policy, social influence, and trust influence the residential building occupants' acceptance and adoption of smart energy technologies (SETs). Finally, findings revealed both drivers and barriers to SETs' acceptance and adoption in residential buildings.

Danish Summary

Klimaforandringer anses for at være et af de mest alarmerende problemer i vor tid. Afbrænding af fossile ressourcer i forbindelse med energiproduktion er en stor bidragyder til dette problem. Bygninger, herunder boliger, industri- og erhvervsejendomme, er storforbrugere af energi og medvirker væsentligt til udledning af drivhusgasser. Selvom beboelsesejendomme forbruger mindre energi end industri- og erhvervsejendomme, kan det samlede energiforbrug fra disse stadig være betydeligt. Derfor fokuserer denne afhandling på beboelsesejendomme.

Beboere i beboelsesejendomme kan spille en afgørende rolle i indsatsen for at afbøde klimaforandringerne ved at anvende smarte energiteknologier. Smarte energiteknologier (SET) såsom intelligente HVAC-systemer, solceller, belysning, termostater og husholdningsapparater, samt Home Energy Management-systemer (HEM), bygningsautomatiksystemer (BAS), intelligente målere og elektriske køretøjer kan medvirke til reduktion af energiforbruget og forbedring af energieffektiviteten i beboelsesejendomme. Men på trods af den dokumenterede effektivitet, viser undersøgelser, at udbredelsen SET fortsat er lav i beboelsesejendomme.

En vellykket implementering af SET i beboelsesejendomme afhænger af beboernes og lokalsamfundenes accept. Derfor har denne afhandling til formål at udforske den overordnede situation og de mønstre der tegner sig for, hvordan beboere i danske beboelsesejendomme anvender SET i deres hverdag. For at opfylde dette mål stiller denne Ph.D.-afhandling tre forskningsspørgsmål.

Forskningsspørgsmål 1: Hvilke faktorer påvirker accepten og anvendelsen af SET?

Forskningsspørgsmål 2: Er beboerne i beboelsesejendomme villige til at anvende SET?

Forskningsspørgsmål 3: Hvorfor beslutter beboerne i beboelsesejendomme at anvende eller forkaste SET, og hvordan træffes disse valg?

For at besvare forskningsspørgsmålene blev der udarbejdet fire forskningsartikler, som er inkluderet i afhandlingen. Forskningsspørgsmål 1 adresseres i to artikler: *A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption,* og *Influential Factors to residential building occupants' Acceptance and Adoption of smart energy technologies in Denmark*. Den tredje forskningsartikel behandler forskningsspørgsmål 2 under titlen, *Examining the path to Smart Energy Technology adoption in residential buildings*, og den fjerde forskningsartikel besvarer forskningsspørgsmål 3 under titlen, *Why Do Some Embrace and Others Resist? Understanding the Drivers and Barriers to the Adoption of Smart Energy Technologies in Residential buildings.*

Til afhandlingen blev der anvendt såvel kvantitative som kvalitative metoder i form af et sekventielt forklarende mixed-methods design, for at skabe en dybere forståelse og fortolkning af forskningsemnet. Det sekventielt forklarende mixed methods-design består af to faser, hvoraf første fase er en kvantitativ undersøgelse, der har til formål generere numerisk indsigt, mens anden fase er en kvalitativ undersøgelse, hvis formål det er at forklare de kvantitative resultater. Projektet repræsenterer desuden en tværfaglig tilgang, som integrerer indsigter fra energiteknik, erhvervsliv og samfundsvidenskab, hvilket giver en holistisk forståelse af accept og anvendelse af SET, som har relevans for en række interessenter.

Den første forskningsartikel, *A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption*, besvarede forskningsspørgsmål 1 ved at etablere et overblik over og en generel forståelse af de faktorer, der påvirker accept af teknologi. Dette skete ved hjælp af en litteraturgennemgang af 54 empiriske studier om accept og brug af teknologi, under anvendelse af

Technology Acceptance Model (TAM), udvidet Technology Acceptance Model (TAM2) og Unified Theory of Acceptance and Use of Technology (UTAUT). Til undersøgelsen blev udviklingen af TAM præsenteret for at etablere et stærkt teoretisk fundament for afhandlingen. Selvom TAM er en velkendt model, der har mange fordele og er tilpasset på tværs af forskellige teknologiske domæner, er det vigtigt at evaluere dens egnethed i forhold til forskningens mål og kontekst. Resultaterne af undersøgelsen afslørede de 10 mest indflydelsesrige faktorer for accept og brug af teknologi: Viden, bevidsthed, politik, social indflydelse, demografi, mestringsforventning, tillid, nydelse, opfattet risiko og kompatibilitet.

Den anden forskningsartikel, *Influential Factors to residential building occupants' Acceptance and Adoption of smart energy technologies in Denmark*, adresserede ligeledes forskningsspørgsmål 1. Da vellykket accept og anvendelse af intelligente energiteknologier afhænger af forskellige faktorer, var formålet med denne undersøgelse at identificere, hvilke faktorer, der har indflydelse på accept og anvendelse af SET i beboelsesejendomme. Der blev i denne forbindelse gennemført en onlineundersøgelse blandt mere end 3.000 beboere i beboelsesejendomme i Danmark. TAM, samt elementer fra TAM2 og UTAUT, blev anvendt til at forudsige de faktorer, der påvirker accepten og anvendelsen af SET. Resultaterne viste, at TAM-begreber som opfattet brugervenlighed og holdninger har betydelig indflydelse, mens opfattet anvendelighed ikke har indflydelse på beboernes villighed til at acceptere SET. Samtidig har viden, bevidsthed, politiske programmer og tilskud, social indflydelse og tillid en betydelig indvirkning på beboernes intention om at bruge SET.

Den tredje forskningsartikel, *Examining the path to Smart Energy Technology adoption in residential buildings*, fokuserede på spørgsmål 2. Resultaterne af denne undersøgelse afslørede en begrænset vilje til at anvende SET blandt beboere i beboelsesejendomme. Studiet undersøgte også de typer af SET, som beboerne ejer, samt årsagerne til den begrænsede anvendelse af SET, for på denne måde at opnå en bedre forståelse af beboernes behov og motivation, når det kommer til brugen af SET. Samtidig undersøgtes sammenhængen mellem viden og bevidsthed om SET og beboernes vilje til at anvende SET, samt sammenhængen mellem demografiske faktorer (indkomst og boligtype) og viljen til at anvende SET.

Den fjerde forskningsartikel, *Why Do Some Embrace and Others Resist? Understanding the Drivers and Barriers to the Adoption of Smart Energy Technologies in Residential buildings*, besvarede forskningsspørgsmål 3 ved at undersøge beboernes opfattelser af det at anvende SET. Til denne undersøgelse blev der gennemført semistrukturerede interviews med 21 beboere, som havde installeret SET i deres hjem, hvor beboernes kendskab til og informationskilder om SET, samt de typer af intelligente energiteknologier, der er installeret i boligerne, blev identificeret. Baseret på resultaterne fra den anden forskningsartikel, undersøgte dette studie desuden, hvordan beboernes accept og anvendelse af SET påvirkes af opfattet anvendelighed og brugervenlighed, samt holdninger, kendskab, bevidsthed, politikker, social indflydelse og tillid. Resultaterne afslørede såvel drivkræfter som barrierer for accept og anvendelse af SET i beboelsesejendomme.

Contents

List of Tables and Figures

List of acronyms and abbreviations

SETs- Smart Energy Technologies

HEMS- Home Energy Management Systems

BAS- Building Automation System

EVs- Electric Vehicles

Smart HVAC- Smart Heating Ventilation and air-conditioning

Solar PV- Solar Photovoltaic

TAM- Technology Acceptance model

PU- Perceived Usefulness

PEOU- Perceived Ease of Use

BI- Behavioural Intention

SI- Social Influence

UTAUT- Unified Theory of Acceptance and Use of Technology

TRA- Theory of reason Action

QUAL method- Qualitative method

QUANT method- Quantitative method

1 Introduction

Chapter 1 provides an overview of the dissertation. First, the dissertation structure is introduced, followed by the motivation and research questions. Afterward, the applied methodology is presented, encompassing elements such as research philosophy and research design. Finally, chapter 1 presents the contribution and novelty of the dissertation.

The dissertation is structured through four journal articles that seek to answer the three research questions (shown in Table 2). Meanwhile, Table 1 presents the connections between the four journal articles and the three research questions.

Table 1. Introduction of the applied journal articles

Research Question	Article Title	Authors	Journal	Year
(RQ1) What factors influence the acceptance and adoption of Smart Energy Technologies?	A critical analysis of ten influential factors to energy technology acceptance and adoption	Billanes J. & Enevoldsen P.	Energy reports	2021
	Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark	Billanes J. & Enevoldsen P.	Energy and Buildings	2022
(RQ2) Are residential building occupants willing to adopt SETs?	Examining the path to smart energy technology adoption in residential buildings	Billanes J. & Enevoldsen P.	Energy efficiency	In review
(RQ3) Why do residential building occupants decide to adopt or reject Smart Energy Technologies, and how do they make these choices?	Why do some Embraces and Others Resist? Understanding the Drivers and Barriers to the Adoption of Smart Energy Technologies in	Billanes J.	Energy efficiency	Under revision for re-submission

	residential buildings

Based on the structure presented in Table 2, the PhD dissertation is arranged in thematic sections, with chapters 2, 3, and 4 addressing the three research questions. Chapter 2 contains two journal articles, one journal article in Chapter 3, and Chapter 4 features one journal article. Chapter 5 highlights the key findings from each article, presents integration of key findings, and offers recommendations. Chapter 6 serves as the appendix.

Table 2. Structure of the Dissertation

Chapter	Research Question	Journal articles	Description
Chapter 1			Introduction of dissertation structure, motivation, research questions, methodology, and contribution and novelty.
Chapter 2	Research Question 1	2	A literature review, and a quantitative study on the influential factors in the acceptance and adoption of SETs
Chapter 3	Research Question 2	1	A quantitative study of the willingness to adopt SETs
Chapter 4	Research Question 3	1	A qualitative study of the barriers and drivers to the acceptance and adoption of SETs
Chapter 5			Presents the key findings, integration of key findings, and recommendations
Chapter 6			Appendix

1.2 Motivation and Background

The literature review establishes the dissertation's direction by guiding the understanding of existing knowledge in energy technology domain, formulating research questions, and shaping the methodologies used. Specifically, this section consists of topics related to energy transition challenges, Smart Energy Technologies (SETs), Technology Acceptance Model (TAM) and influential factors to the acceptance and adoption of SETs.

1.2.1 Energy Transition Challenges

Energy is important in various aspects of our lives. As the population continues to grow, the demand for energy is on the rise, particularly in residential, commercial, and industrial buildings.

This increasing energy demand contributes to an increased need for energy resources. Buildings account for approximately 40% of global energy consumption and over 30% of greenhouse gas emissions (Fink, 2011). Residential buildings, for instance, share for about 25% of the total global energy consumption and 17% of the total global CO2 emissions (Tirado Herrero, Nicholls, & Strengers, 2018), indicating the need to reduce energy consumption and enhance energy efficiency (Liu, Ma, Xing, Liu, & Wang, 2022). Likewise, Guerreiro, Batel, Lima, and Moreira (2015) emphasize that enhancing energy efficiency is essential for addressing the climate and the energy crisis.

In connection to the Paris Agreement, Denmark has set a target to eliminate the use of fossil fuel and reduce energy consumption in buildings (Engvang & Jradi, 2021). The country is considered a frontrunner in wind power generation on global scale (Unander, Ettestøl, Ting, & Schipper, 2004). The excessive consumption of energy can be attributed to the significant amount of time spent indoors by engaging in various household activities (Hayles & Dean, 2015). In 2021, Denmark had nearly 2.75 million residential buildings, making it a crucial area for efforts to reduce energy consumption and carbon emissions (Billanes & Enevoldsen, 2022).

Achieving carbon neutrality requires more than just switching to clean and sustainable energy sources. The collective participation of everyone is needed in reaching the carbon neutrality goal, emphasizing the involvement from residential building occupants (Tuomela, Iivari, & Svento, 2021). Residential building occupants, for example, can support energy transition by adopting SETs (Zawadzki, Vrieling, & van der Werff, 2022). Implementing energy efficiency practices such as installing SETs at home not only helps lower emission levels but also fosters a more sustainable environment (Fink, 2011). However, encouraging participation among residential building occupants can be challenging (Chadwick, Russell-Bennett, & Biddle, 2022).

1.2.2 Smart Energy Technologies (SETs)

Smart Energy Technologies (SETs) are known by various names, including smart home technologies (Tirado Herrero et al., 2018), energy efficient technologies (Decuypere, Robaeyst, Hudders, Baccarne, & Van de Sompel, 2022; Hafner, Elmes, Read, & White, 2019), home energy technologies (Tuomela, Iivari, et al., 2021), and electrification technologies (Brown, Kale, Cha, &

Chapman, 2023). SETs are considered a game-changer in reducing energy consumption and improving energy efficiencies (Spence et al., 2021).

Examples of SETs are solar photovoltaics (PV) (Malik & Ayop, 2020), smart HVAC (O'Grady, Chong, & Morrison, 2021), smart thermostat (Girod, Mayer, & Nägele, 2017), smart lighting (Bhati, Hansen, & Chan, 2017), smart home appliances (An-Chi & Tsung-Yu, 2020). Other SETs include Home Energy Management Systems (HEMS) (C.-f. Chen, Xu, et al., 2020), Building Automation Systems (BAS) (Ahmadi-Karvigh, Ghahramani, Becerik-Gerber, & Soibelman, 2017), smart meters (Guerreiro et al., 2015) and Elective Vehicles (EVs) (N. Wang, Tian, Zhu, & Li, 2022). To illustrate, employing a Home Energy Management System (HEMS) to change energy usage to off-peak hours can result in energy savings of up to 30% during winter months (Tuomela, de Castro Tomé, Iivari, & Svento, 2021). In addition, smart meters provide detailed usage information, enabling users to manage electricity consumption, make informed decisions during peak demand, monitor appliance usage for potential reductions (Warkentin, Goel, & Menard, 2017) and help improve energy efficiency (Guerreiro et al., 2015).

Moreover, SETs need to be installed in buildings to reach their full potential (Gimpel, Graf, & Graf-Drasch, 2020) and their success depend on how residential building occupants accept and adopt them (Spence et al., 2021). The word "acceptance" refers to the willingness to use and support the adoption of SETs while "adopt" means buying or purchasing and actual use of SETs (Dessi et al., 2022).

Despite, the effectiveness of SETs, the adoption of SETs is still low (Decuypere et al., 2022; Gimpel et al., 2020). This could be due to various reasons, for example, residential building occupants do not want to compromise their indoor comfort (Tuomela, de Castro Tomé, et al., 2021). Furthermore, a study suggests that there is stronger support for SETs in workplaces or within the framework of policies compared to residential contexts due to quicker decision-making and a shared sense of responsibility among individuals in those contexts (Spence et al., 2021).

Understanding the influential factors to individuals' acceptance and adoption of SETs is indeed crucial to foster the adoption of SETs (Gimpel et al., 2020; Whittle, Jones, & While, 2020). For example, Guerreiro et al. (2015) examine the socio-psychological factors that influence individuals' perceptions to adopt smart meters. Another study suggests that making energy-efficient lighting more affordable could stimulate higher adoption among consumers (Hicks & Theis, 2014).

1.2.3 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis (1986), is one of the most known models in the field of technology acceptance (discussed in chapter 2). TAM is derived from Theory of Reasoned Action (TRA), and its primary aim is to simplify TRA(An-Chi & Tsung-Yu, 2020). According to Wu (2012), TAM is simple, robust and widely known model that focuses on the individual perceptions and motivations to accept and embrace a technology. Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) are the two key elements of TAM. PU refers to the extent to which an individual believes that using a particular technology will enhance their job performance (Davis, Bagozzi, & Warshaw, 1989). Perceived Ease of use (PEOU) is the degree to which an individual believes that using a particular technology will be free of effort (Davis et al., 1989). PU and PEOU influence Attitudes, which in turn, influence the Behavioural Intention (BI) to use a technology (An-Chi & Tsung-Yu, 2020). Attitude refers to a degree of user's positive or negative feelings about incorporating a certain technology into their lives, while Behavioral Intention (BI) indicates the strength of a user's readiness or acceptance to adopt technology (An-Chi & Tsung-Yu, 2020; Shuhaiber & Mashal, 2019).

Studies highlight the effectiveness of TAM in predicting the intention to use a technology. Nikou (2019), for instance, has examined the influence of PU and PEOU on adoption of smart home technology. While PU and PEOU are highly relevant to the research objective, this study argues depending solely on these two elements is not enough to predict technology acceptance and adoption. Therefore, it is essential to examine other factors related to the acceptance and adoption of SETs.

1.2.4 Influential factors to the acceptance and adoption of SETs

There are 21 referenced studies discussed in chapter 2 related to SETs that applied TAM models to predict technology acceptance and adoption. Specifically, this section presents the significance of TAM elements such as PU, PEOU and Attitudes- alongside influential factors including knowledge, awareness, policy, trust, and social influence in driving the acceptance and adoption of SETs.

Studies consistently indicate that PU positively influences BI to use SETs (C.-f. Chen, Xu, et al., 2020; Chou & Gusti Ayu Novi Yutami, 2014; Girod et al., 2017; Guerreiro et al., 2015; Hubert et al., 2019; Malik & Ayop, 2020; Sepasgozar, Hawken, Sargolzaei, & Foroozanfa, 2019; Shin, Park, & Lee, 2018; Whittle et al., 2020; Xingdong, Yanling, Rong, & Peijuan, 2019). For example, studies emphasize that PU influences consumers' willingness to adopt smart meters in residential buildings (Chou & Gusti Ayu Novi Yutami, 2014; Guerreiro et al., 2015).

Additionally, studies reveal that Perceived Ease of Use (PEOU) influence the Behavioural Intention to use SETs (Chou & Gusti Ayu Novi Yutami, 2014; Sepasgozar et al., 2019; Shin et al., 2018; Whittle et al., 2020). For example, a study by Shin et al. (2018) shows that PEOU significantly and positively influence the purchase intention of smart homes.

Studies by Chin and Lin (2015), Shuhaiber and Mashal (2019), An-Chi and Tsung-Yu (2020), Ali, Poulova, Akbar, Javed, and Danish (2020) highlight that both PU and PEOU significantly influence individuals' Attitudes toward using SETs. Additionally, Attitudes influence the intention of adopt a technology (Badri-Harun, Shaari, Jaafar, & Julayhe, 2017; C.-f. Chen, Xu, et al., 2020; Whittle et al., 2020). For example, a study reveals that when customers believe smart home appliances as easy to use and find them useful, they are more likely to develop a positive Attitude towards these devices (An-Chi & Tsung-Yu, 2020). Additionally, Chin and Lin (2015) finds that good Attitudes toward Building Energy Management Systems (BEMS) influence the intention to adopt them. Similarly, a study illustrates that Attitudes toward embracing green homes directly influence the intention to adopt them (Badri-Harun et al., 2017).

Knowledge and awareness play a big role in explaining why people interested to using SETs. Several studies claim that knowledge and awareness can influence PU (Kardooni, Yusoff, & Kari, 2016), Attitudes (Badri-Harun et al., 2017; Shuhaiber & Mashal, 2019) and intention to use SETs (Alkawsi, Ali, & Baashar, 2020). For instance, knowledge and awareness positively influence the perception on the usefulness of renewable energy technology (Kardooni et al., 2016). Likewise, a study by Alkawsi et al. (2020) explains how increased knowledge about electricity-saving practices and increased environmental awareness significantly contribute to understanding the reasons consumers are more likely to accept and utilize smart meters.

Policy can influence the intention to use SETs (Girod et al., 2017; Xingdong et al., 2019). For example, Girod et al. (2017) argue that policies have the potential to speed up the initial acceptance of smart thermostat by incentivizing retailers for promoting these technologies. Moreover, social influence affects the intention to use SETs (C.-f. Chen, Xu, et al., 2020; Guerreiro et al., 2015; Xingdong et al., 2019) as well as the actual use of SETs (Pathania, Goyal, & Saini, 2017). Social influence (e.g., subjective norms and social factors) refers to the extent to which people in one's social environment impacts individual's decision to adopt specific technologies (Baudier, Ammi, & Deboeuf-Rouchon, 2020; C.-f. Chen, Xu, et al., 2020; N. Wang et al., 2022).

Trust also plays an important role in shaping Attitudes (Shuhaiber & Mashal, 2019). Trust refers to users' confidence in the reliability of the system (Shuhaiber & Mashal, 2019), and manifested as the reliance on the agent's support and assistance, especially in challenging or unpredictable circumstances (N. Wang et al., 2022). For example, Shuhaiber and Mashal (2019) suggest that when an individual has a high level of trust in smart homes, believing them to be reliable, controllable, and competent, they tend to have a more positive attitude towards adopting smart home technology. Additionally, Ahn, Kang, and Hustvedt (2016) reveal the other influential factors to intention to adopt SETs such as performance, compatibleness, hedonic expectancy, and consumer characteristics. In the study of (Chin & Lin, 2015), other factors such as compatibility and technology complexity are expected to have a direct influence on users' Attitudes toward the use of BEMS.

1.3 The research questions

This dissertation provides a comprehensive understanding of the technology acceptance and adoption by exploring nine different types of SETs (e.g., solar PV, smart HVAC, smart home appliances, smart lightings, smart thermostat, HEMS, BAS, smart meters and EVs). To achieve this goal, three research questions were formulated. These research questions serve as a foundation of the entire study, aiming to address the gaps within smart energy technology acceptance and adoption.

Research question 1. *What factors influence the acceptance and adoption of smart energy technologies?*

Research Question 1 aims to uncover the influential factors to the acceptance and adoption of SETs among residential building occupants in Denmark. The study is conducted via a quantitative survey, investigating the effects of PEOU, PU, and Attitudes on Behavioral Intention (BI) to adopt SETs. Additionally, the study explores other influential factors including policy, knowledge, awareness, social influence, and trust (detailed in chapter 2).

Research question 2. *Are residential building occupants willing to adopt SETs?*

Research Question 2 involves an investigation into the attitudes and behaviors of residential building occupants regarding SETs. This includes conducting an online survey to examine familiarity with SETs, current ownership, willingness to adopt SETs, and reasons for reluctance to adopt SETs (discussed in chapter 3).

Research question 3. *Why do residential building occupants decide to adopt or reject smart energy technologies, and how do they make these choices?*

Research Question 3 investigates why residential building occupants choose to adopt or reject smart energy technologies (SETs). To explore comprehensively the drivers and barriers in SETs' acceptance and adoption, this study integrates elements from the Technology Acceptance Model (TAM), TAM2, and UTUAT. Chapter 4 details how factors like knowledge, awareness, policy, trust, social influence, and TAM elements (PU, PEOU, Attitudes) addresses research question 3.

1.4 Methodology

Methodology section discusses the selected and applied research paradigm and research strategies.

1.4.1 Research paradigm

Creswell (2014) highlights the four research philosophies including postpositivism, constructivism, transformative and pragmatism. Post-positivists acknowledge that there can be different perspectives and interpretations truth influenced by various factors such as values, biases, and social context. Post-positivist researchers encourage critical examination of assumptions and recognition of the multiple ways in which truth can be understood and constructed(Creswell, 2014). Meanwhile, postpositivism emphasizes numerical measures, applies deductive reasoning, and consider the value of theories and hypothesis (Onwuegbuzie & Leech, 2005). In conducting a study, post positivist researcher starts with a theory followed by collecting data that accept or reject the theory, and making revisions and conduct additional test(Creswell, 2014). Meanwhile, a constructivist or interpretivist researcher emphasizes inductive reasoning and formulating a generalized conclusion based on observation of a particular event (Onwuegbuzie & Leech, 2005).

Moreover, a pragmatic researcher is flexible and aim to tackle various research questions that arise while promoting collaboration among researchers, regardless of their philosophical orientation (Onwuegbuzie & Leech, 2005). Pragmatist researcher believes that reality is constantly evolving and developed based on specific needs and circumstances (Baker & Schaltegger, 2015). Specifically, pragmatism emphasizes that individuals actively shape their understanding of the world, rather than merely discovering it (Baker & Schaltegger, 2015). It means that a pragmatist is motivated to address specific problems and aim to generate findings and recommendations that can lead to effective solutions. Pragmatic researcher employs mixed methods to validate the findings obtained from another method, thereby enhancing the robustness and credibility of the research (Onwuegbuzie & Leech, 2005).

This dissertation applies pragmatism as a research philosophy to understand the truth through practical perspectives rather than aiming for absolute truths. Specifically, this dissertation explores both residential building occupants' perceptions and experiences; and applies that knowledge to achieve the desired results.

1.4.2 Explanatory sequential mixed methods

Research methods consist of qualitative, quantitative, or mixed methods. Applying qualitative or quantitative method alone is not adequate for addressing the research questions of the dissertation. This dissertation therefore applied mixed methods to enhance the credibility and confidence in the research outcomes. Denscombe (2010) introduced the different purposes of using mixed methods strategies such as improving accuracy and compensating strengths and weaknesses of different methods to develop the analysis and supporting the sampling. Likewise, Venkatesh, Brown, and Sullivan (2016) claim that using mixed methods enable researchers to address both confirmatory and explanatory research questions and provide a stronger evidence and conclusions as well as explore a wider range of diverse perspectives. In particular, employing quantitative method to investigate the factors combined with qualitative study of the perceptions and experiences provide a comprehensive understanding of SETs' acceptance and adoption among residential building occupants. Furthermore, mixed methods can apply inductive and deductive reasoning to benefit from the strengths of both approaches, leading to richer and more comprehensive findings (Venkatesh et al., 2016).

There are two types of mixed methods approach: exploratory sequential (QUAL to QUANT) and explanatory sequential (QUANT to QUAL) (Creswell, 2014; Wu, 2012). This dissertation applies an explanatory sequential design to combine the strengths of quantitative and qualitative methods (Harrison & Reilly, 2011; Wu, 2012). The process begins with a data collection, followed by conducting statistical analysis of quantitative data. Subsequently, semi-structured interviews and thematic analysis were conducted in the qualitative phase, to explain, interpret and validate the quantitative results.

a. Quantitative Phase

The general purpose of a quantitative method is to measure, quantify and investigate relationships between specific variables (Harrison & Reilly, 2011). According to (Evans & Mathur, 2005; Van Selm & Jankowski, 2006) conducting online survey saves both time and would reach larger number or respondents in a country with high internet accessibility like in Denmark. Another advantage of using online survey is the flexibility to be conducted in various formats, including embedded surveys within emails or emails containing links to survey URLs (Evans & Mathur, 2005). In addition, online survey is useful when collecting sensitive information as it provides anonymity, which in turn, respondents feel comfortable sharing sincere responses(Van Selm & Jankowski, 2006). On the other hand, conducting an online survey has also some challenges. For example, individuals often receive a large volume of emails daily, so it would be difficult for the respondents to distinguish the genuine emails and unsolicited ones. As a result, respondents may delete the survey link email perceiving is as junk mail (Evans & Mathur, 2005).

b. Qualitative phase

Qualitative study is conducted to interpret the quantitative results. The purpose of the study is to explore deeper the perception, experience, motivation of interview participants. Qualitative research provides results in narrative that answers "how" and "why" of a phenomenon (Harrison & Reilly, 2011). In addition, the flexibility and open nature of qualitative research can lead to new insights.

Semi-structured interview is one of the qualitative data collection methods that provides flexibility for researchers to approach different interviewees while ensuring consistent coverage of key questions (Azungah, 2018). In this method, an interview participant has a freedom to express himself or herself and share experiences and opinions, allowing for a detailed exploration of topics. According to Azungah (2018) qualitative data is subjective and prone to bias, and employing triangulation by cross-referencing interviews with documents can enhance the credibility, reliability, and validity of qualitative data.

1.4.3 Research Design

This dissertation employed an explanatory sequential design, presented in Table 3. The process begins with literature review, followed by a quantitative study, and finally a qualitative study.

Quantitative Phase: An online survey with residential building occupants is conducted is conducted to carry out a quantitative study. Two separate quantitative studies were undertaken to gain insights addressing the research problem. The first study explores the influential factors in the acceptance and adoption of SETs, specifically examining the effects of the original TAM elements (PU, PEOU, Attitudes) and five other influential factors (knowledge, awareness, policy, trust, social influence) on intention to adopt SETs. The second study also focuses on the intention to adopt SETs among residential building occupants, aiming to identify their level of knowledge and willingness to adopt SETs and identify barriers. Additionally, three hypotheses were formulated to test the associations between knowledge and awareness, demographics (income and types of dwelling), and the willingness of residential building occupants to adopt SETs.

Qualitative Phase: In second stage, a qualitative study is conducted to interpret and explain quantitative results. This phase provides richness to the research by uncovering the reasons behind adoption and reluctance to adopt SETs among residential building occupants. Data were collected through a semi-structured interview with 21 interview participants in Denmark and were analyzed using deductive thematic analysis. The results ultimately revealed the drivers and barriers to SETs acceptance and adoption.

Table 3. Explanatory Sequential Design

Phase	Research Questions	Article No.	Data Collection	Data Analysis	Subject
Literature review	What factors influence the acceptance and adoption of Smart Energy Technologies?	Journal article 1	54 peer reviewed literature	Literature review	Influential factors to technology acceptance and adoption
Quantitative Phase	What factors influence the acceptance and adoption of Smart Energy Technologies?	Journal article 2	Online survey of more than 3,000 respondents	Multiple linear regression analysis via SPSS	TAM factors and five other factors to technology acceptance to accept and adopt SETs
	Are residential building occupants willing to adopt SETs?	Journal article 3	Online survey of more than 3,000 respondents	Descriptive analysis using Chi-square test and Cross tabulation	Willingness to accept and adopt SETs
Qualitative Phase	How do residential building occupants perceive, what motivates them, and what is their overall experience when adopting Smart Energy Technologies (SETs)?	Journal article 4	Interview of 21 owners of SETs	Deductive thematic analysis	Barriers and drivers to SETs' adoption

1.5 Contribution and Novelty

This dissertation offers significant contribution and novelty in several ways. *First,* this study offers novel insights in its application of explanatory sequential mixed methods, integrating both quantitative and qualitative studies to explore both drivers and barriers to the acceptance and adoption of Smart Energy Technologies (SETs). This approach enhances the overall understanding of the research topic by capturing both general and detailed perceptions of residential building occupants. *Second,* examining the influential factors to the acceptance and adoption of nine different types of SETs instead of just one, this study offers a novel contribution. It provides a broader perspective that can help develop strategies for promoting various smart energy technologies and uncover insights not seen when focusing a single type of SET. *Third,* this study offers a fresh theoretical insight by extending the Technology Acceptance Model (TAM) to incorporate factors like trust, social influence, knowledge, awareness, and policy. This advancement enhances the model to better explain SETs adoption and making it more relevant to real-world scenarios.

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2 What factors influence the acceptance and adoption of smart energy technologies?

The first research question is addressed by presenting the following publications:

1. A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption. Published in Energy reports. *J. Billanes, & Enevoldsen, P., Vo. 7, s. 6899-6907. October 2021. DOI: 10.1016j.egyr.2021.09.118*
2. Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark. Published in Energy and Buildings. *Billanes, J., & Enevoldsen, P., Vol. 276, 112524. September 2022. DOI:10.1016 j.enbuild.2022.112524*

This chapter presents two journals about the influential factors in the acceptance and adoption of Smart Energy technologies in residential buildings. The first journal article is a literature review that contributes to foundational understanding of the influential factors related to technology acceptance and adoption. The second journal article presents a quantitative study specifically examining the factors influencing occupants' decisions to accept and adopt SETs in residential buildings.

2.1. A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption

The Technology Acceptance Model (TAM) is a widely used model to explain individual perceptions of technology adoption. TAM's main constructs, Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), suggest that when individuals perceive a certain technology as useful and easy to use, will develop positive attitudes toward the technology, leading to their willingness to use it. However, depending solely on PU and PEOU may not offer a comprehensive understanding of technology acceptance and adoption. Therefore, this literature review examined literatures that conducted studies applying other models (e.g. TAM2 and UTAUT). Specifically, this study examines 54 empirical studies on the factors influencing the acceptance and adoption of various technologies utilizing models other than TAM original, including 21 studies specifically related to SETs. The critical review analysis involves the classification and extraction of selected literature attributes (e.g., sample size, technology type). Additionally, identifying and selecting influential factors based on their frequency in the literature and analyzing the influence of these identified factors on the main elements of the TAM model to understand their interrelationships. Findings reveal the direct effects of PU and PEOU, and the effects of 10 identified factors on individuals' intentions to adopt SETs. However, there are limited studies focusing on the associations between the ten identified factors (e.g. influence of trust on social influence). Overall, this review highlights the diverse nature of technology acceptance and adoption in the context of SETs, emphasizing the importance of considering a wide range of factors beyond TAM elements (e.g. PU and PEOU) to fully understand individuals' intentions to adopt such technologies.

2.1.1 Introduction

Technologies are changing our lives in various ways. Recent technological developments include mobile banking (Ho, Wu, Lee, & Pham, 2020; Malaquias & Silva, 2020), social medias, smart phones (Cho, Chi, & Chiu, 2020), smart energy technologies (Chen, Xu, & Arpan, 2017; Shin, Park, & Lee, 2018) and many others. A recent study shows that 325,000 health-related apps were developed in 2017 (Cho et al., 2020). Indeed, technology is a key element to competitiveness and growth (Malaquias & Silva, 2020). Moreover, the successful implementation of any new technology depends on the number of people using it. Furthermore, Sepasgozar, Hawken, Sargolzaei, and Foroozanfa (2019) further confirm that technology acceptance is essential for the future development towards sustainable smart cities. In sum, technology acceptance is a main barrier for enabling the future trends of humanity.

However, not everyone has the access to the technologies needed to improve lives. The very success of technology acceptance is dependent on understanding how and why users accept new technologies (e.g. smart home technologies) (Shuhaiber & Mashal, 2019). An example was established in a case study in Argentina showing that users perceived internet as useful despite having poor internet connection and have limited access to technologies such as computers and laptops (Alderete, 2019). Even if such exists, smart home penetration remains very low (Baudier, Ammi, & Deboeuf-Rouchon, 2020) due to users' lack of interest to adopt technologies (e.g. internet banking) (Alzubi, Farea, & Al-Dubai, 2017). Studies such as Alkawsi, Ali, and Baashar (2020), Dutot (2015) and Whittle, Jones, and While (2020) adopt Technology Acceptance Model (TAM) for understanding the users' reasons and decisions to technology adoption. Moreover, Sepasgozar, Loosemore, and Davis (2016) elaborate on the three main perspectives of technology adoption, being 1) a socio-economic perspective at the industry (macro) level, 2) a psychological perspective at the individual level, and 3) a managerial perspective at the company (intermediate) level.

This research will focus on the psychological perspective of Technology Acceptance Model (TAM) developed by Davis (1986) to predict user acceptance and adoption to technologies. This study adopts the Technology Acceptance Model (TAM) because TAM has been widely applied and proved model for explaining users' adoption to technology. TAM suggests external factors affecting TAM constructs but did not specify them, therefore, various studies such as in the study of Malik and Ayop (2020) and Chou and Gusti Ayu Novi Yutami (2014) were they examined the influential factors to technology acceptance and adoption.

The initial literature review revealed that despite decades of rapid technological development enhanced by the development of the worldwide web and information and communication technologies, few, if any studies have adequately covered the application and impact of TAM. This paper aims to apply a comprehensive approach to examine and structure various empirical studies based on Technology Acceptance Model (TAM) and Unified Technology Acceptance and Use of Technology (UTAUT) in order to identify the influential factors of technology acceptance and adoption. This study defines influential factors as elements that affect the users' decision to accept and adopt the technology.

2.1.2 Research Methods and Materials

This research is structured by a critical literature review, which has been conducted to identify the potential factors of users' adoption decisions of technology. The literature review starts with searching articles from different databases (Science Direct, IEEE Explore and EBSCOhost) for review spanning from 2011 to 2020. The articles were filtered using the following keywords: 'TAM', 'Technology Acceptance Model', and 'technology adoption'. The search was limited to peer-reviewed articles while duplicates and irrelevant sources were excluded. Moreover, title, abstract, methods and text of the selected literature were screened to ensure the relevance of the content in terms of the inclusion criteria following the reproductive principles of Enevoldsen (2016), ensuring an iterative process. Afterwards, the selected literature resulted in journal articles and conference proceedings. A screening of abstracts helped eliminate the scientific contributions, which have a loose relation with TAM and do not fulfill the requirements.

2.1.2.1 Article Selection

This section provides the inclusion criteria. First, articles are original and peer-reviewed adopting written in English are selected. Next, articles are empirical research applying quantitative, qualitative, and mixed methods. And more importantly, articles on influential factors to technology acceptance and adoption that examined the Technology Acceptance Model and its updated and comprehensives versions. On the other hand, articles that did not meet the minimal screening criteria of a checklist are excluded.

2.1.2.2 Examining the Literature

The search for literature was finalized after reaching a point where no new information on the topic was found, which resulted in 54 peer reviewed empirical research papers on Technology Acceptance and UTAUT models (shown in Table 4). There are 3 articles for review from 2011-2013, 6 from 2013-2015, 16 from 2016-2018, and 29 from 2019-2020 (shown in Figure 1). Moreover, the data shows that various scholars from different regions adopt TAM. The finding shows that there are 29(54%) articles studied in an Asian context, which covers most studies. Meanwhile, there are 14(26%) studies focusing on Europe, 5(9%) in South and North America, 1(2%) in Africa, 1 (2%) in Canada (1) and 3 (5%) in multi-countries as shown in Figure 2.

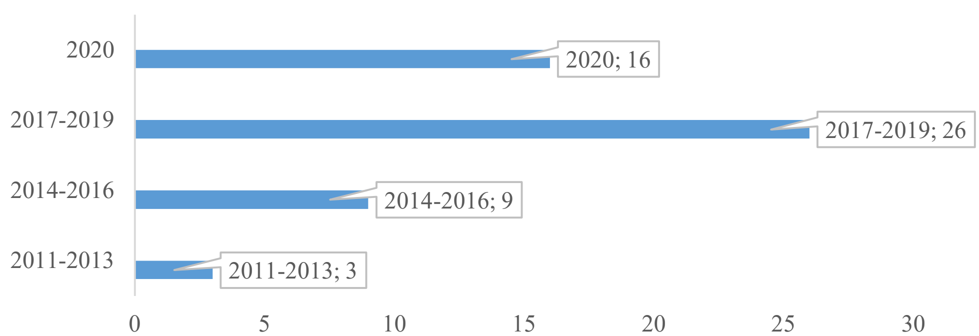

Figure 1. Scientific papers examining technology acceptance models in the period 2011- 2020

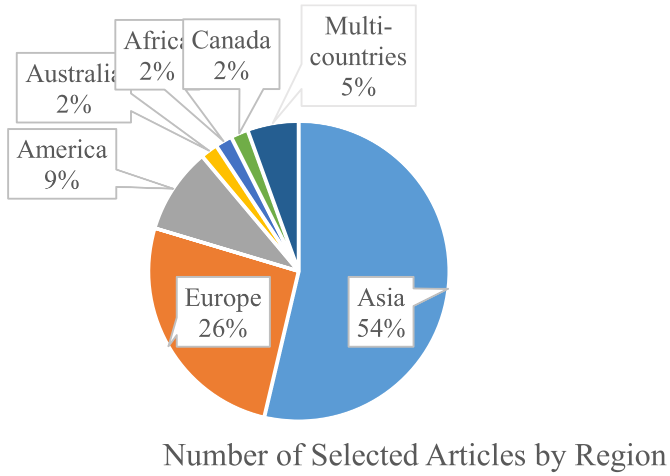

Figure 2. Popularity by region and number of selected studies focusing on Technology Acceptance Models

Table 4. Total number of technologies associated with TAM

Technologies	**Numbers**
Smart energy technologies	21
IT	2
Health system/technologies	3
Mobile payment	4
Internet banking	2
Mobile internet/apps	4
Autonomous/driverless vehicles	2
Blockchain	1
e-learning system	1
NFC	1
Smart glasses	1
Others	12
Total	54

Table 4 also shows technologies associated with TAM including smart energy technologies (e.g. smart meters, smart thermostat, BEMS, HEMS, solar PV)(21), Information technology or IT (2), health system/technologies (3), mobile payment (4), internet banking (2), mobile internet/apps (4), autonomous/driverless vehicles (2), blockchain (1), e-learning system (19), NFC (1), smart glasses (1) and others (12).

Table 5. An overview of the examined scientific contributions revealing focus areas and technology associations

Year	Authors	Main Focus	Technology
2011	(Suur-Inkeroinen & Seppänen, 2011)	Technology usage	IT
2012	(Kung-Teck, Teo, & Russo, 2012)	Technology acceptance	Computer
2013	(Nath, Bhal, & Kapoor, 2013)	Influential factors to adoption	IT
2014	(Chou & Gusti Ayu Novi Yutami, 2014)	Technology adoption	Smart meter
2015	(Chieh-Heng & Chun-Chieh, 2015)	Technology adoption	Biometric technology
2015	(Koenig-Lewis, Marquet, Palmer, & Zhao, 2015a)	Technology adoption	Mobile pay
2015	(Dutot, 2015)	Influential factors to adoption	NFC
2015	(Chin & Lin, 2015)	Users' perspectives	BEMS
2015	(Guerreiro, Batel, Lima, & Moreira, 2015)	Determinants to use	Smart meter
2016	(Nabhani, Daryanto, Machfud, & Rifin, 2016)	Technology adoption	Mobile apps
2016	(Ahn, Kang, & Hustvedt, 2016)	Technology acceptance	Household technology
2016	(Kardooni, Yusoff, & Kari, 2016)	Technology acceptance	Renewable energy tech

2017	(Basoglu, Ok, & Daim, 2017)	Technology adoption	Smart glasses
2017	(Warkentin, Goel, & Menard, 2017)	Technology adoption	Smart meter
2017	(Pathania, Goyal, & Saini, 2017)	Technology adoption	Solar energy products
2017	(Girod, Mayer, & Nägele, 2017)	Technology adoption	Intelligent thermostat
2017	(Badri-Harun, Shaari, Jaafar, & Julayhe, 2017)	Attitude and acceptance	Green homes
2017	(Sánchez-Mena, Martí-Parreño, & Aldás-Manzano, 2017)	Intention to use	Educational video game
2017	(Alzubi et al., 2017)	Intention to use	Internet banking
2018	(Matemba & Li, 2018)	Willingness to adopt and use	WeChat wallet
2018	(Shin et al., 2018)	Technology adoption and diffusion	Smart home
2018	(Kumar, Sachan, Mukherjee, & Kumar, 2018)	Influential factors to adoption	e-Government
2018	(Koul & Eydgahi, 2018)	Technology adoption	Driverless car
2018	(Alalwan, Baabdullah, Rana, Tamilmani, & Dwivedi, 2018)	Examining adoption	Mobile internet
2018	(Etemad-Sajadi & Gil Gomes Dos, 2019)	Technology acceptance	Health technologies
2019	(Chauhan, Yadav, & Choudhary, 2019)	Impacts to adoption	Internet banking
2019	(Spatar, Kok, Basoglu, & Daim, 2019)	Factors to technology adoption	EHR system
2019	(Tung-Sheng, Kuo-Chung, & Phuc Hung, 2019)	Technology adoption	Mobile app

2019	(Zare Shahabadi, Abbasi Harofteh, & Zare Shahabadi, 2019)	Factors to technology acceptance	Earthen houses
2019	(Hubert et al., 2019)	Factors to acceptance and adoption	Smart home
2019	(Xingdong, Yanling, Rong, & Peijuan, 2019)	Determinants of adoption intention	Solar water heater
2019	(Shuhaiber & Mashal, 2019)	Users' acceptance	Smart home
2019	(Sepasgozar et al., 2019)	Technology acceptance	Urban technologies
2019	(Silva-C, Montoya R, & Valencia A, 2019)	Technology adoption	Telework
2019	(Farhan, Razmak, Demers, & Laflamme, 2019)	Factors in predicting the use	e-Learning systems
2019	(Talukder, Shen, Hossain Talukder, & Bao, 2019)	Determinants of user acceptance & use	Open government data
2019	(Shirahada, Ho, & Wilson, 2019)	Determinants of technology readiness	Online public service
2019	(Michels, Bonke, & Musshoff, 2019)	Technology adoption	Smart phone apps
2020	(Alkawsi et al., 2020)	Technology acceptance	Smart meter
2020	(Cho et al., 2020)	Intention to continue use	Health and fitness app
2020	(Malik & Ayop, 2020)	Technology acceptance	Solar energy technology
2020	(Whittle et al., 2020)	Predictors of intentions to use	HEMS
2020	(An-Chi & Tsung-Yu, 2020)	Behavioral intention	HEMS
2020	(Baudier et al., 2020)	Technology acceptance	Smart home technologies
2020	(Chen et al., 2020)	Technology adoption	HEMS

2020	(Ali, Poulova, Akbar, Javed, & Danish, 2020)	Influencing factors to adoption	Solar PV
2020	(Kasilingam, 2020)	Attitude and intention to use	Chatbots
2020	(Lin, Lee, Chang, & James Fu, 2020)	Behavioral intention	Mobile learning
2020	(Albayati, Kim, & Rho, 2020)	Technology acceptance	Blockchain
2020	(Kamal, Shafiq, & Kakria, 2020)	Technology acceptance	Telemedicine
2020	(Dirsehan & Can, 2020)	Technology adoption	Autonomous vehicle
2020	(Al-Okaily, Lutfi, Alsaad, Taamneh, & Alsyouf, 2020)	Determinants of acceptance	Mobile pay
2020	(Al-Saedi, Al-Emran, Ramayah, & Abusham, 2020)	Technology adoption	M-payment
2020	(Malaquias & Silva, 2020)	Technology adoption	Mobile banking

Table 5 presents an overview of the examined scientific contributions between 2011 and 2020 revealing focus areas and associated technologies. The application of TAM and UTAUT has been crucial in guiding the deployment and promotion of new technologies by providing insights into the factors that drive acceptance and adoption.

Studies by Chou and Gusti Ayu Novi Yutami (2014), Warkentin et al. (2017), Guerreiro et al. (2015) and Alkawsi et al. (2020) employed TAM to examine the influential factors to adoption of smart meters. Smart meters are SETs that measure electricity usage (Chen et al., 2017). For instance, a study explores smart meter adoption by analyzing household data to identify key factors influencing acceptance, offering insights for policymakers and utility companies (Chou & Gusti Ayu Novi Yutami, 2014).
TAM has also been also applied in predicting the acceptance and adoption of Home Energy Management Systems (HEMS) (Chen et al., 2020), (An-Chi & Tsung-Yu, 2020), (Whittle et al.,

2020), Building Energy Management Systems (BEMS) (Chin & Lin, 2015), and smart thermostat (Girod et al., 2017). A study in the United Kingdom utilizes the TAM along with constructs measuring psychological empowerment and environmental attitudes to explore residential building occupants' intentions to use Home Energy Management System (HEMS) (Whittle et al., 2020).

Additionally, TAM has been applied in studies on solar products or technologies (Pathania et al., 2017), (Malik & Ayop, 2020) such as solar PV(Ali et al., 2020) and solar water heater (Xingdong et al., 2019). Meanwhile, TAM and UTAUT are used to predict the acceptance of smart home products among highly educated digital natives (Baudier et al., 2020). For instance, Ahn et al. (2016) applied UTAUT to develop and test a model that predict the intention of consumers to adopt sustainable household technology.

Sepasgozar et al. (2019) proposed an Urban Services Technology Acceptance Model (USTAM), incorporating TAM with Social Cognitive Theory (SCT) (e.g. work facilitating, cost reduction, energy saving and time saving) concepts for predicting the acceptance of urban technologies. Furthermore, studies also utilized TAM to predict acceptance and adoption of smart buildings such as smart homes (Zare Shahabadi et al., 2019) (Hubert et al., 2019), (Shuhaiber & Mashal, 2019), (Shin et al., 2018); green homes (Badri-Harun et al., 2017) and earthen houses (Zare Shahabadi et al., 2019).

2.1.2.3 Examining the development of the Technology Acceptance Model (TAM)

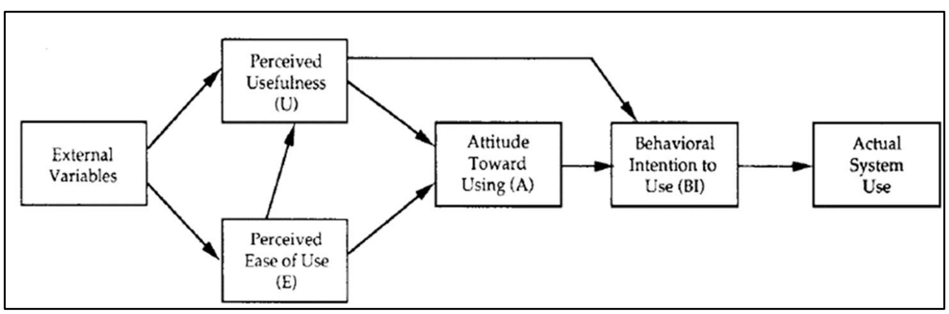

Figure 3 Original TAM (Davis, Bagozzi, & Warshaw, 1989)

TAM was developed in 1986 to improve the understanding of user acceptance processes in new systems before implementation(Davis, 1986). In addition, design system is considered as external stimulus that indirectly affects users' attitude or behavior towards the system through Perceived

Usefulness (PU) and Perceived Ease of Use (PEOU)(Davis, 1986). Moreover, TAM adopted psychological theory known as the Theory of Reasoned Action (TRA) to explain acceptance and usage behavior towards information technology(Davis, 1986).

Three decades ago, Davis (1989) validated the influence of perceived usefulness and perceived ease of use to users' decision of system use. Perceived Usefulness (PU) is the degree to which the user assesses that using a technology would help perform the work better (Davis, 1989). While Perceived ease of use (PEOU) is the degree to which a user considers that using a technology would be free of effort (Davis, 1989). Moreover, Davis (1989) considers perceived ease of use as antecedent to perceived usefulness. Meanwhile, perceived usefulness is strongly linked to behavioral intention to use technology (Davis, 1989). During the same year, Davis et al examined the ability of TAM and TRA to predict computer-based technology (Davis et al., 1989). Result shows that attitude is affected by perceived usefulness and ease of use (Davis et al., 1989) and then attitude affects behavioral intention (BI), which in turn, influences the actual system use. Mathieson (1991) conducted a comparative study showing that TAM and Theory of Planned Behavior (TPB) are based on Theory of Reason Action (TRA). While TAM provides information about the ease of use and usefulness, TPB provides more information measures of the system performance and identifies the barriers to system use (Mathieson, 1991). Furthermore, Bagozzi, Davis, and Warshaw (1992) argue that people form attitudes and intentions toward learning to use the new technology prior to use, and suggests further studies on the impact of various external factors (e.g. experience, education, and social processes) on beliefs and attitudes.

In 1993, Davis (1993) examined how to improve user acceptance through system designs in the workplace. The result validates that external variables (e.g. system design features) directly influence Perceived Ease of Use (PEOU) and Perceived Usefulness (PU), but indirectly influences attitude toward using and actual using behavior (Davis, 1993). On the other hand, Hendrickson et al (1993) conducted a test re-test reliability of TAM elements: perceived usefulness and perceived ease of use scales (Hendrickson, Massey, & Cronan, 1993). In another study, Segars and Grover (Segars & Grover, 1993) suggest "effectiveness" as an additional TAM element.

In 1996, Davis and Venkatesh (Davis & Venkatesh, 1996) introduced the modified version of TAM, eliminating the attitude construct, but introducing the construct of behavioral intention (BI).

Behavioral Intention (BI) to use construct is determined by one's attitude towards using or accepting technologies, which is acquired through direct influence of perceived usefulness, which in turn, influences the actual system use (Davis & Venkatesh, 1996). Moreover, in the same year, Venkatesh and Davis (Venkatesh & Davis, 1996) find out that self-efficacy act as antecedent of Perceived Ease of Use (PEOU). Moreover, Szajna (Szajna, 1996) confirms that TAM is an essential tool in predicting intention to use of information technology and suggests that original TAM is more appropriate than the revised version. Furthermore, Chau (Chau, 1996) modifies TAM and includes two types of perceived usefulness, such as near-term and long-term usefulness, arguing that near-term usefulness has the most significant influence on behavioral intention. In 1999, a field study of broker workstations shows that social norms and prior work performance are more important in predicting technology use than Perceive Ease of Use (PEOU) (Lucas & Spitler, 1999).

In 2000, to enhance the effectivity of TAM, Venkatesh and Davis (Venkatesh & Davis, 2000) developed an extended model known as the Technology Acceptance Model 2 or TAM2. TAM2 keeps the original constructs and adds social influences and cognitive instrumental processes to measure intention of use and perceived usefulness. Subjective norms, voluntariness and image are three interrelated social forces for adopting or rejecting new systems (Venkatesh & Davis, 2000). In addition, job relevance, output quality, result demonstrability and perceived ease of use are considered cognitive instrumental processes (Venkatesh & Davis, 2000).

In addition, Venkatesh and Davis (2000) identify perceived ease of use (PEOU) as an antecedent of perceived usefulness (PU) variable in TAM. In the same year, Venkatesh (2000) presents determinants of Perceived Ease of Use (PEOU) in the TAM model, including internal and external control (computer self-efficacy and facilitating condition), intrinsic motivation (e.g. perceived enjoyment and computer playfulness) and emotion. In 2003, a more comprehensive model known as the United Theory of Acceptance and Use of Technology (UTAUT) is developed to predict influential factors of technology acceptance or Behavioral Intention (BI) to use the technology (Venkatesh, Morris, Davis, & Davis, 2003). In UTAUT, behavioral intention (BI) is directly affected by factors including Performance Expectancy (PE), Effort Expectancy (EE) and Social

Influence (SI), which in turn influence users to actual use of the system. Meanwhile, facilitating conditions directly influence use behavior.

Moreover, Lu et al (June Lu' Chun-Sheng, Liu, & Yao, 2003) develop a model based on TAM to explain the influential factors in the acceptance of wireless internet via mobile devices. Furthermore, Lee, Kozar, and Kai (2003) study the future directions for TAM and emphasize the need to understand the factors contributing to usefulness and ease of use of technologies. Furthermore, a study on the applicability of the TAM incorporating three moderating factors shows the influences of usefulness and ease of use on attitudes and intention to use while gender and educational level showed the presence of moderating effects of ease of use on attitudes (Al-Gahtani, 2008).

Table 6. Development of the Technology Acceptance Model over time

Year		***Model***	***Authors***	***Key Points***
1986	*Introduction*	*TAM original*	*(Davis, 1986)*	*External stimulus indirectly affects users' attitude or behavior towards the system through PU and PEOU*
1989	*Validation*	*TAM original*	*(Davis et al., 1989)* *(Davis, 1989)*	*PEOU as antecedent to PU* *PU is strongly linked to BI* *PEOU and PU affect attitude* *Attitude influences BI*
1991	*Validation*	*TAM original*	*(Mathieson, 1991)*	*TAM and Theory of Planned Behavior (TPB) are based on Theory of Reason Action (TRA)*
1993	*Validation*	*TAM original*	*(Davis, 1993)*	*External variables directly influence PEOU and (PU)* *PU and PEOU influence attitude and actual use behavior*

1996	*Modified*	*TAM*	*(Davis & Venkatesh, 1996)*	*Eliminates attitude construct* *Introduces the behavioral intention (BI) construct* *Confirms the validity and reliability of TAM variables*
2000	*Extended*	*TAM 2*	*(Venkatesh & Davis, 2000)*	*Keeps the original constructs* *Adds social influences, and cognitive instrumental processes*
2003	*Comprehensive*	*UTAUT*	*(Venkatesh et al., 2003)*	*integrates the main model of technology acceptance* *PE, EE, SI, and FC are considered as the key factors* *Age, gender, experience, and voluntariness are considered as moderators*

2.1.3 Data analysis

This section examines the influential factors of users' decision to adopt smart technologies. There are 3 steps involved in the literature analysis. ***First,*** classifying and extracting of study characteristics (e.g. sample size, respondents, and technology type), year of publication, topic, applied model, location, technology focus and results of the study. The reviewed literatures on predicting the factors that influence the acceptance and adoption of different technologies, 21 of which focus on SETs. ***Second,*** analyzing the literature that applied TAM involves selecting the influential factors related to the acceptance and adoption of technologies. This process includes applying a frequency-based feature selection method to quantify how often certain variables appear in the literature. The selected articles are extracted and discussed the application of TAM and UTAUT on different technologies. For instance, there are 21 studies that applied TAM and UTUAT to examine the influential factors to acceptance and adoption of SETs. Table 7 reveals how perception on usefulness and ease of use influence Attitudes and intention to adopt SETs.

Subsequently, the identified factors were identified including knowledge, awareness, trust, social influence, policy, self-efficacy, compatibility, demographics, perceived risk, and perceived enjoyment. ***Third*** involves examining the influence of the identified influential factors or external variables on PU, PEOU, Attitudes, BI, and Actual Use. Although the interrelationships among the 10 identified factors are acknowledged, for instance, examining the positive influence of trust on social influence, the focus on the interactions between these factors remains limited in this study.

Knowledge on the benefits of using SETs plays a significant role in shaping how individuals perceive and intend to use new technologies. Existing studies by Alkawsi et al. (2020), Kardooni et al. (2016), Badri-Harun et al. (2017), Shuhaiber and Mashal (2019), Malik and Ayop (2020), and Chou and Gusti Ayu Novi Yutami (2014) have demonstrated the importance of knowledge and awareness in influencing the perceptions and intention to use SETs (as shown in Table 7). For instance, Alkawsi et al. (2020) integrates knowledge on electricity-saving and environmental awareness into the UTAUT2 model to explain the user intention to adopt smart meters. Moreover, providing knowledge as well as practical experience such as through actual green home demonstrations can also encourage users' attitudes (Badri-Harun et al., 2017). Furthermore, Kardooni et al. (2016) reveals the positive influence of knowledge and awareness on the Perceived Usefulness (PU) of renewable energy technology.

Findings also indicate that effective policies can be leveraged to increase awareness through training programs and initiatives, as well as to promote the adoption of technologies by offering incentives to retailers who promote them (Ali et al., 2020), (Girod et al., 2017),(Xingdong et al., 2019). Examples from Europe illustrate the importance of policy for the successful adoption of smart meters- Finland and Sweden lead with mandates, Denmark focuses on carbon goals, the Netherlands addressed privacy concerns with a 2011 mandate, and Germany is behind due to lack of incentives (Zhou & Brown, 2017). Moreover, in the context of smart thermostat, Girod et al. (2017) suggests policies that offers incentives to retailers can enhance the adoption these technologies (shown in Table 7).

Studies by Warkentin et al. (2017) and Shuhaiber and Mashal (2019) reveal the importance of trust in influencing Attitudes, Behavioral Intention, and actual use of SETs. For instance, trust positively influences people's attitudes toward adopting smart homes (Shuhaiber & Mashal, 2019).

In addition, a study shows that trusting beliefs positively influence behavioral intention to adopt smart metering technology (Warkentin et al., 2017). It means that if individuals believe that their utility companies will securely manage their personal data, are indeed more likely to intend to adopt smart meters (shown in Table 7).

Studies have highlighted the effects of social influence, an element from UTAUT, on the adoption of Smart Energy Technologies (SETs). Studies reveal the crucial role of social influence on the acceptance and actual use of SETs (Guerreiro et al., 2015), (Xingdong et al., 2019), (Chen et al., 2020) and (Pathania et al., 2017). For instance, findings on significant impacts of social influence, particularly through subjective norms on the adoption of smart meters, highlighting how individuals' perceptions of others' opinions affect their own behavior (Guerreiro et al., 2015).

Table 7. Analyzing the influential factors to TAM model application for various technologies

Factor	Description	Impact on TAM	References
Knowledge	Refers to an individual's possession of information about something (e.g. electricity savings)	Public knowledge has a positive impact on PU, PEOU, and BI. Changing user's attitude requires knowledge and experience (e.g. providing actual product demonstration)	(Alkawsi et al., 2020),(Kardooni et al., 2016),(Badri-Harun et al., 2017),(Huijts, Molin, & Steg, 2012),(Koenig-Lewis, Marquet, Palmer, & Zhao, 2015b),(Michels et al., 2019)
Awareness	The degree to which a consumer is aware or understand something	Awareness can influence attitude and BI to use technology. Awareness is the first step for user towards knowing that a certain technology exists, thus, government should	(Al-Okaily et al., 2020),(Shuhaiber & Mashal, 2019),(Alkawsi et al., 2020),(Almuraqab & Jasimuddin, 2017),(Malik & Ayop, 2020),(Chou & Gusti Ayu Novi Yutami,

	(e.g. technology)	implement awareness initiatives	2014),(Alzubi et al., 2017), (Kumar et al., 2018)
Trust	The level of comfort, confidence or belief that the technology or service is reliable and safe to use. It is essential for building good relationship with the technology.	Trust can influence PU, PEOU, Attitude, BI and actual use. People put their trust to actors who are responsible for technology (e.g. technology providers) especially when they know a little about the technology	(Gefen, Karahanna, & Straub, 2003),(Albayati et al., 2020),(Etemad-Sajadi & Gil Gomes Dos, 2019),(Warkentin et al., 2017),(Matemba & Li, 2018), (Shuhaiber & Mashal, 2019),(Huijts et al., 2012),(Almuraqab & Jasimuddin, 2017),(Al-Saedi et al., 2020), (Kamal et al., 2020), (Alalwan et al., 2018),(Kasilingam, 2020),(Dirsehan & Can, 2020),(Malaquias & Silva, 2020)
Social influence	The degree to which an individual perceives the importance of others to believe that he or she should use the new system. Social	Social intention can influence PEOU, PU, trust, attitude and BI. Peers such as family and friends or superiors are important on users' decision to adopt to new technology	(Al-Okaily et al., 2020),(Chou & Gusti Ayu Novi Yutami, 2014),(Dutot, 2015),(Nabhani et al., 2016),(Albayati et al., 2020),(Koenig-Lewis et al., 2015b), (Al-Saedi et al., 2020),(Kamal et al., 2020),(Nabhani et al., 2016),(Almuraqab & Jasimuddin, 2017),(Baudier et al., 2020), (Nath et al., 2013),(Talukder et al.,

	influence has several sub-constructs including social factors, social norms and subjective norms		2019),(Lin et al., 2020),(Chen et al., 2020),(Xingdong et al., 2019),(Guerreiro et al., 2015)
Policy	The principles or regulations to guide decisions and achieve rational outcomes (e.g. energy labelling of household appliance policy)	Policy can influence the user's behavioral intention. Policy can be used as tools to enhance awareness through trainings or programs and enhance the diffusion of technologies by providing incentives to retailers in promoting the technologies	(Ali et al., 2020),(Girod et al., 2017),(Xingdong et al., 2019)
Self-efficacy	A person's judgement or confidence in using a technology effectively	Self-efficacy has an influence to PEOU, BI and actual use of technology. Citizens with high technological self-efficacy	(An-Chi & Tsung-Yu, 2020; Nath et al., 2013),(Al-Saedi et al., 2020),(Silva-C et al., 2019),(Suur-Inkeroinen & Seppänen, 2011),(Kung-Teck et al., 2012),(Nath et al., 2013),(Sepasgozar et al., 2019)

		use technology more frequently	
Compatibility	An important factor when choosing smart home services, as it requires connections and communications with technologies (e.g. home appliances)	High compatibility between technology and users' existing values and experiences will reduce uncertainties, and will positively influence PU, PEOU and BI	(Shin et al., 2018),(Silva-C et al., 2019),(Hubert et al., 2019),(Sepasgozar et al., 2019),(Ahn et al., 2016)
Demographics	Consist of age, gender, race and education	Demographics influence PU and attitude towards using the technology. A study reveals that men are more concern about the usefulness of a technology compare to women	(Shin et al., 2018),(Sánchez-Mena et al., 2017),(Girod et al., 2017),(Kung-Teck et al., 2012),(Sánchez-Mena et al., 2017)
Perceived risk	The probability of something happening and the	Perceived risk can influence PU, PEOU and BI. Meanwhile, perceived risk of technology (e.g. m-payments) can be reduced	(Al-Saedi et al., 2020),(Koenig-Lewis et al., 2015b),(Hubert et al., 2019),(Chou & Gusti Ayu Novi Yutami, 2014),(Shuhaiber

	outcome of the consequences	through word-of-mouth from leaders or social influence, and by providing customers with an enjoyable experience.	& Mashal, 2019),(Warkentin et al., 2017)
Perceived Enjoyment	A belief that using a technology is enjoyable. Perceived enjoyment somewhat similar to hedonic expectancy, which described as to which a consumer expects that using a technology is interesting and fun	Perceived enjoyment can influence PU, PEOU, perceived risk, attitude and behavioral intention. Perceived enjoyment to technology (e.g. m-payment) can be increased by designing a good and enjoyable user interface for users.	(Shuhaiber & Mashal, 2019),(Ahn et al., 2016),(Koenig-Lewis et al., 2015b),(Basoglu et al., 2017),(Girod et al., 2017),(Kasilingam, 2020),(Ahn et al., 2016)

2.1.4 Conclusion and implications

This paper investigated the application of TAM to various technologies. Understanding the phenomenon of technology adoption is key for sustainable growth. This study finds that TAM is an effective theory to use for examining factors that influence users' decisions to adopt the technology. Specifically, utilizing 54 empirical articles, this study is among the few to propose a review of a comprehensive technology adoption framework, which includes the different technology contexts within different publication phases from 2011 to 2020 across the geographic regions of Asia, Europe, Africa, Canada and America. Our findings highlight the ten most influential factors associated with users' acceptance and adoption to technology. Specifically, this study finds that **policy** has a significant effect on behavioral intention (BI), while **self-efficacy** and **social influence** have impacts on PU, PEOU, Attitude, trust and BI. **Compatibility** has an impact on PU, PEOU, Attitude and BI. **Enjoyment** can influence PU, PEOU, Attitude and BI. Meanwhile, **Trust** can influence PU, Attitude, BI and actual use. **Perceived risk** has an impact on PU, PEOU and Attitude. **Demographics** can influence PEOU, PU, Attitude, and Actual Use. **Awareness** can influence attitude and BI. **Knowledge** can influence PU, PEOU and BI.

Furthermore, our findings have both theoretical and practical implications. Theoretically, this study will contribute to the emerging technology acceptance literature as it can be used as a guide when conducting empirical research on influential factors to technology adoption of a specific technology. Practically, results provide additional insights into the field of user behavior that can benefit various stakeholders when making decisions on technology adoption matters. In addition, this study will help technology providers in understanding key factors surrounding technology adoption context that may support the successful adoption of technology. Finally, our results suggest that understanding users' behavior by enhancing awareness and knowledge about current environmental conditions could be an appropriate political measure to improve individuals' acceptance of technology.

2.2 Influential Factors to Residential Building Occupants' Acceptance and Adoption of Smart Energy Technologies in Denmark

After the literature review, a quantitative study of more than 3,000 residential building occupants in Denmark was conducted. This study extended the original TAM by integrating other factors from different models (e.g. TAM2 and UTUAT) to achieve a more holistic understanding of technology acceptance. To conduct an in-depth analysis, only five of the identified factors from the literature review were considered. Specifically, the study examined how factors like Perceived

Usefulness (PU), Perceived Ease of Use (PEOU), Attitudes, policy, awareness, knowledge, trust, and social influence impact behavioral intention (BI) to adopt smart energy technologies.

2.2.1 Introduction

Buildings (e.g., residential, commercial, and industrial) share 40% of the total global energy consumption and are responsible for 30% of total global greenhouse gas emissions (He and Chen (2021). Residential buildings are considered the main contributors of carbon dioxide emissions (Badri-Harun, Shaari, Jaafar, & Julayhe, 2017). In Denmark, there were nearly 2.75 million residential buildings in 2021[1] . According to Kragh and Wittchen (2014), residential buildings in Denmark share 30% of country's energy consumption and single-family occupied houses have a significant potential for energy savings. Danish residential buildings are divided into houses or villas, farmhouses, townhouses, dormitories, 24-hour care centres, and others (Kristensen & Petersen, 2021). According to Climate Action Strategy ("Global Climate Action Strategy," 2021), Denmark aims to cut 70% of its emissions by 2030 and to be completely climate neutral by 2050. To achieve this goal, deploying clean energy technologies and improving energy efficiency(Kragh & Wittchen, 2014) are necessary. Similarly, Attour, Baudino, Krafft, and Lazaric (2020) argued that sustainable energy transition requires high acceptance and adoption of SETs. In response, Prete et al. (2017) suggested applying Energy Efficiency Measures (EEMs) in residential buildings to help reduce energy consumption. Moreover, to reduce energy consumption and improve energy efficiency (Bhati, Hansen, & Chan, 2017), adoption of SETs has become one of the top priorities of the European Commission since 2015(Baudier, Ammi, & Deboeuf-Rouchon, 2020).

SETs are energy-saving technologies comprise of sensors and automatic control(Schieweck et al., 2018) such as solar PV, HVAC systems, smart appliances, smart meters, energy monitoring and control systems, and electric vehicles (Geelen, Reinders, & Keyson, 2013; Nižetić, Djilali, Papadopoulos, & Rodrigues, 2019; Perri, Giglio, & Corvello, 2020). In addition, Baudier et al. (2020) identified international SETs providers to include Whirlpool, Electrolux, Bosh/Siemens, General Electric, Samsung, LG, AT&T, and Philips. Furthermore, SETs help improve energy

[1] **Number of residential buildings in Denmark from 2010 to 2021**
https://www.statista.com/statistics/1089866/number-of-residential-buildings-in-denmark/

efficiency and increase the integration of renewable energy sources (Spence et al., 2021). For instance, Engvang and Jradi (2021) claim that 29% of energy-savings come from using building automation and control systems (BACS) in buildings.

However, even though the public is aware of environmental issues, many continue adapting their current energy consumption practices and are somewhat reluctant to accept SETs (Gimpel, Graf, & Graf-Drasch, 2020). In this case, better understanding of users' perception (Rice et al., 2021) and identifying the factors (Rizzo, Piper, Irene Prete, Pino, & Guido, 2018; Sharma et al., 2021) that influence behaviour are essential to promote a successful integration of SETs in buildings (Shin, Park, & Lee, 2018; Vassileva & Campillo, 2017). However, very few, if any, have studied the influential factors of SETs adoption in a green pioneering country, such as Denmark, identifying the influential factors and their effects on user behaviours to improve energy efficiency. In response, this study adopts TAM in order to examine the influential factors and their effects on individuals' intention to adopt SETs in residential buildings. Moreover, considering the wide variety of SETs intended for different purposes, this paper focuses on SETs in general. This study aims to identify the influential factors on residential building occupants' acceptance and adoption of SETs.

2.2.2 Theoretical Frameworks

This chapter proposes an approach to addressing the influential factors of acceptance and adoption of SETs. This study applied Technology Acceptance Model (TAM) due to the ease of application (Mathieson, 1991) and being most useful model for explaining factors that influence technology acceptance and adoption (C.-f. Chen et al., 2020). Through this framework, significant effects of TAM constructs and external factors are highlighted. Before outlining the framework, TAM and external factors will be introduced in order to explain technology acceptance and adoption.

2.2.2.1 Understanding the Technology Acceptance Model

Fred Davis (1986) developed Technology Acceptance Model (TAM) based on Theory of Reason Action (TRA). Theory of Reason Action (TRA) was developed by Ajzen & Fishbein, suggesting that "actual use is determined by behavioural intentions, which in turn are determined by two factors: attitudes and subjective norm" (p.4)(Chiung-Wen, Chun-Po, & Li-Ting, 2017). Moreover, TAM is a widely used model explaining the behavioural intention of technology acceptance (An-Chi & Tsung-Yu, 2020; Chin & Lin, 2015). For instance, TAM is applied to predict user acceptance of smart home appliances (An-Chi & Tsung-Yu, 2020), smart meters (C.-f. Chen, Xu, & Arpan, 2017) and internet banking (Chauhan, Yadav, & Choudhary, 2019). In addition, a study claimed that TAM can predict both users' initial and continued usage behaviour (Hong, Thong, & Tam, 2006). TAM constructs include Perceived Usefulness (PU), Perceived Ease of Use (PEOU), attitudes, and Behavioural Intention (BI), which combines to influence users' actual use of a technology (Davis, 1989). Fred Davis defined PU as the individual's belief that a certain technology can enhance job performance, while PEOU refers to individual's belief that using the technology is free of effort (Davis, 1986, 1989). Moreover, attitudes toward using a technology is defined as the degree of the user's feelings about using technology, whereas behavioural intention refers to the user's readiness to adopt the technologies (Davis, 1989).

According to TAM, PEOU can influence PU (Hong et al., 2006), while PU and PEOU would develop attitudes toward using the technology and BI, which in turn, influences individuals to use the technology (Davis, 1989). Moreover, studies revealed that PU is a significant factor affecting the adoption of SETs (Shin et al., 2018). For example, Xingdong, Yanling, Rong, and Peijuan (2019) argued that PU predicts users' adoption to solar water heating. Furthermore, PU and PEOU are important factors for driving the adoption of smart home technology (Nikou, 2019). In addition, C.-f. Chen et al. (2020) claimed that PU and attitudes are positively associated with the BI of adopting HEMS in Japan and the United States. A recent study claimed that attitudes (Prete et al., 2017) has a significant impact on BI to adopt Energy Efficiency Measures (EEMs). Furthermore, Hong et al. (2006) argued that BI influences the actual usage of SETs.

However, PU and PEOU may not be enough to predict users' attitudes and intention to use the technology (C.-f. Chen et al., 2017). An-Chi and Tsung-Yu (2020) mentioned that "different external variables (e.g., personal factors and group factors) influence PU and PEU in a system, which in turn indirectly affect AT and BI, and BI would influence individual's actual usage of technology" (p.102).

2.2.2.2 External factors that influence smart energy technology acceptance and adoption

Devaraj, Easley, and Crant (2008) examined the relationship between external factors (personality) and technology acceptance. In addition, Shuhaiber and Mashal (2019), An-Chi and Tsung-Yu (2020), and Alkawsi, Ali, and Baashar (2020) applied TAM to examine the influential factors of users' acceptance to SETs. Furthermore, there are various factors to acceptance and adoption to SETs, making consideration of all these factors impossible. Meanwhile, Billanes and Enevoldsen (2021) provided a guide on influential factors of technology acceptance and adoption such as awareness, knowledge, policy, trust, and social influence, etc.

1. Awareness

Awareness is referred to as human's state of consciousness (Almuraqab & Jasimuddin, 2017) that can influence user's intention to use the technology (Alzubi, Farea, & Al-Dubai, 2017; Shuhaiber & Mashal, 2019). Awareness reduces uncertainty (Shuhaiber & Mashal, 2019) and provides understanding of the different aspects of technology including its benefits (Shahzad, Xiu, Wang, & Shahbaz, 2018). For example, users' awareness of the level of energy consumption (Perri et al., 2020) and negative impacts of energy consumption to the environment help increase users' willingness to adopt smart energy technologies (Taso, Ho, & Chen, 2020). Likewise, Parag and Butbul (2018), and Alkawsi et al. (2020) claimed that understanding the environmental benefits of energy saving increases the user's willingness to adopt the technology. Moreover, the study of Chou and Gusti Ayu Novi Yutami (2014) on smart meters and Sharma et al. (2021) on solar lamps revealed awareness as one of the influential factors to users' willingness to adopt SETs.

2. Knowledge

According to Alkawsi et al. (2020) knowledge is an individual's possession of information. Studies show how increasing knowledge about a technology has a positive effect on users' behavioural intention to accept and adopt SETs (Egnér & Trosvik, 2018; Sovacool, Martiskainen, & Furszyfer Del Rio, 2021; Wang, Wang, Lin, & Li, 2019). On the other hand, lack of users' knowledge of smart energy technologies (Ochieng et al., 2014) can result in low adoption of SETs (Cristino, Lotufo, Delinchant, Wurtz, & Faria Neto, 2021; Shuhaiber & Mashal, 2019). Knowledge about renewable energy can influence users' perceptions on the usefulness of technology, which in turn, influences their attitudes toward using renewable energy (Kardooni, Yusoff, & Kari, 2016). The study of Egnér and Trosvik (2018) shows that knowledge and experience of driving EVs are important to increase EV adoption.

3. Policy subsidy and program

Effective policies can influence adoption of SETs (e.g., solar water heater)(Xingdong et al., 2019). According to Yang, Chen, Mi, Li, and Qi (2021), environmental taxes, subsidies, and carbon trading are effective policy instruments for installing SETs in buildings. Likewise, Marino and Marufuzzaman (2020) explained that law and regulation framework, financial incentives, and non-financial incentives can promote EV adoption. Meanwhile, Zhou and Brown (2017) examined how different policy measures have been adopted in Sweden, Finland, Denmark, Germany, and Netherlands to address the barriers of smart meter deployment. Energy labelling mechanism on appliances (Zhang, Xiao, & Zhou, 2020) is also an efficient policy for SETs adoption. Singapore, for example, introduced a Mandatory Energy Labelling program known as Energy Conservation Act (2012) that mandates energy labels on all electrical appliances (e.g., refrigerators, air conditioners, etc.)(Bhati et al., 2017). Moreover, banning incandescent lamps is considered as the most effective policy to increase the adoption of efficient lighting (Hesselink & Chappin, 2019).

According to Girod, Mayer, and Nägele (2017), policies that incentivize retailers for selling SETs to their customers is an effective approach to increase widespread adoption of SETs. A study showed that government programs in China, such as providing non-interest loans, can motivate low income households to adopt solar water heating (Xingdong et al., 2019). Subsidies can also compensate for the high cost of SETs and motivate users (L. Chen, Gao, Hua, Gong, & Yue, 2021), such as incentivizing companies to support the deployment of smart thermostats and other smart energy technologies (Girod et al., 2017). Studies of He and Chen (2021), Hesselink and Chappin (2019), Zhang et al. (2020) and L. Chen et al. (2021) show that subsidies can help stimulate SET adoption. On the other hand, Chou and Gusti Ayu Novi Yutami (2014) suggested that understanding consumer concerns and preferences are needed when designing policies for technologies like smart meters.

4. Trust

Trust in technology refers to the level of belief and confidence that the users have when using the technologies (Al-Azawei & Alowayr, 2020; Albayati, Kim, & Rho, 2020; Chiung-Wen et al., 2017). According to Shuhaiber and Mashal (2019), trust is important as it reduces social complexity (Gefen, Karahanna, & Straub, 2003) and maintains confidence among stakeholders (Albayati et al., 2020). A study showed that trust affects users' behavioural intention and hedonic motivation in mobile learning in Saudi Arabia and Iraq (Al-Azawei & Alowayr, 2020). Likewise, a study revealed that trust is one of the influential factors of residents' acceptance and use of smart homes (Shuhaiber & Mashal, 2019).

5. Social influence

Social influence is synonymous to subjective norms (Dutot, 2015) and social norms (Al-Saedi, Al-Emran, Ramayah, & Abusham, 2020). Social influence is defined as the degree to which a user believes that others, such as peer groups, family members, friends, and acquaintances believe that he/she should use a new technology (Ahn, Kang, & Hustvedt, 2016; Geelen et al., 2013; Girod et al., 2017; Kamal, Shafiq, & Kakria, 2020; Siddiki et al., 2015). According to C.-f. Chen et al. (2020), social norms are positively associated with behavioural intention of adopting HEMS in Japan and the US. Likewise, in the study of Dutot (2015), social influence is considered to be one of the factors influencing Near Field Communication (NFC) adoption.

2.2.2.3 Research model and hypotheses of the present study

This study's contribution to the technology acceptance and adoption literature is twofold. First, this study adds to the collective body of knowledge on the role of PU, PEOU, and Attitudes of technology acceptance and adoption. This is done by examining how the TAM constructs' influence on residents' behavioural intention to accept and adopt SETs (shown in Figure 4). The effects of BI on the actual use of SETs were not studied because TAM claims that the actual use of the technology is an outcome of the behavioural intention. Therefore, in this study, it is anticipated that BI leads to actual use of SETs. Second, this study examines how external factors (trust, knowledge, policy, awareness, and social influence) influence residents' intention to accept and adopt SETs. In general, hypotheses were inspired by the literature (e.g., TAM) and findings of the empirical studies discussed in Table 8.

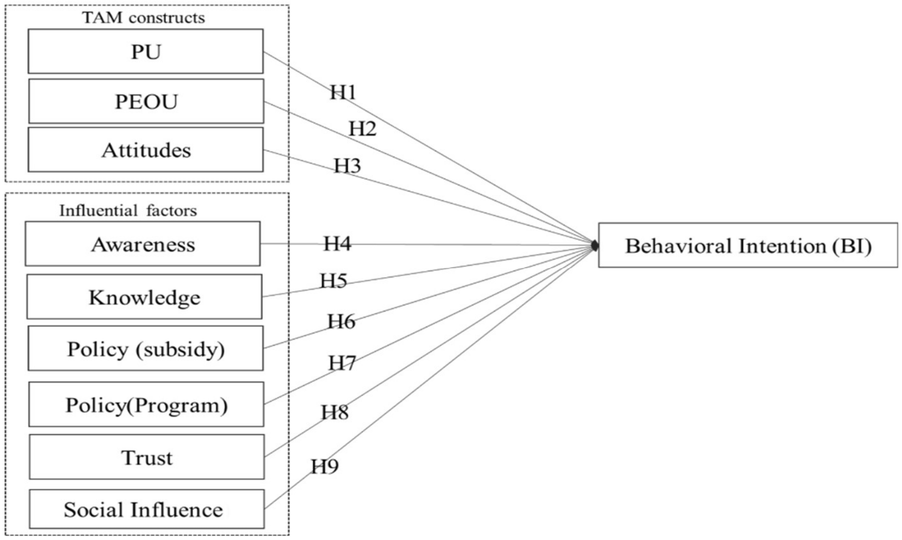

Figure 4 Research Model of hypothesized influential factors

Table 8. Hypotheses

H1	PU has a significant effect on BI
H2	PEOU has a significant effect on BI
H3	Attitudes have significant effects on BI
H4	Awareness has a significant effect on BI
H5	Knowledge has a significant effect on BI
H6	Subsidy has a significant effect on BI
H7	Government program has a significant effect on BI
H8	Trust has a significant effect on BI
H9	Social influence has a significant effect on BI

2.2.3 Methodology

This is a quantitative study applying TAM as a theoretical framework to formulate survey questions and then to interpret results. Specifically, this study tested the relationships between TAM variables (PU, PEOU, Attitudes and BI) and assessed the effects of five external factors of technology acceptance and adoption of SETs. The targeted respondents of the present study are energy consumers in Denmark. Data is collected through a self-administered questionnaire and analysed statistically.

2.2.3.1 Survey design and data collection

An online survey was conducted with energy consumers in Denmark. The study was distributed randomly to more than 3,000 residents in Denmark. Data for this research were collected in spring 2021 via SurveyXact online survey platform. A set of screening criteria was used to ensure that the survey was completed by a relevant sample of potential consumers. Respondents had to meet the following criteria: be at least 18 years of age, resident of Denmark, and pay utility bills. The survey was first developed in English and then translated into Danish, and then distributed to residential building occupants across Denmark. Demographic information was collected at the end part of the survey. The final valid responses include 32% residential building occupants from main cities, 23% from middle Jutland, 22% from Southern Denmark, 14% from Zealand, and 9% from North Jutland. Among the respondents, 51% were male and 49% were female. The largest age group was aged 65 and above (43%) while the smallest group was aged 18-24(6%). The largest income group was 10,000-19,999kr per month, (26%), followed by 20,000-29,000kr (20%), then 18% preferred not to say their income, 30,000-39,999Kr (15%), 40,000kr and above (14%), and under 9,999kr (7%) as shown in Table 9.

Table 9. Sample profile of respondents

Item	Variable	Frequency	Percentage (%)
Gender			
	Male	1,633	51%
	Female	1,562	49%
	Others	5	0%
	Prefer not to say	5	0%
Age			
	18-24	189	6%
	25-34	394	12%
	35-44	332	10%
	45-54	394	12%
	55-64	516	16%
	65 and above	1,377	43%

Education			
	Primary school	360	11%
	Secondary	428	13%
	Diploma	911	29%
	Bachelor or undergraduate	875	27%
	Post-graduate	519	16%
	Prefer not to say	100	3%
Employment			
	Fulltime	945	30%
	Part-time	193	6%
	Self-employed	136	4%
	Unemployed	154	5%
	A student	230	7%
	Retired	1,430	45%
	Others (please specify)	105	3%
Types of dwellings			
	House/villa	1,445	45%
	Apartment	1,149	36%
	Townhouse	437	14%
	Rural property	132	4%
	Others	30	1%
Region			
	Main cities	1,006	32%
	Middle Jutland	737	23%
	Southern Denmark	709	22%
	Zealand	443	14%
	North Jutland	298	9%
Income			
	Under 9,999kr	235	7%
	10,000-19,999kr	818	26%
	20,000-29,999kr	628	20%
	30,000-39,999Kr	487	15%
	40,000kr and above	435	14%
	Prefer not to say	590	18%

2.2.3.2 Measures

The survey instrument is based on reviewing the literature about the most influential factors of technology adoption. The online questionnaire is divided into two sections. First*,* residential building occupants' perceptions and intentions to adopt smart energy technologies. This section contained measures of TAM constructs and five influential factors of users' behavioural intention to accept and adopt to SETs. There was one item in each measured construct, except for policy, which contained two items (shown in Table 8). The responses are measured using 5-point Likert scale, ranging from 1 which indicates *"strongly agree"* to 5 indicating *"strongly disagree"* to capture deviations of the respondents' opinion. Second*,* respondents were asked about demographic information including gender, age, employment, location, education, types of dwelling, and income.

2.2.4 Analysis and results

Cronbach´s alpha, correlation matrix and multiple regression were conducted via SPSS to measure the effects of identified influential factors to acceptance and adoption of SETs.

2.2.4.1 Validity and reliability of the data

Cronbach's alpha is one of the common measures for internal consistency and reliability (Zhang et al., 2020). The 10 items that were checked include PU, PEOU, attitudes, BI, policy (subsidy), policy (program), awareness, trust, social influence, and knowledge. The Cronbach's alpha for the sample data is $\alpha = 0.86$, indicating that measures reach good reliability, exceeding the recommended lowest threshold of 0.70 (Cronbach, 1951). In addition, item-total statistics show that most items are worthy of retention, and even though it will result an increase in the alpha when one item is deleted. For example, deleting the social influence item would show minor improvement in $\alpha = 0.87$. Since, $\alpha = 0.86$ is already a good alpha measure, there is no need to drop a social influence item.

Table 10. Correlation Matrix

	BI	PU	PEOU	Attitudes	Subsidy	Program	Trust	Awareness	SI	Knowledge
BI	1.000									
PU	0.343	1.000								
PEOU	0.403	0.394	1.000							
Attitudes	0.455	0.569	0.494	1.000						

Subsidy	0.447	0.340	0.360	0.479	1.000					
Program	0.442	0.385	0.311	0.424	0.635	1.000				
Trust	0.306	0.405	0.402	0.497	0.334	0.350	1.000			
Awareness	0.406	0.437	0.452	0.503	0.342	0.324	0.498	1.000		
SI	0.340	0.169	0.152	0.192	0.257	0.298	0.126	0.178	1.000	
Knowledge	0.505	0.427	0.379	0.511	0.481	0.513	0.410	0.469	0.380	1.000

Notes: SI=social influence; BI=behavioural intention; PEOU= perceived ease of use; PU= perceived usefulness

Correlation matrix shows the linear association between variables (see in table 10). According to Schober, Boer, and Schwarte (2018), thresholds with absolute correlations of 0.36-0.39 are considered weak, 0.40-0.69 are moderate, while 0.90-1.00 are strong or high. Results indicate significant weak and moderate correlations, and as shown on Table 3, correlations of the 10 constructs range from 0.126 to 0.635. For instance, weak correlation between PEOU and PU, p=0.394. In addition, weak correlation between subsidy and PU, p=.340; and SI and PU, p=0.169. Meanwhile, Attitudes and PU demonstrate moderate correlation, p=0.569. Similarly, knowledge is moderately correlated to PU, p=0.427, subsidy and program are moderately correlated at p=0.635, and subsidy is moderately correlated to Attitudes, p=0.479.

2.2.4.2 Multiple linear regression analysis

This section presents the multiple linear regression analysis on the influence of PU, PEOU, Attitudes, trust, knowledge, awareness, social influence and policy (program and subsidy) on behavioural intention to use SETs (see table 11).

Table 11. Multiple linear regression analysis summary model

Model	R	R-square	Adjusted R	Std. Error of the Estimate		
1	.624	0.390	0.388	0,757		
ANOVA						
Model		Sum of squares	df	Mean square	F	Sig
1	Regression	1164.201	9	129.356	226.021	<0.001
	Residual	1822.830	3185	0.572		
	Total	2987,031	3194			
Coefficients						

Model		B	Std. Error	BETA (standardized)	t	Sig.
1	(Constant)	0.551	0.063		8.691	<.0001
	PU	-0.002	0.021	-0.002	-0.121	0.904
	PEOU	0.159	0.019	0.138	8.170	<0.001
	Attitudes	0.151	0.024	0.126	6.285	<0.001
	Subsidy	0.117	0.019	0.116	6.054	<0.001
	Program	0.118	0.020	0.112	5.826	<0.001
	Trust	-0.042	0.019	-0.039	-2.248	0.025
	Awareness	0.123	0.020	0.112	6.272	<0.001
	SI	0.145	0.015	0.147	9.687	<0.001
	Knowledge	0.206	0.021	0.184	9.738	<0.001

Notes: SI=social influence; BI=behavioural intention; PEOU= perceived ease of use; PU= perceived usefulness a. Dependent Variable: BI; b. Predictors: (Constant), knowledge, PEOU, SI, Trust, PU, Subsidy, Awareness, program, Attitudes

The R-squared value indicates that 40% of the variance in BI can be predicted from the variables knowledge, PU, PEOU, SI, Trust, policy (subsidy and program), awareness and Attitudes, collectively, (R^2 = 0.40, F (9, 3185) =226.021), p<0.001. Looking at the unique individual contribution, PU (β= -0.002*, t*=-0.121*, p*=0.904) has no significant effect on BI, indicating that one-unit increase in PU resulted to decrease in BI by 0.002. On the other hand, PEOU (β=0.159*, t*= 8.170*, p*<0.001) and Attitudes (β=0.151*, t*= 6.285*, p*<0.001) positively influence BI. In means that for every 1-unit increase in PEOU, behavioural intention to use SETs goes up by 0.159. Meanwhile, increase of 1-unit in the rating of positive attitudes led to increase in behavioural intention to use SETs by 0.126. Moreover, subsidy (β=0.117*, t*= 6.054*, P*<0.001), program (β=0.118*, t*= 5.826*, p*<0.001) influence BI. Interestingly, Trust (β=-0.042*, t*=-2.248*, p*= 0.025) has positive significant effect on BI even though in every one-unit increase of trust led to the decrease on BI by 0.042. Moreover, awareness (β=0.123*, t*=6.272*, p*<0.001), SI (β=0.145*, t*= 9.687*, p*<0.001) and knowledge (β=0.206*, t*=9.738*, P*<0.001) positively influence BI.

Furthermore, we see that knowledge (β=0.184.) had the strongest predictive relationship to the BI, followed by SI (β=0.147), PEOU (β=0.138), Attitudes (β=0.126), subsidy (β=0.116), program (β=0.112) then trust (β=-.039), and then PU (β=-.002).

2.2.5 Discussion

Understanding the factors that can influence behaviour are valuable insights for policy makers and technology providers when stimulating the deployment of SETs. To do so, this study investigates the effects of trust, social influence, policy (subsidy and program), awareness, and knowledge on intention to accept and adopt SETs from the residential occupants' perspectives. The effects of TAM constructs (PU, PEOU and attitudes) to users' behavioural intention to use SETs were also measured. The results show that most of the hypotheses were statistically significant except first hypothesis (H1). Based on Technology Acceptance Model (TAM), PU can influence BI, however, regression analysis shows that PU has no significant effect on BI. The results imply that residential building occupants are not willing to adopt SETs even if they perceived SETs are useful for lowering energy consumption. This may be due to limited knowledge of the benefits of using SETs or may be because residential building occupants do not relate their reasons for adopting SETs with electricity consumption. This result is in line with Dutot (2015) revealing that PU has no effect on intention to use a technology. Even though PU has no effect on BI, PU is associated with PEOU and attitudes. Moreover, findings showed that PEOU and attitudes have significant effects on residential building occupants' intention to use SETs. The results indicate that residents in Denmark would be willing to accept and adopt SETs if they believe it is easy to use and they have positive attitudes of using SETs.

Furthermore, influential factors such as policy (subsidies, program), trust, awareness, knowledge, and social influence can positively influence BI. The positive effects of subsidies and programs on residential building occupants' willingness to adopt SETs implies that policymakers should consider providing programs and subsidies to foster adoption of SETs. The results also revealed that residential building occupants would be interested in adopting SETs if they are aware and have knowledge about the benefits of using these technologies. Moreover, this study revealed that trust and social influence of friends, colleagues, and family could influence residents in Denmark's' intention to use SETs. The result is similar to the study of De Giorgi et al (2020) about Danish consumption where they find that peers can influence other consumers' decisions. (De Giorgi, Frederiksen, & Pistaferri, 2020)

2.2.6 Conclusion and future studies

This paper provides a new contribution to technology acceptance research by examining the influential factors to acceptance and adoption to SETs by applying TAM as theoretical framework. The relationships between TAM variables were tested and the effects of five external factors of technology acceptance and adoption of SETs among residential building occupants were assessed. The future acceptance and adoption of SETs will depend significantly on their knowledge ($p<0.001$), awareness ($p<0.001$) and trust ($p=0.025$) of SETs. In addition, awareness ($p<0.001$), knowledge ($p<0.001$), and trust ($p<0.001$) will also play important roles in increasing the acceptance and adoption to SETs.

The results also suggest that residential building occupants would be willing to adopt SETs if they perceived SETs as easy to use and had a positive attitude towards using it. Specifically, both PEOU and attitudes p-value at <0.001 have positive effects on BI. On the other hand, the finding shows that PU ($p=0.904$) does not influence behavioural intention (BI) to use SETs. It implies a need for technology providers and researchers to focus on exploring about users' perceptions of the usefulness of SETs. Overall, this study presented policymakers and technology providers with valuable recommendations. For example, the result showing the negative effect of PU on BI provides insights of the significant factor to consider when developing strategy to increase users' adoption of SETs. Moreover, the insights on the correlations between variables contributes new knowledge to the literature on SET's acceptance and adoption.

Despite these new insights into the importance of the influential factors of SETs acceptance, the study has some limitations that could be addressed in future research. First, TAM is the theory adopted by this study, so factors such as PU, PEOU, attitudes, and external influential factors are confined under the framework of the TAM theory. Secondly, the descriptive analysis results showed that more than 43% of the respondents are 65+, which may not represent the average resident in Denmark. Lastly, this study only measured the quantitative effects of influential factors of SETs acceptance and adoption. For future studies, we suggest qualitative study of the five influential factors, for example, exploring the effects of policy and social influence on knowledge and awareness of users to increase adoption to SETs.

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3 Are residential building occupants willing to adopt smart energy technologies?

Examining the path to smart energy technology adoption in residential buildings. *J Billanes, P Enevoldsen.* 2023. *In review in the Energy Efficiency Journal*

3.1. Examining the path to smart energy technology adoption in residential buildings

The third journal article is a quantitative study on the willingness to adopt SETs involving residential building occupants in Denmark. To address the research question, smart energy technologies owned by residential building occupants and the reasons for not buying these technologies were identified. The residential building occupants were also asked how familiar they are with SETs. Moreover, how factors such as knowledge and awareness, types of dwelling and income are associated to the willingness to adopt SETs were examined. To do that, three hypotheses were tested: (1) association between knowledge and awareness, and the willingness to adopt SETs; (2) association between income and willingness to adopt SETs; and (3) association between types of dwelling and willingness to adopt SETs. Overall, journal article 3 provides answers to whether residential building occupants are willing to adopt SETs or not, as well as the reasons for rejecting these technologies.

3.1.1 Introduction

Denmark commits to reducing its carbon emissions by 70% in 2030 compared to 1990 levels and become carbon neutral by 2050(B. K. Sovacool & Blyth, 2015). To reach the target, identifying the different types of energy consumers is necessary. Buildings are large energy consumers that share almost 36% of the total global energy consumption, exceeding the transport and industry sectors (Badri-Harun et al., 2017; Balaban & Puppim de Oliveira, 2017) and are responsible for about 40% of total global greenhouse gas emissions(Darko, Chan, Ameyaw, He, & Olanipekun, 2017). Excessive energy consumption implies a need for energy efficiency and energy savings (Ameli & Brandt, 2015; Cristino et al., 2021; Hesselink & Chappin, 2019). This study defines energy efficiency as using less energy while performing and achieving the same services (Hesselink & Chappin, 2019). A smart approach to increasing energy efficiency and reducing energy demand is through the integration of smart energy technologies (SETs) in buildings(Ameli

& Brandt, 2015),(Vrain & Wilson, 2021). In this regard, the European Union implemented Energy Efficiency Directives of 2012 (Directive 2012/27/EU)(Casado-Mansilla et al., 2018) that encourage countries like Denmark, Sweden, and Spain to adopt SETs such smart meters(Y. Chawla, Kowalska-Pyzalska, & Widayat, 2019). Moreover, Chen & Sintov (2016) state *"to achieve energy savings, emerging energy technologies and programs require customer adoption"*. Adoption of smart energy technologies occurs when the user purchases, operates, and utilizes the technology(Attour et al., 2020).

Despite the potential advantages of SETs, individual's uptake of these technologies remains low (Berardi, 2013; Cristino et al., 2021; Gimpel et al., 2020; Wilson, Hargreaves, & Hauxwell-Baldwin, 2017). Examining the willingness to adopt SETs(R. Li, Dane, Finck, & Zeiler, 2017) and identifying barriers of adoption are important for technology providers and policymakers in determining approaches to widespread adoption of SETs. A study reveals that energy consumers are not familiar with SETs, for example, in responses to questions about the definitions of "smart metering" and "smart grid"(Y. Chawla & Kowalska-Pyzalska, 2019). Understanding users' level of knowledge, referring to the individual's possession of relevant information (Alkawsi et al., 2020), and preferences of smart energy technologies (Chou & Gusti Ayu Novi Yutami, 2014) are also essential for the successful adoption of smart energy technologies, and conclusively for achieving a sustainable society(Ghansah, Owusu-Manu, Ayarkwa, Edwards, & Hosseini, 2021). In Europe, for example, energy consumers are concerned about the environment but lack knowledge on the benefits of using smart energy technologies (Biresselioglu, Nilsen, Demir, Røyrvik, & Koksvik, 2018; Shirani, Groves, Henwood, Pidgeon, & Roberts, 2020). Denmark is often highlighted for its advanced transition to renewables (Mey & Diesendorf, 2018), and for being the birthplace of multiple critical wind energy innovations(B. Sovacool & Enevoldsen, 2015). However, despite that, Danes identify themselves as being green, energy know-how is limited among Danish residents (B. K. Sovacool & Blyth, 2015). Meanwhile, Yuan, Zuo, and Ma (2011) argue that socio-demographic characteristics (e.g. Income, age and education) play an important role in the level of knowledge and adoption of SETs. For example, a study suggests that younger men with high income and higher education have greater potentials for technology adoption (Girod et al., 2017). In response to this apparent lack of consensus and transparency on the topic of SETs' adoption, this study aims to examine residential building occupant's knowledge of SETs and willingness to adopt to SETs in Denmark.

3.1.2 Literature review

3.1.2.1 Smart energy technologies in buildings

Different types of smart energy technologies are presented in Table 12. Smart energy technologies refer to energy-saving technologies(Gimpel et al., 2020) that incorporate information and communication technologies (ICT)(Biresselioglu et al., 2018; R. Li et al., 2017) to provide thermal comfort, better air quality, and low greenhouse gas emissions(Cristino et al., 2021). SETs are also known as "smart technologies" (R. Li et al., 2017; O'Grady et al., 2021); "smart home technologies"(Furszyfer Del Rio, Sovacool, & Griffiths, 2021; Nikou, 2019; Schieweck et al., 2018; Tirado Herrero et al., 2018; Wilson et al., 2017); "smart home products"(Ford, Pritoni, Sanguinetti, & Karlin, 2017), "smart home technology"(Parag & Butbul, 2018); "novel green consumer technologies"(Girod et al., 2017); "energy-saving technology"(Berardi, 2013); "smart building technologies"(Ghansah et al., 2021); and "building energy-efficient (BEE) technologies"(Cristino et al., 2021). SETs include micro-generators (e.g., solar panels), smart HVAC systems, smart appliances, smart meters, energy monitoring, and control systems etc. (Geelen et al., 2013; Nižetić et al., 2019; Perri et al., 2020). Furthermore, smart homes are equipped with SETs such as HEMS, smart home appliances, EVs, and smart lightings (Furszyfer Del Rio et al., 2021).

Table 12. Most common description of Smart energy technologies

Smart Energy Technologies	Description and Usage	Reference(s)
Smart HVAC systems	• Refers to heating, ventilation, and air-conditioning system known to be responsible for large energy consumption in buildings	(O'Grady et al., 2021; Sharda, Singh, & Sharma, 2021)
Home Energy Management System (HEMS)	• Enable consumers to visualise, monitor, and manage energy consumption	(Schieweck et al., 2018; Whittle et al., 2020; B. Zhou et al., 2016)

Building Automation System (BAS)	• Control and monitor building technologies	(O'Grady et al., 2021)
Smart lightings	• Energy efficient lightings (e.g., LED) that reduces energy usage by up to 40%	(Bhati et al., 2017)
Smart thermostat	• Optimize the heating and cooling systems in buildings	(Gimpel et al., 2020)
Smart meters	• Measure electricity consumption and generation	(Geelen et al., 2013)
Photovoltaic solar panels (Solar PV)	• Distributed renewable generation in residential buildings	(B. Zhou et al., 2016), (Malik & Ayop, 2020)
Electric vehicles (EVs)	• Cars equipped with electric motors	(Vassileva & Campillo, 2017)
Smart home appliances	• Programmed and remote appliances that provide comfort and smart lifestyle to building occupants	(An-Chi & Tsung-Yu, 2020; Sharda et al., 2021)

3.1.2.2 Residential building occupants' knowledge and willingness to adopt SETs

According to studies, knowledge has a positive impact to the energy consumer's awareness and perceptions about the usefulness of the smart energy technology (Ghansah et al., 2021; Kardooni et al., 2016; Torstensson & Wallin, 2015). In addition, knowledge can also influence residential building occupant's willingness to adopt SETs(S. Wang et al., 2019). For instance, Parsad, Mittal, and Krishnankutty (2020) claim that knowledge and awareness about the benefits of solar PV are significant factors to willingness to adopt solar PV.

Meanwhile, understanding how technology users make decisions about their usage of energy and technologies is important (B. Chen & Sintov, 2016). In addition, Sanguinetti, Karlin, and Ford (2018) categorized users of Home Energy Management System (HEMS) categorized into unfamiliar, unpersuaded, persuaded, and owners. Literature suggests that socio-demographic factors such as age group, gender (C.-f. Chen et al., 2017; Schieweck et al., 2018), education, income (Yuan et al., 2011), and individual differences in household characteristics and knowledge (Biresselioglu et al., 2018) are considered influential factors to the willingness to adopt SETs. For example, a study suggests that young men with high income and higher education have greater potentials for technology adoption (Girod et al., 2017). Moreover, B. K. Sovacool, Kester, Noel, and de Rubens (2018) suggested that men with higher levels of education, in fulltime employment, and ages between 30-45, are the most likely to buy EVs. Similarly, a comparative study in Nordic countries shows that age, income and experience with EVs are significant factors to adoption of EVs(C.-f. Chen, Zarazua de Rubens, Noel, Kester, & Sovacool, 2020). Meanwhile, a study in Germany finds that willingness to install solar PV are positively related to home ownership and income(Schaffer & Brun, 2015). In Denmark, most registered owner of solar PV are male and technically educated (Hansen, Jacobsen, & Gram-Hanssen, 2022). Moreover, a study found that types of dwelling has an impact on residential building occupant's willingness to adopt energy efficient heating system(Jia, Xu, Fan, & Ji, 2018). Similarly, a study in Sweden reveals that electric vehicle drivers as male, well-educated and with medium-high income(Vassileva & Campillo, 2017).

Furthermore, studies reveal the barriers to SETs' adoption, for example, Zakaria, Basri, Kamarudin, and Majid (2019) explain that interest or exposure to a certain technology can affect users' level of knowledge to SETs. In addition, there are also studies that claim high initial cost as one of the barriers to SETs' adoption (Karytsas, 2018; W. Li, Yigitcanlar, Erol, & Liu, 2021). For instance, high battery cost (She, Qing Sun, Ma, & Xie, 2017) and higher price (Vassileva & Campillo, 2017) are considered barriers to widespread adoption of EVs. Additionally, lack of incentives(Chan, Darko, Olanipekun, & Ameyaw, 2018), lack of information or public awareness, and long-term equipment replacement are also considered barriers to SETs adoption (Bollinger, 2015; Karytsas, 2018). The lack of awareness about SETs could be due to the lack of government efforts in disseminating general information about the technologies to the people(Dutt, 2020).

3.1.2.3 Introducing three hypotheses related to set adoption

There are different types of SETs, therefore, respondent's perception of each type of SETs was measured. Hypothesis 1 measures the significant association between residential building occupant's knowledge and awareness, and willingness to adopt SETs. Socio-demographics such as age, education and gender are the most common studies we could find in the literature but very few studies looking at the other socio-demographic aspects. Therefore, in hypothesis 2, we were interested examining the association between types of dwelling and willingness to adopt SETs (shown in table 13). The study's focus is SETs' installed in buildings, therefore, it is interesting to understand whether residential building occupants consider their type of dwelling when buying technologies. In addition, high initial cost is one of the barriers in adopting SETs. Therefore, in hypothesis 3, we examined the association between income range and willingness to adopt SETs.

Table 13. Hypotheses related to knowledge and willingness to adopt SETs

Focus	**Analysis Method**	**Hypothesis**
Knowledge	Chi-square test/cross tabulation	**H1.** There is an association between awareness of sets and residential building occupant's willingness to adopt SETs
Socio-demographic factors	Chi-square/cross tabulation	**H2.** There is an association between types of dwelling and willingness to adopt SETs **H3.** There is an association between income and willingness to adopt SETs

3.1.3 Research Methods and Materials

This section presents the method of data collection, survey questions, survey participants, and demographic information. A quantitative approach is employed in data collection and analysis to examine residential building occupant's knowledge and willingness to adopt SETs.

3.1.3.1 Data collection

An online survey via surveyXact was conducted in April 2021 in Denmark. Survey participation was voluntary, and respondents had the option to refuse to participate at any time. The data collection was restricted to respondents who were minimum 18 years old and who pay household energy bills. An invitation to answer the online survey was sent to 4,392 residential building occupants, and the online survey remained open for 10 days. A total of 3,193 respondents completed the survey, representing a response rate of 73% return rate, while 84 (2%) were partially completed.

3.1.3.2 Survey questions

The survey questions were developed based on the initial literature review, which indicated a gap in insights of residential building occupants' awareness and willingness to adopt smart energy technologies. Before launching the survey, a draft of questions was shown to experts for feedback and iterations. The survey questions were developed in English and translated to Danish to avoid any misinterpretations of the questions. In addition, to ensure a high response rate, questions were asked in clear and concise sentences. The questionnaire was divided into three sections. First, examined the knowledge and awareness of SETs even without experiencing about using the technologies by asking question: *"How familiar are you with the following technologies?"* The question was answered using 4-level familiarity scale ranging from "*not familiar"* to "*very familiar"*. The 4-Point Likert Scale allows this study to include four extreme options without a neutral choice and collect specific responses[2]. Based on the respondents' answer, this study created two knowledge level comparisons: "good knowledge" to those who answered very familiar and somewhat familiar, and "low knowledge" of SETs included those who answered slightly familiar and not familiar. The second question was *"Which among the following would you consider as smart energy technology?"* This study posits that buying technology is followed by adopting it. So, the second part of the questionnaire focuses on the users' willingness to adopt smart energy technologies by asking "*Do you own any of the following SET?"* And the choices are: *Yes; No, but I plan to buy one in the next 12 months; and No and I do not plan to buy one in the next 12 months. A follow- up question was added to*, the survey asked a follow-up question understand reasons for not buying of SETs, in general. The last part of the survey consists of demographic characteristics of respondents including age, gender, education, employment, types of dwelling occupation and income.

[2]**The 4,5, and 7 Point Likert Scale + [Questionnaire Examples]** https://www.formpl.us/blog/point-likert-scale

3.1.3.3 Socio-demographic information of respondents

The respondents are residential building occupants in Denmark who are also known as energy consumers. Table 14 highlights the specifications of the survey respondents by dividing the variables and introducing the frequency and percentage, respectively.

Table 14. Respondent socio-demographic information

Variable	Count
Gender	
Male	1,633
Female	1,562
Others	5
Prefer not to say	5
Age	
18-24	189
25-34	394
35-44	332
45-54	394
55-64	516
65 and above	1,377
Education	
Primary school	360
Secondary	428
Diploma	911
Bachelor or undergraduate	875
Post-graduate	519
Prefer not to say	100
Employment	
Employed (Fulltime)	945
Employed (Part-time)	193
Self-employed	136

A student	154
Retired	1,430
Others(specify)	105
Types of dwelling	
House/villa	1,445
Apartment	1,149
Townhouse	437
Rural property	132
Others	30
Income	
Under 9,999kr	235
10,000-19,999kr	818
20,000-29,000kr	628
30,000-39,999kr	487
40,000kr and above	435
Prefer not to say	590

Starting with the gender of the survey respondents, 51% male and 49% female respondent (shown in Table 3). In addition, respondents were divided into six age group, aged 18-24(6%), 25-34(12%), 35-44(10%), 45-54(12%), 55-64 (16%), and 43% aged 65 and above. Meanwhile, 11% of the respondents have primary education, 13% secondary education, 29% with diploma, 27% with bachelor's degree, 16% post-graduate and 3% did not mention their education. For income, 26% with income 10,000-19,000kr, 20% with income 20,000-29,000kr, 18% prefer not to mention their income, 15% with income 30,000-39,000kr, 14% with income 40,000kr and above and 7% with income under 9,999kr.

3.1.4 Findings

The result and discussion were divided into four sections: (1) knowledge and awareness of smart energy technologies, (2) willingness to adopt SETs, (3) knowledge and awareness and willingness to adopt SETs, and (4) socio-demographics (income and types of dwelling) and willingness to adopt SETs.

3.1.4.1 Residential building occupants' knowledge and awareness of SETs

The frequency distribution of more than 3,000 residential building occupant's knowledge and awareness of SETs is presented in Fig. 5. Even though the familiarity vary from one smart energy technology to another, in general, this study found low awareness of SETs, especially HEMS and BAS. For instance, out of 3,165 respondents, about 2% were very familiar and 75% were not familiar with HEMS. Similarly, out of 3,158 respondents, only 2% were very familiar and 76% were not familiar with BAS. Lighting is considered as the most common technologies at home yet out of 3,162 respondents, only 15% were very familiar about smart lighting, 29% somewhat familiar, about 43% slightly, and 13% were not familiar. The result showed that out of 3,183 respondents, about 9% were very familiar with HVAC, 20% somewhat familiar, about 40% slightly, while 31% were not familiar. Concerning solar PV, out of 3,164 respondents, about 8% were very familiar with solar PV, 18% somewhat familiar, about 50% slightly, and about 23% respondents were not familiar. In addition, awareness on smart appliances among residential building occupants has also been included in the survey, showing that out of 3,174 respondents, about 10% were very familiar, 24% somewhat familiar, about 38% slightly and about 29% respondents were not familiar. Out of 3,163 respondents, about 7% were very familiar with smart thermostat, 19% somewhat familiar, about 35% slightly, and about 39% respondents were not familiar. When it comes to familiarity with smart meters, out of 3,157 respondents, 5% were very familiar, 13% somewhat familiar, about 28% slightly, and about 55% respondents were not familiar. Finally, the result showed that out of 3,147 respondents, about 8% were very familiar with EVs, 24% somewhat familiar, about 43% slightly and about 24% respondents were not familiar. We also examined the residential building occupants' familiarity of SETs (see in Figure 6). The result revealed that out of 3,163 respondents, about 44% considered HVAC systems as smart energy technologies, 48% on solar PV, 57% on smart lightings, 57% on smart thermostat, 62% on HEMS, 43% on BAS, 37% on smart meters and 49% considered EVs as smart energy technologies. On the other hand, 40% of respondents have not considered any in the lists as SETs, while 4% of respondents consider geothermal and wind energy as SETs. Overall, figure 6 showed that less than 65% of the respondents considered the mentioned technologies as SETs implying limited knowledge and awareness about the existing smart energy technologies.

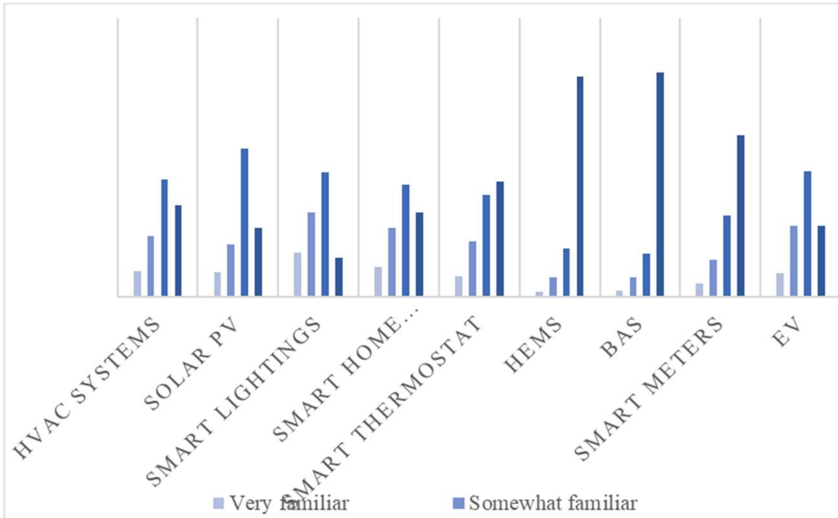

Figure 5. Residential occupants' knowledge of SETs

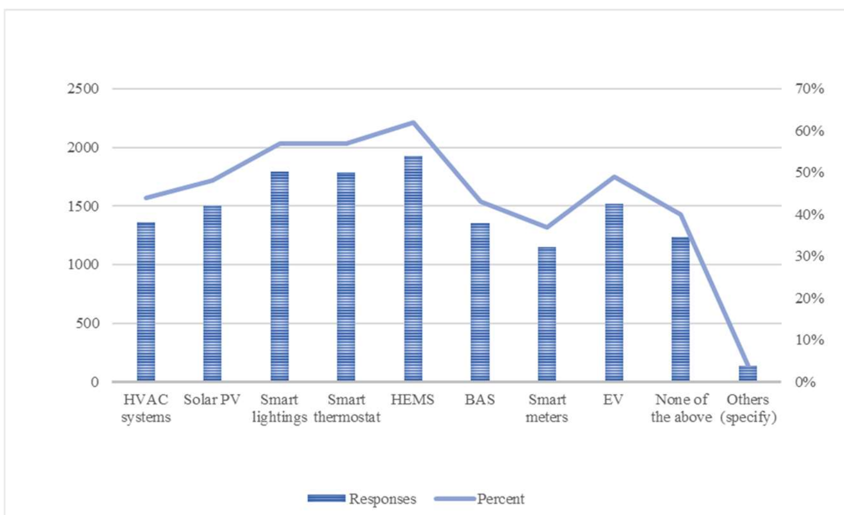

Figure 6. Residential occupants' perceptions of SETs answering, "Which among the following would you consider as smart energy technology?"

3.1.4.2 Residential occupants' willingness to adopt to SETs

This section describes the residential building occupants' willingness to adopt to SETs including HVAC, solar PV, smart lighting, smart home appliances, smart thermostat, HEMS, BAS, smart meters and EVs. Figure 7 presents the respondents' ownership and willingness to adopt SETs. In other words, it is to identify whether the respondents own or plan to purchase SETs. Overall, result revealed that very few respondents own SETs and also very few were who are willing to buy SETs, for instance, out of 3,120 respondents, only 16% own an HVAC system, 7% answered *"No, but I plan to buy one in the next 12 months"*, and 77% responded *"No, and I do not plan to buy new one in the next 12 months".* Similarly, out of 3,098 respondents, 9% own solar PV, whereas 5% do not own but were planning to buy in the next 12 months, while 86% do not own solar PV and were not planning to install (shown in Figure 7).

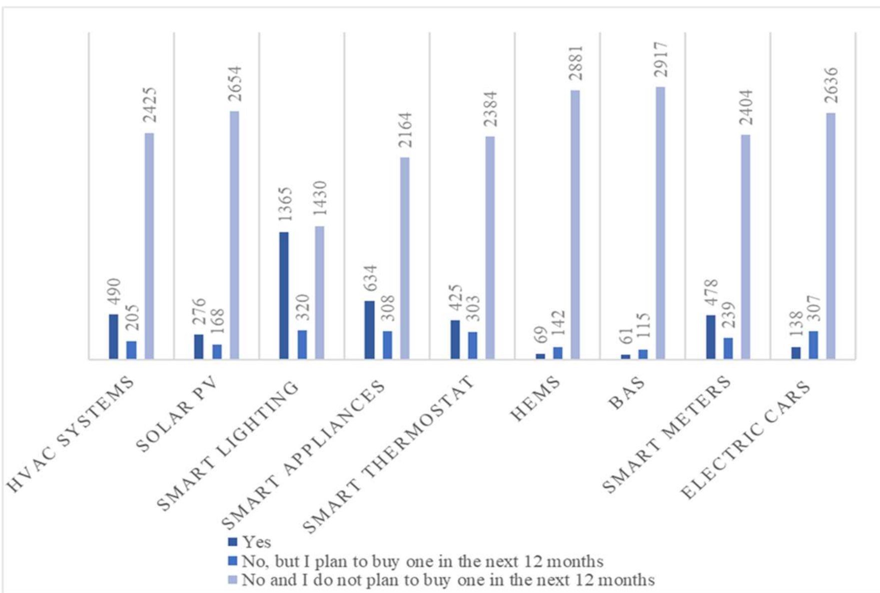

Figure 7. Residential building occupants' ownership of SET answering "Do you own any of the following smart energy technologies?"

Afterwards, a follow-up question was initiated to get a general overview of the crucial barriers to residential building occupant's willingness to buy SETs (shown in Figure 8). For example, out of 2,826 responses, about 30% stated that it's expensive, whereas 18% mentioned they lack knowledge about the benefits of adopting SETs, 21% lack of interest in using SETs, 20% lack confidence to use SETs, and 12% mentioned other reasons for not adopting SETs (e.g., not owning a house or apartment and lack of budget).

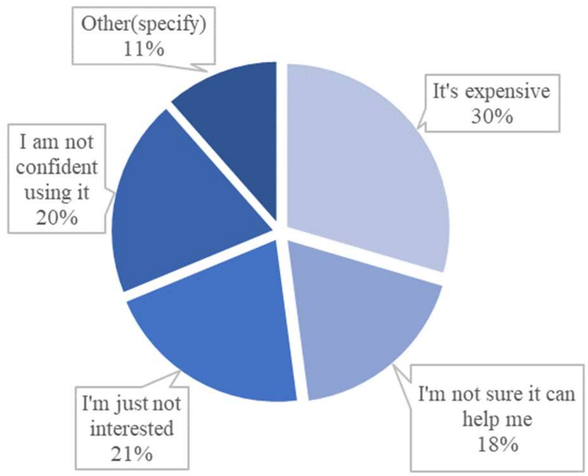

Figure 8. Barriers to SETs' adoption answering "What is your reason for not buying (of SETs)?"

3.1.4.3 Association between knowledge and awareness of SETs, and willingness to adopt to SETs

H1. *There is an association between knowledge and awareness of SETs and residential building occupant's acceptance to SETs*

A chi-square test was conducted to determine whether familiarity (very familiar, somewhat familiar, slightly familiar, and not familiar) is independent of willingness to adopt SETs. The overall results are significant, meaning we reject the null hypothesis that knowledge is not related to willingness to adopt SETs (in Table 15).

Table 15. Association between knowledge and awareness of SETs and acceptance to SETs

	1	**2**	**3**	**Sub-total**	**Contingency Coefficient**	**Chi-Square**	**P-Value**
HVAC					**0.397**	**579.73**	**<0.001**
Very familiar	125	35	112	272			
Somewhat familiar	196	79	364	639			
Slightly familiar	150	67	1,013	1,230			
Not familiar	17	24	932	964			
N	488	205	2,412	3,105			
Solar PV					**0.445**	**757.09**	**<0.001**
Very familiar	118	20	114	252			

Somewhat familiar	93	80	377	550			
Slightly familiar	53	55	1,445	1,553			
Not familiar	8	11	698	717			
N	272	166	2,634	3,072			
Smart lighting					**0.445**	**760.19**	**<0.001**
Very familiar	373	39	62	474			
Somewhat familiar	508	139	238	885			
Slightly familiar	448	124	748	1,320			
Not familiar	28	13	367	408			
N	1,357	315	1,415	3,087			
Smart appliances					**0.451**	**787.48**	**<0.001**
Very familiar	187	27	91	307			
Somewhat familiar	264	124	347	735			
Slightly familiar	163	120	885	1,168			
Not familiar	15	37	830	882			
N	631	308	2,153	3,092			
Smart thermostat					**0.445**	**761.97**	**<0.001**
Very familiar	122	34	65	221			
Somewhat familiar	146	128	311	585			
Slightly familiar	134	98	835	1,067			
Not familiar	22	42	1,153	1,217			
N	424	302	2,364	3,090			
HEMS					**0.455**	**801.37**	**<0.001**
Very familiar	20	10	26	56			
Somewhat familiar	28	50	125	203			
Slightly familiar	16	56	432	504			
Not familiar	5	24	2,281	2,310			
N	69	140	2,864	3,073			
BAS					**0.406**	**607.78**	**<0.001**
Very familiar	17	15	39	71			
Somewhat familiar	21	43	141	205			

Slightly familiar	17	34	395	446			
Not familiar	6	22	2,321	2,349			
N	61	114	2,896	3,071			
Smart meters					**0.482**	**934.62**	**<0.001**
Very familiar	88	18	39	145			
Somewhat familiar	116	82	141	389			
Slightly familiar	177	85	598	860			
Not familiar	45	49	1,606	1,700			
N	476	234	2,384	3,094			
EVs					**0.363**	**463.49**	**<0.001**
Very familiar	57	49	142	248			
Somewhat familiar	54	148	544	746			
Slightly familiar	22	92	1,201	1,315			
Not familiar	3	15	721	739			
N	136	304	2,608	3,048			

Note: 1. Yes 2. No, but planning to buy within 12 months 3. No, but not planning to buy within 12 months

The association between knowledge and awareness, and the willingness to adopt HVAC was found to be significant, as the null hypothesis was not supported (X^2=579.73, p<0.001). The strength of the association is moderate, as suggested by the contingency coefficient of 0.397 with Approx. Value, Sig= <.001. Moreover, the association between knowledge and awareness of Solar PV and willingness to adopt Solar PV was also found to be significant, (X^2=757.09, p<0.001) with moderate strength of association, as suggested by the contingency coefficient of 0.445 with Approx. Value, Sig =<.001. Meanwhile, result shows a significant association between knowledge and awareness of smart lightings and willingness to adopt smart lightings, (X^2=760.19, p<0.001) with moderate strength of the association, as suggested by the contingency coefficient of 0.445, Approx. Value, Sig =<.001. Furthermore, result also indicate a significant association between knowledge and awareness of smart appliances and willingness to adopt smart appliances, (X^2=787.48, p<0.001) showing a moderate strength of the association by contingency coefficient of 0.451 and Approx. Value, Sig =<.001. For smart thermostat, result also showed a significant association between knowledge and awareness, and willingness to adopt smart thermostat, as rejecting the null hypothesis, (X^2=761.97, p<0.001). The strength of the association is moderate, as suggested by the contingency coefficient of 0.455, Approx. Value, Sig =<0.001.

Furthermore, there is a significant association between knowledge and awareness, and willingness to adopt SETs, for example, HEMS at (X^2=801.37, p<0.001) with moderate strength of association, as suggested by the contingency coefficient of 0.455, Approx. Value, Sig =<.001; and BAS (X^2=607.78, p<0.001). The strength of the association is moderate, as suggested by the contingency coefficient of 0.406, Approx. Value, Sig =<0.001. There is a significant association between knowledge and awareness of smart meters and willingness to adopt smart meters, (X^2=934.62, p<0.001). The strength of the association is moderate, as suggested by the contingency coefficient of 0.482, Approx. Value, Sig =<0.001. Finally, a significant association between knowledge and awareness of EVs and willingness to adopt EVs, (X^2=463.49, p<0.001) with moderate strength of the association, as suggested by the contingency coefficient of 0.363, Approx. Value, Sig =<0.001.

Moreover, cross tabulation also presents the relationship between knowledge and awareness and willingness to adopt to SETs. For example, out of 3,105 respondents, 78% do not own HVAC and not planning to buy within 12 months. Moreover, out of those 2,412 who do not own and not planning to buy HVAC system within 12 months, only 5% were very familiar with HVAC and 39% not familiar of HVAC system. Then, out of 488 respondents who own HVAC, 26% were very familiar, 40% somewhat familiar, 30% slightly familiar and 3% not familiar indicating that knowledge has a significant association with the willingness to adopt HVAC. Interestingly, result also revealed that out of 272 who were very familiar of HVAC, 46% own HVAC, 13% do not own but planning to buy within 12 months and 41% do not own but not planning to buy within 12 months. On the other hand, out of 964 respondents who are not familiar of HVAC, only 1 % own HVAC, 2% do not own but planning to buy within 12 months while 97% do not own but not planning to buy with 12 months.

A cross-tabulation of knowledge and awareness, and willingness to adopt solar PV reveals the similar result. Out of 3,072 respondents, 9% said they own solar PV, 5% do not own but planning to but within 12 months and 86% do not own but not planning to buy within 12 months. Out of 272 who own solar PV, 43% were very familiar, 34% somewhat familiar, 19% slightly familiar and 1% were not familiar of solar PV. Meanwhile, of 2,634 who do not own solar PV, only 4% were very familiar, 14% somewhat familiar, 55% slightly familiar and 26% not familiar of solar PV. Looking at the 252 respondents who responded very familiar, 47% own solar PV, 8% who do not own but planning to buy within 12 months while 45% who do not own but not planning to buy within 12 months. Then out of 717 respondents, who were not familiar with solar PV, only 1% own solar PV, 1% do not own but planning to invest one within 12 months and 97% do not own but not planning to buy within 12 months.

Moreover, a cross tabulation of knowledge and awareness, and willingness to adopt smart lighting were also conducted. The result revealed that out of 3,087 respondents, 44% own smart lighting, 10% do not own but planning to buy within 12 months while 46% do own but not planning to buy within12 moths. Of 3,087 respondents, 15% were very familiar, 29% somewhat familiar, 43% slightly familiar and 13% not familiar of smart lighting. Moreover, out of 1,357 who own smart lighting, 27% were very familiar, 37% somewhat familiar, 33% slightly familiar and 2% not familiar of smart lighting. On the other hand, out of 1,415 respondents who do not own smart lighting but not planning to buy within the next 12 months, 4% were very familiar, 17% somewhat familiar, 53% slightly familiar and 26% not familiar of smart lighting. Meanwhile, out of 315 who do not own but planning to buy smart lighting within 12 months, 12% were very familiar, 44% somewhat familiar, 39% slightly familiar and 9% not familiar.

Looking at the cross tabulation between knowledge and awareness, and willingness to adopt smart appliances, out of 3,092 respondents, 10 % were not familiar, 24% somewhat familiar, 38% slightly familiar, and 28% not familiar. In addition, out of 3,092 respondents, 20% own smart appliances, 10% do not own but planning to buy within 12 months, and 70% who do not own but not planning to buy smart appliances within 12 months. Interestingly, results also revealed that out of 631 who own smart appliances, 30% were very familiar and only 2% were not familiar of the said technology while out of 2,153 who do not own smart appliances, 4% were very familiar, 16% somewhat familiar, 41% slightly familiar, and 39% were not familiar of smart appliances.

Looking at the cross tabulation with knowledge and awareness, and willingness to adopt smart thermostat, of the 3,090 respondents, 7% were very familiar of smart thermostat, 19% somewhat familiar, 34% slightly familiar and 39% not familiar. Out of 3,090 respondents, 14% own smart thermostat, 10% do not own but planning to buy within 12 months and 76% do not own smart thermostat but planning to buy within 12 months. In addition, out of 424 respondents, 29% were very familiar of smart thermostat, 34% somewhat familiar, 31% slightly familiar and 5% not familiar. On the other hand, out of 2,364 who do not own but not planning to buy smart thermostat within 12 months, 3% were very familiar of smart thermostat, 13% somewhat familiar, 35% slightly familiar and 49% not familiar.

Cross tabulation with knowledge and awareness, and willingness to adopt HEMS was also conducted. For instance, out of 3,073 respondents, 2% own HEMS, 5% do not own but planning to buy HEMS within 12 months while 93% do not own hems but not planning to buy within 12 months. Also out of 3,073 respondents, 2% were very familiar of HEMS, 7% somewhat familiar, 16% slightly familiar and 5% were not familiar. In addition, out of 69 who own HEMS, 29% were familiar, 41% somewhat familiar, 23% slightly familiar and 7% not familiar. And, out of 2,864 who do not own HEMS but not planning to buy within 12 months, 1% were very familiar of HEMS, 4% somewhat familiar, 15% slightly familiar and 80% not familiar.

Cross tabulation between knowledge and awareness, and willingness to adopt BAS reveals similar results. For instance, out of 3,071 respondents, only 2% own BAS, 4% do not own BAS but planning to buy within 12 months while 94% do not own but not planning to buy within 12 months. Moreover, out of 3,071 respondents, 2% were very familiar of BAS, 7% somewhat familiar, 14% slightly familiar and 76% not familiar. Meanwhile, out of 61 who own BAS, 28% were very familiar, 34% somewhat familiar, 28% slightly familiar and 10% not familiar of BAS. Out of 2,896 who do not own BAS but not planning to buy within 12 months, 1% were very familiar, 5% somewhat familiar,14% slightly familiar and 80% not familiar of BAS.

Cross tabulation also reveals significant association between knowledge and awareness, and willingness to adopt smart meters. For example, out of 3,094 respondents, 15% own smart meters, 8% do not own but planning to buy within 12 months and 77% do not own but not planning to buy within 12 months. Meanwhile, out of 3,094 respondents, 4% were very familiar of smart meters, 13% somewhat familiar, 28% slightly familiar and 55% not familiar. Out of 476 who own smart meters, 18% were very familiar, 24% somewhat familiar, 37% slightly familiar and 9% not familiar. And out of 2,384 who do not own but not planning to buy smart meters within 12 months, only 2% were very familiar, 6% somewhat familiar, 25% slightly familiar while more than 60% were not familiar of smart meters.

Cross tabulation with knowledge and awareness, and willingness to adopt EVs showed that out of 3,048 respondents, only 4% own EVs, 10% do not own but planning to buy within 12 months and more than 80% do not own but not planning to buy EVs within 12 months. Moreover, out of 3,048 respondents, only 8% were very familiar, 24% somewhat familiar, 43% slightly familiar and 24% not familiar o EVs. Then out of 136 who own EVs, 42% were very familiar of EVs while 40%) somewhat familiar, 16% slightly familiar and 2% not familiar. On the other hand, out of 2,608 who do not own EVs and not planning to buy within 12 months, only 5% were very familiar, 21% somewhat familiar, 46% slightly familiar and 28% not familiar of EVs.

3.1.4.4 Association between socio-demographics and willingness to adopt to SETs

H2. *There is an association between types of dwelling and willingness to adopt SETs*

First, we examined whether there is an association between types of dwelling and willingness to adopt SETs using chi-square test/cross-tabulation (Table 16). Result showed a significant association between types of dwelling and willingness to adopt HVAC system as shown in chi-square test, (X^2=51.27 p<0.001) with weak association as shown in contingency coefficient at 0.128, Approx. Value, Sig=<0.001. In solar PV, Chi-square test a significant association, (X^2=76.93 p=<0.001) with weak association as indicated in contingency coefficient 0.157, Approx. Value, Sig=<0.001. Results also revealed significant association between types of dwelling and willingness to adopt smart lightings (X^2=34.93 p<0.001), with weak association at 0.106, Approx. Value, Sig=<0.001; in smart appliances where chi-square at (X^2=28.03 p=<0.001) with contingency coefficient of 0.095, Approx. Value, Sig=<0.001. Moreover, a significant of association between types of dwelling and willingness to adopt smart thermostat (X^2=41.60 p<0.001) indicating weak association at 0.116, Approx. Value, Sig=<0.001. Results also showed a significant association between types of dwelling and willingness to adopt smart meters (X^2=16.57 p=0.035), contingency coefficient of 0.073, Approx. Value, Sig=0.035, and in EVs with chi-square (X^2=16.69 p=0.033) and indicating weak association as shown in contingency coefficient, Approx. Value, 0.074, Sig=0.033.On the other hand, results showed no association between types of dwelling and willingness to adopt HEMS at chi-square (X^2=9.33 p=0.315) and in BAS (X^2=10.14 p=0.255).

Table 16. Association between types of dwelling and willingness to adopt SETs

	1	2	3	Total	Contingency Coefficient	Chi-square	P-Value
HVAC					**0.128**	**51.27**	**<0.001**
House/villa	283	82	1,010	1,375			
Apartment	122	76	916	1,114			
Townhouse	52	33	334	419			
Rural property	23	11	94	128			
Others	5	0	24	29			
N	485	202	2,378	3,065			
Solar PV					**0.157**	**76.93**	**<0.001**
House/villa	170	61	1,133	1,364			
Apartment	56	74	979	1,109			
Townhouse	17	23	376	416			
Rural property	25	6	94	125			
Others	4	1	25	30			
N	272	165	2,607	3,044			
Smart lighting					**0.106**	**34.93**	**<0.001**
House/villa	667	128	577	1,372			
Apartment	423	129	562	1,114			
Townhouse	180	42	197	419			
Rural property	69	11	46	126			
Others	12	4	14	30			
N	1,351	314	1,396	3,061			
Smart appliances					**0.095**	**28.02**	**<0.001**
House/villa	323	123	919	1,365			
Apartment	193	131	787	1,111			
Townhouse	71	40	306	417			
Rural property	35	7	85	127			
Others	5	2	23	30			
N	627	303	2,120	3,050			
Smart thermostat					**0.116**	**41.60**	**<0.001**
House/villa	239	143	981	1,363			

Apartment	115	105	899	1,119			
Townhouse	50	44	324	418			
Rural property	17	7	104	128			
Others	1	0	29	30			
N	422	299	2,337	3,058			
HEMS					**0.055**	**9.33**	**0.315**
House/villa	27	63	1,266	1,356			
Apartment	25	60	1,025	1,110			
Townhouse	15	14	385	414			
Rural property	2	3	122	127			
Others	0	1	29	30			
N	69	141	2,827	3,037			
BAS					**0.058**	**10.14**	**0.255**
House/villa	25	41	1,291	1,357			
Apartment	24	45	1,041	1,110			
Townhouse	9	24	382	415			
Rural property	2	3	122	127			
Others	0	0	29	29			
N	60	113	2,865	3,038			
Smart meters					**0.073**	**16.56**	**0.035**
House/villa	244	112	1,021	1,377			
Apartment	150	82	885	1,117			
Townhouse	58	35	322	415			
Rural property	16	5	106	127			
Others	3	1	26	30			
N	471	235	2,360	3,066			
EVs					**0.074**	**16.69**	**0.033**
House/villa	76	129	1,150	1,355			
Apartment	33	124	949	1,106			
Townhouse	16	38	356	410			
Rural property	8	12	104	124			
Others	2	0	28	30			
N	135	303	2,587	3,025			

Note: 1. Yes 2. No, but planning to buy within 12 months 3. No, but not planning to buy within 12 months

Cross tabulation of the association between types of dwelling and willingness to adopt HVAC shows that most of the respondents reside in a house/villa. In addition, out of 1,375 who lived in house/villa, 21% own HVAC, 6% do not own but planning to buy within 12 months and 73% do not own but not planning to buy within 12 months. Meanwhile, out of 2,378 who do no own HVAC and not planning to buy within 12 months, 42% reside in house/villa and 38% in apartment.

The cross tabulation revealed that out of 1,364 respondents who reside in house or villa, only 12% own solar PV while 4% do not own but planning to buy within 12 months and 83% do not own and no plans to buy within 12 months. Moreover, result also showed that out of 272 owners of solar PV, 62% reside in house or villa, 21% in apartment, 6% in townhouse, 9% in rural property and 1% reside in other type of dwelling. Out of 2,607 who do not own solar PV and not planning to adopt solar PV, 43% reside in house/villa, 37% in apartment, 14% in townhouse, 4% in rural property and 1% in other types of dwelling.

Cross tabulation of types of dwelling and willingness to adopt smart lightings revealed that most of the respondents reside in house/villa and apartment. For example, out of 1,351 who installed smart lighting, 49% reside in house/villa, 32% in apartment, 13% in townhouse, 5% in rural property and 1% in other type of dwelling. Then, out of 1,396 who do not own smart lightings, 41% reside in house/villa, 40% in apartment, 14% in townhouse, 3% in rural property and 1% reside in other type of dwelling.

Cross tabulation of types of dwelling and willingness to adopt smart appliances, showed that only 21% own smart appliances and more than 60% do not own smart appliances but not planning to buy within 12 months. In addition, out of the 627 who own smart appliances, mostly reside in house/villa (51%) and apartment (31%) and the rest reside in other type of dwelling. In addition, out of 2,120 who do not own smart appliances but not planning to buy within 12 months, 43% reside in house/villa, 37% in apartment, 14% in townhouse, 4% in rural property and 1% in other type of dwelling.

Moreover, tabulation of types of dwelling and willingness to adopt smart thermostat also showed that most of the respondents reside in house/villa and in apartment. Out of 3,058 respondents, only 14% own smart thermostat while 76% do not own but not planning to buy within 12 months. Moreover, of the total number of those who own smart thermostat, 57% reside in a house/villa and 27%) reside in apartment.

Cross tabulation of types of dwelling and willingness to adopt HEMS showed that 93% respondents do own and not planning to buy. The result also revealed that out of 69, who own HEMS, 39% reside in house/villa, 36% in apartment, 22% in townhouse and 3% in rural property.

Cross tabulation of the types of dwelling and willingness to adopt BAS showed that 45% of the total respondents reside in house/villa and apartment and 36% in apartment. For example, of the total respondents who own BAS, 47% reside in house/villa and 40% in apartment. In addition, we found that majority of the respondents who do not own BAS but not planning to buy within 12 months also reside in a house/villa (45%), and in apartment (36%).

Cross tabulation of types of dwelling and willingness to adopt smart meters also revealed that most of respondents reside in house/villa and apartment. For example, out of 471 who own smart meters, 52% reside in house/villa and 32% in apartment. Also, out of 2,360 who do not own and not planning to buy smart meters within 12 months, 43% reside in house/villa and 37% in apartment.

Cross tabulation of types of dwelling and willingness to adopt EVs also revealed that majority of the respondents reside in house/villa and apartment. For instance, out of 3,025, about 45% reside in house/villa and 37% in apartment. In addition, we found that out of 135 who own EVs, about 56% reside in house/villa, 43% reside in apartment and the rest of the respondents reside in other types of dwelling. Similarly, majority of the respondents who do not own EVs but not planning to buy within 12 months also reside in house/villa and apartment.

H3. *There is a significant association between income and willingness to adopt SETs*

Chi-square test and cross tabulation were also conducted to examine the association between income and willingness to adopt SETs. Most of the results showed significant associations except in solar PV and BAS (shown in table 17).

Table 17. Association between income and willingness to adopt SETs

	1	**2**	**3**	**Sub-Total**	**Contingency Coefficient**	**Chi-square**	**P-Value**
HVAC					**0.123**	**47.46**	**<0.001**
Below 9,999	38	16	176	230			
10,000-19,999	112	41	629	782			
20,000-29,999	86	34	483	603			

30,000-39,999	69	35	365	469			
40,000- above	98	47	273	418			
Prefer not to say	82	29	452	563			
N	485	202	2,378	3,065			
Solar PV					**0.075**	**17.41**	**0.066**
Below 9,999	13	20	194	227			
10,000-19,999	60	34	685	779			
20,000-29,999	61	33	507	601			
30,000-39,999	39	27	402	468			
40,000- above	49	24	338	411			
Prefer not to say	50	27	481	558			
N	272	165	2,607	3,044			
Smart lightings					**0.118**	**43.26**	**<0.001**
Below 9,999	83	21	124	228			
10,000-19,999	333	89	360	782			
20,000-29,999	276	51	278	605			
30,000-39,999	213	65	189	467			
40,000- above	220	43	154	417			
Prefer not to say	226	45	291	562			
N	1351	314	1,396	3,061			
Smart appliances					**0.102**	**32.31**	**<0.001**
Below 9,999	38	26	164	228			
10,000-19,999	141	77	559	777			
20,000-29,999	131	57	414	602			
30,000-39,999	90	47	329	466			
40,000- above	106	60	251	417			
Prefer not to say	121	36	403	560			
N	627	303	2,120	3,050			
Smart thermostat					**0.143**	**64.21**	**<0.001**
Below 9,999	31	18	180	229			
10,000-19,999	89	60	633	782			
20,000-29,999	73	68	462	603			
30,000-39,999	79	59	328	466			
40,000- above	82	62	271	415			
Prefer not to say	68	32	463	563			
N	422	299	2,337	3,058			
HEMS					**0.103**	**32.76**	**<0.001**
Below 9,999	6	12	209	227			
10,000-19,999	10	37	728	775			
20,000-29,999	9	28	562	599			
30,000-39,999	7	16	437	460			
40,000- above	23	27	366	416			
Prefer not to say	14	21	525	560			

N	69	141	2,827	3,037			
BAS					**0.066**	**13.48**	**0.198**
Below 9,999	3	6	219	228			
10,000-19,999	14	35	725	774			
20,000-29,999	7	20	574	601			
30,000-39,999	14	13	433	460			
40,000- above	11	22	382	415			
Prefer not to say	11	17	532	560			
N	60	113	2,865	3,038			
Smart meters					**0.138**	**59.34**	**<0.001**
Below 9,999	24	18	186	228			
10,000-19,999	97	53	632	782			
20,000-29,999	92	44	467	603			
30,000-39,999	67	45	356	468			
40,000- above	108	42	267	417			
Prefer not to say	83	33	452	568			
N	471	235	2,360	3,066			
EVs					**0.122**	**45.34**	**<0.001**
Below 9,999	9	17	201	227			
10,000-19,999	32	70	672	774			
20,000-29,999	10	59	525	594			
30,000-39,999	27	47	387	461			
40,000- above	33	64	317	414			
Prefer not to say	24	46	485	555			
N	135	303	2,587	3,025			

Note: 1. Yes 2. No, but planning to buy within 12 months 3. No, but not planning to buy within 12 months

Majority of the results showed significant association between residential building occupant's income and willingness to adopt SETs vary from one technology except in solar PV and BAS. For example, significant association found between income and willingness to adopt HVAC at (X^2=47.46, p<0.001) but indicating weak association, as suggested by the contingency coefficient of 0.123 with Approx. Value, Sig =<0.001. In addition, the result also revealed a significant association between income and willingness to adopt SETs. For example, smart lightings, (X^2=43.26, p<0.001), with weak strength of association as shown in contingency coefficient, 0.118, Approx. Value, Sig=<0.001; and smart thermostat, (X^2=64.21, p<0.001), with weak strength of association as indicated in contingency coefficient of 0.143, Approx. Value, Sig=<0.001. Furthermore, results showed a significant association between income and willingness to adopt smart appliances (X^2=32.31, p<0.001), contingency coefficient 0.102, Approx. Value, Sig=<.001, HEMS (X^2=32.76, p<0.001), contingency coefficient, Approx. Value , 0.103, Sig=<.001; smart meters (X^2=59.34, p=<.001), contingency coefficient, 0.138, Approx. Value, Sig=<.001; and in EVs (X^2=45.34, p=<.001) with contingency coefficient 0.122, Approx. Value, Sig=<0.001. On the other hand, the findings show no association between income and willingness to adopt BAS, (X^2=13.48, p=0.198); and solar PV, (X^2=17.41, p<0.66).

Cross tabulation revealed that out of 485 who own smart HVAC, only 8% with income below 9,999kr, 23% with income 10,000-19,999kr, 18% with income 20,000-29,999kr, 14%(30,000-39,999kr), 20% (above 40,000kr) and 17% prefer not to mention their income. On the other hand, we also found that majority (80%) of the respondents do not own smart HVAC and not planning to buy within 12 months. These respondents have income range of 10,000kr to 19,000kr. In addition, cross tabulation revealed that only 9% of the total number of respondents own solar PV while 85% do not own and not planning to buy within 12 months. In addition, most owners of solar PV with income between 10,000 and 19,000kr (22%), and 20,000 to 29,999kr (22%). Furthermore, for those who do not own and not planning to buy solar PV within 12 months, 88% with income range of 10,000 to 19,000kr. Meanwhile, the cross tabulation between income and willingness to adopt smart lightings showed balance distribution where 44% own smart lightings and 46% who do not own but not planning to buy within 12 months. About 43% who own smart lightings and 46% do not own and not planning to buy within 12 months have an income between 10,000-19,000kr. Similarly, more than 65% do not own smart appliances but not planning to buy within 12 months while only 21% own smart appliances. In addition, more than 70% of those who do not own smart appliances in their homes have income range of 10,000 to19, 999kr. Cross tabulation in smart thermostat also revealed that of 3,058 respondents, more than 75% do not own smart thermostat but not planning to buy within 12 months. In addition, most of the respondents with income range between 10,000 and 19,999kr. In addition, result showed that out of 3,037 respondents, only 2% who own HEMS and more than 90% do not own but not willing to buy HEMS within 12 months. Moreover, majority of respondents who do not own HEMS have income between 10,000-19,999kr while most of respondents who own HEMS belong to income range of 40,000kr and above. Looking at the cross tabulation in BAS, out of 3,038 respondents, only 2% own BAS, 4% do not own but planning to purchase within 12 months and 94% do not own BAS and not planning to purchase within 12 months. The result also revealed that out of 60 respondents who own BAS, mostly with income range of 23% with income 10,000-19,999kr (23%), and 30,000-39,999kr (23%). Moreover, out of 3,066 respondents, only 15% claimed they own smart meters, 8% do not own but planning to buy smart meters within 12 months and 77% do not own smart meters but not planning to buy within 12 months. Moreover, 774 respondents belong to income range of 10,000-19,999kr, where 12% own smart meters and 82% do not own smart meters and not planning to buy within 12months. Cross tabulation of income and willingness to adopt EVs showed that out of 3,025 respondents, more than 80% do not own but not planning to buy within 12 months. Meanwhile, looking at the 135 respondents who own EVs, 24% with income between 40,000kr and above, 24% with income 10,000-19,000kr and about 20% with income between 30,000 and 39,000kr.

3.1.5 Discussion

This paper attempts to describe the level of knowledge and awareness, as well as the willingness to adopt SETs in residential buildings. Our findings reveal that residential building occupants have limited knowledge and awareness of SETs. Overall findings show significant associations between knowledge and awareness of SETs and willingness to adopt SETs (p=<0.05) with moderate strength of association as shown in contingency coefficient. A cross tabulation between knowledge and awareness, and willingness to SETs reveals that most of the respondents who own SETs are slightly and not familiar of SETs. Overall findings showed low willingness to adopt SETs.

The findings reveal the primary reasons for low willingness to adopt SETs include high cost, lack of knowledge about the benefits of adopting SETs, lack of interest and lack of confidence in using SETs. Other factors contributing to the reluctance of residential building occupants to adopt SETs, including living in rental properties, dwelling types, and lack of budget. For instance, the presence of pre-installed home technologies provided by building owners in rented apartments, dormitories, and even nursing homes might influence the willingness of residential building occupants to adopt SETs. Findings for instance, indicate that the pre-installed SETs could create a perception among the occupants that their energy needs are already being addressed, leading to reduced motivation to invest in additional SETs. This correlation suggests that residential building occupants living in such dwellings may show lower interest in buying SETs.

In hypothesis 2, confirms that majority of the results showed significant ($p=<0.05$) association between types of dwelling and willingness to adopt SETs. However, no significant association was observed in BAS ($p=0.255$) and hems ($p=0.315$). Types of dwelling can influence residential building occupant's decision as they that they take into account consider the specific dwelling characteristics when making decisions about buying smart energy technologies.

Moreover, we also examined the association between income and willingness to adopt SETs where most of the results showed significant association ($p=<0.05$), except in BAS, ($X^2=13.48$, $p=0.198$); and solar PV, ($X^2=17.41$, $p<0.66$) where results indicate no association. These results predict, for instance, that the financial resources and flexibility have positive effect on residential building occupants' willingness to adopt SETs. However, SETs adoption is influenced by various factors, and income is just one of them. Other variables may also play a role in the decision-making process.

3.1.6 Conclusion and further studies

To conclude, residential building occupants display limited familiarity with SETs. In addition, the findings confirm that level of willingness to adopt SETs is also low. Furthermore, this study presents the various reasons contributing to the reluctance to adopt SETs, including high cost, low awareness, lack of interest, and lack of confidence to use SETs. Other barriers include lack of budget, residing in a dormitory or elderly homes, no budget, lack of awareness about SETs, and not owning a house or apartment. Recognizing reasons for not adopting SETs enables relevant stakeholders to find ways to address each barrier effectively.

Technology providers and distributors always seek valuable insights to understand their customers' needs and demands. Findings regarding the willingness to adopt SETs would provide them with several significant implications regarding SETs. To increase the knowledge and awareness as well as the willingness rate, this study suggests implementing awareness programs and promoting SETs among residential building occupants to enhance their understanding of these technologies, which in turn, positively influence their level of willingness to adopt SETs.

Furthermore, there is a limited empirical study on residential building occupants' acceptance to smart energy technologies. This study, therefore, supports the line of research that confirmed knowledge and socio-demographic (income and types of dwelling) are important factors to consider when developing approaches on how to increase the willingness to adopt SETs. Besides the theoretical contributions, this study provides new insight into the developing area of smart energy technology acceptance, providing an overview for practice as well as for future research into this area. Thus, we hope our findings encourage future studies to further explore how knowledge of SETs can be enhanced to ensure widespread adoption to SETs.

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4. Why do residential building occupants decide to adopt or reject smart energy technologies, and how do they make these choices?

Why do some Embrace and Others Resist? Understanding the Drivers and Barriers to the Adoption of Smart Energy Technologies in residential buildings. *Billanes, J., 2023. Under revision for resubmission to Energy Efficiency Journal*

Chapter 4 seeks to uncover the influential factors that shaping the adoption and rejection of SETs in residential buildings. It is a qualitative study participated by 21 homeowners and tenants who owned SETs.

4.1. Why do some embraces and others resist? Understanding the Drivers and Barriers to Adoption of Smart Energy Technologies in residential buildings

Semi-structured interviews were conducted to explore the influential factors that guide residential building occupants' decisions for adopting and rejecting SETs. Findings from this study clarify and explain the quantitative results presented in chapter 2. The results on drivers and barriers to SETs' acceptance and adoption provide valuable insights to those who are aiming to develop strategies that encourage the widespread adoption of SETs.

4.1.1 Introduction

Human activities in buildings such as burning fossil fuel to generate electricity contribute to climate change. Buildings in Denmark, for example, share about 40% of the total energy consumption and greenhouse gas emissions (Engvang & Jradi, 2021). To address the issue, the Danish government sets a plan to become carbon neutral by 2050(Drysdale, Mathiesen, & Paardekooper, 2019) while maintaining the reliability of the energy system by increasing the generation of renewable energy and combined heat and power (CHP)(B. K. Sovacool, 2013). However, very limited focus on the participation of residential building occupants in energy transition goals.

Energy consumption in residential buildings may depend on the time spent at home doing activities (e.g. heating, cooling, cooking)(Hansen et al., 2022). A study confirmed that retired people or those working at home both full-time or part-time, consumed more energy for space heating, cooking, lighting, cleaning, and computer use during weekdays (X. Wang, Ghanem, Larkin, & McLachlan, 2021).

Due to the high energy consumption in buildings, improving energy efficiency and reducing energy consumption are necessary (Tirado Herrero et al., 2018). Energy efficiency means using less energy while performing the same task without compromising the quality of desired outcomes and is considered as an effective approach to ensure a safe, and reliable energy system in buildings (Su, 2019). Buildings have the potential to achieve energy efficiency and reduce energy demand by at least 50% by adopting new technologies as well as promoting energy-conscious behaviour among occupants(Johansson, Gentile, & Neij, 2021). According to Mortensen, Heiselberg, and Knudstrup (2016), Danish single-family houses constructed in 1960–1979 have energy saving potentials.

Several studies have proved that smart energy technologies (SETs) are effective tools for improving energy efficiency and reducing energy consumption in residential buildings (Große-Kreul, 2022). SETs is also known as building technologies(L. Chen et al., 2021), sustainable energy technology(L. Wang, Morabito, Payne, & Robinson, 2020), smart home technologies(Tirado Herrero et al., 2018), smart home services(Shin et al., 2018) and smart home products(Ford et al., 2017). In this study, SETs refer to energy efficient technologies that allows users to control and monitor energy activities via digital devices. Examples of SETs in residential buildings are smart heating, ventilation and air-conditioning system (HVAC), solar PV, smart meters, smart lightings, smart thermostat, Building Automation System (BAS), Home Energy Management Systems (HEMS) and Electric Vehicles (EVs).

Numerous literature claim the advantages of using SETs, for example, Tirado Herrero et al. (2018) argued the potential of SETs to achieve substantial energy savings in residential buildings. Similarly, Hansen et al. (2022) claimed the contribution of solar PV installed in residential buildings on the sustainable transition of the energy system.

However, despite the benefits, SETs may not be easily accessible to vulnerable energy consumers(e.g. low income households)(Tirado Herrero et al., 2018), and uptake of SETs remains low, as stated in studies of Berger, Ebeling, Feldhaus, Löschel, and Wyss (2022) and Coskun, Kaner, and Bostan (2018). For example, adoption of SETs such as smart meter and smart thermostat in Germany remains limited(Große-Kreul, 2022).

A comprehensive understanding of the perceptions and expectations of potential users is important in order to achieve widespread adoption of SETs (Coskun et al., 2018; Ferreira, Oliveira, & Neves, 2023). Quantitative studies dominate research on influential factors to smart energy technology acceptance and adoption while very few studies that focuses on qualitative understanding of experiences, perceptions and reasons for acceptance and adoption of SETs. Thus, to foster the acceptance and adoption to SETs, two research questions are introduced:

- How do knowledge, awareness, social influence, policy, trust, perceived ease of use (PEOU), attitudes, and perceived usefulness (PU) influence residential building occupants' Behavioural Intention (BI) to use Smart Energy Technologies (SETs)?
- What factors hinder the adoption of SETs?

The remainder of this paper is organized as follows. Section 4.1.2 literature review on benefits of Smart Energy Technologies (SETs), stakeholders, and drivers and barriers to SETs' adoption. Section 4.1.3 explains the methodology. Section 4.1.4 presents the findings and data analysis. Section 4.15 discusses the results and section 4.1.6 concludes with recommendations.

4.1.2 Literature review

4.1.2.1 Benefits of using Smart energy technologies

In Smart Energy Technologies (SETs), the term "smart" refers to the capability of technologies to communicate wirelessly with each other, transmit data to end users, and enable remote operation and automation(Ford et al., 2017). Several studies have claimed about the benefits of smart energy technologies can help to reduce energy consumption. For example, Amega, Lare, and Moumouni (2022) highlight the need of smart appliances to save energy and reduce carbon emissions while Tuomela, de Castro Tomé, et al. (2021) suggest using Home Energy management systems (HEMs) to save up to 30% energy. Moreover, Tirado Herrero et al. (2018) claims that smart thermostats can save energy on heating and cooling for up to 30%. Moreover, Adu-Gyamfi et al. (2022) argues that using EVs help reduce energy consumption and reduce pollution while (Hicks & Theis, 2014) suggest reducing energy use for lighting by using light emitting diodes (LED) lamps. Moreover, controllable lights are smart lightings that provide security and convenience where energy efficiency can be achieved by replacing traditional lights to LED and by reducing lighting intensity and unnecessary usage(Ford et al., 2017). Building Automation System (BAS) is also known as Building Automation and Control System (BACS) that control and optimize building technologies, enabling energy-efficient, economical and safe operation of building services(Van Thillo, Verbeke, & Audenaert, 2022). While, solar PV installed in homes can increase the value of the property and leads to cost savings through reduced energy bills(Ma, Polyakov, & Pandit, 2016).

4.1.2.2 Residential Building Occupants and relevant stakeholders

This section discusses the various stakeholders who influence the decisions made by residential building occupants when adopting smart energy technologies (Table 18).

SETs' users or residential building occupants. In a study, Hai (2019) mentions the four different types of technology users such as unwilling, active, unconditional and conditional users. These groups include active users who are actually adopting the technology; unwilling users who are hesitant to adopt the technology, unconditional users who are willing to adopt but have not yet done so, and conditional users who are willing to adopt but require certain conditions to be met (Hai, 2019). Moreover, Hansen et al. (2022) identified the early adopters of solar PV as educated men, environmental conscious, and who want to become self-sufficient and receive financial gain. In another study, Mortensen et al. (2016) classified homeowners into younger and older generations, where younger generations who have children, have lived for at shorter period of time in their house and have a high income are more interested in and willing to conduct energy renovation. Shin et al. (2018) and Yash Chawla, Kowalska-Pyzalska, and Skowrońska-Szmer (2020) suggest targeting older people with higher income. In addition, older individuals can be motivated to adopt smart technology if the perceived it useful while this positive attitude towards using a technology leads to increased willingness among to embrace SETs into their daily lives(W. Li et al., 2021).

Policy makers. Responsible for making rules and regulations and actively promote and support the utilization of SETs(B. K. Sovacool, 2013). In 2019, for example, a European Union (EU) directive known as Energy Performance of Buildings Directive (EPBD) required the installation of BACS in non-residential buildings with a total energy supply system capacity of over 290 kW in Europe(Engvang & Jradi, 2021). In addition, city and municipal government, for example, can provide relevant information during the annual meeting with building association, building owners and residential building occupants to address various matters(Hai, 2019).

Technology providers. Google, Amazon, and Samsung are the leading providers of SETs(Ferreira et al., 2023). Nest Labs is also one of the leading smart home providers of thermostats(Pang et al., 2021), security cameras, and doorbells(Shin et al., 2018). Meanwhile, Tado[3] and Danfoss[4] are the most popular smart thermostat providers in Denmark.

Builders, installers and electricians. Responsible for installing SETs(Härkönen, Hannola, & Pyrhönen, 2022).The installers or the builders have influences in homeowners' decisions in energy renovations(Mortensen et al., 2016). For example, according to (Decuypere et al., 2022), residential building owners can seek advice from installers when buying heat pumps. In addition, home builders, contractors, realtors and retrofit auditors can also give advice about SETs (Zhao, McCoy, Du, Agee, & Lu, 2017). Other relevant stakeholders are service providers, building/property owners and technology distributors/retailers. For instance, building management companies and utilities are service providers who are responsible on operating HVAC systems in buildings (Härkönen et al., 2022). The building/property owners are the companies that own rental buildings such as Boligselskabet Fruehøjgaard [5]. Meanwhile, technology distributors/retailers are shops that sell SETs to residential building occupants such as Elgiganten [6], Power[7] and Bilka[8].

Table 18. Relevant stakeholders and their roles and involvement in the adoption of SETs

Stakeholder	Role	To
Policy makers	Develop programs and policy related to SETs	Technology provider Retailers Builders

[3] Starter Kit – Smart Thermostat https://www.tado.com/dk-da/smart-thermostat
[4] Danfoss Eco https://www.danfoss.com/da-dk/products/dhs/smart-heating/smart-heating/danfoss-eco/#tab-overview
[5] Boligselskabet Fruehøjgaard. https://fruehojgaard.dk/om-os
[6] Elgiganten. https://www.elgiganten.dk/
[7] Power. https://www.power.dk/?gclid=CjwKCAjw67ajBhAVEiwA2g_jEHBMHd34yLpJ-qfd0FEFtHvCzmuB0NLzMM8qdsmM7BMq-No15Nob3RoC8T8QAvD_BwE&gclsrc=aw.ds
[8] Bilka. https://www.bilka.dk/?gclid=CjwKCAjw67ajBhAVEiwA2g_jEA__tbXt8HiDI6wpI4bivI1ch9NLvQDHu5zs_tlzZI8xcce-mBlXZRoCIQoQAvD_BwE&gclsrc=aw.ds

		Building/property owners SETs' users
Technology providers	Provide SETs Provide knowledge and awareness Offers incentives	SETs' users Retailers Builders Building/property owners
Retailers	Marketing channel Incentives and financing options Provide knowledge and awareness	Technology provider SETs' users
Builders	Knowledge and awareness	SETs' users
Building/property owners	Provide or install SETs Awareness and knowledge	SET's users (tenant)
Service providers	monitor and measure the energy consumption offer energy efficiency programs and incentives	SETs' users
SETs' users	Provide feedback	Policy maker Technology provider Technology distributor Builders Building/property owners

4.1.2.3 Drivers to SETs' adoption

Various studies have identified the influential factors to smart energy technology acceptance and adoption. For example, Billanes and Enevoldsen (2022) suggest other influential factors to residential building occupants' acceptance and adoption to SETs including trust, knowledge, awareness, policy and social influence. In another study, energy efficiency, better services, financial savings and benefits, and enhanced quality of life can also drive SETs' adoption(W. Li et al., 2021).

Moreover, (Drysdale et al., 2019) identified that (1) knowledge of the user, (2) user norms and (3) user habits can influence user behaviour to adopt SETs. (Curtius, Hille, Berger, Hahnel, & Wüstenhagen, 2018) examined the influence of social norms on the decisions to adopt solar PV in Switzerland. Social norms is a form of social influence that consist of two types: descriptive norms (refers to refer to individuals' perceptions of what others are doing) and injunctive norms (refers to what others approve or disapprove)(Curtius et al., 2018). Moreover, Große-Kreul (2022) found that social influence has a strong positive influence on the intention to adopt smart meter and smart thermostat.

Perception on the usefulness of the benefits of SETs can also influence residential building occupants decisions (Shin et al., 2018). In Germany, for example, the motivation of residential building occupants to use smart meters was linked to their perception of the technology as having the potential for energy savings(Berger et al., 2022). Conducting energy audit and providing information about SETs to enhance knowledge and awareness among SETs' users(Decuypere et al., 2022). Moreover, Streimikiene (2022) claim that awareness, knowledge and assistance on energy saving can help reduce the behavioural barriers. Hicks and Theis (2014) suggest educating residential building occupants about using smart lightings to influence their attitudes toward the adoption of LED.

In Denmark, the government implemented energy labelling measure for buildings and appliances as one of the energy efficiency policies(B. K. Sovacool, 2013). Similarly, a study found that promoting energy labelling measures on home appliances and reduce energy consumption and improve the energy efficiency in buildings (Su, 2019). In addition, subsidy or monetary incentive is the biggest motivation for the adoption of smart meters (Berger et al., 2022). Likewise, Norway became the world leader in Electric Vehicles (EVs) adoption per capita by 2019 due to government subsidies(Korsnes & Throndsen, 2021). Meanwhile, Mateus, Oliveira, and Neves (2023) claim that individual's adoption to smart thermostat increases their willingness to recommend the technology to others. Motivations to adopt HEMS include the promise of economic and environmental benefits, the prospect of enhanced living comfort, improved safety, and a sense of curiosity about the technology(Tuomela, Iivari, et al., 2021). Moreover, early adopters of solar PV in Denmark were more inspired by news articles and product advertisement while peers influenced the later adopters(Hansen et al., 2022). Moreover, social media (e.g. Facebook and YouTube) is a prominent platforms to increase in consumer acceptance to SETs(Yash Chawla et al., 2020).

4.1.2.4. Barriers to Smart Energy Technology adoption

Residential building occupants who have limited knowledge about smart energy technologies and low concerns about climate change are less motivated to invest in them (Brown et al., 2023). In addition, a study claims that a significant number of households have limited awareness regarding solar technology (Hai, 2019). And, for those who are planning to sell their property in the future, the reluctance to adopt to solar PV may be influenced by their concerns how could solar PV affect the selling price of the property and whether the potential buyers understand the benefits of having solar PV(Ma et al., 2016). Another study reveals that installers experienced challenges in convincing homeowners to adopt energy efficient technologies because they have lack of knowledge and information (Decuypere et al., 2022). Furthermore, Curtius (2018) found that real estate owners, developers and architects have low awareness and lack of knowledge regarding solar PV that can impede the adoption of solar PV.

Moreover, the pre-existing home appliances and privacy concerns can delay adoption especially among younger users(Shin et al., 2018). Other barriers to the SETs adoption include distrust and resistance, low knowledge on the benefits of using SETs, high upfront cost, privacy and security concerns, technology anxiety and negative social influences(W. Li et al., 2021). In a study in Switzerland, for example, (Curtius, 2018) revealed that high upfront costs and complexity in investment calculations are some of central product-specific obstacles to solar PV adoption. Similarly, reasons for low adoption to HEMs include high cost, low ROI, complexity of these systems and difficulties in retrofitting (Tuomela, Iivari, et al., 2021). so Meanwhile, policy risk, initial dependence on incentive or building codes and restrictive building permits are also considered as barriers to solar PV adoption (Curtius, 2018). In addition, residential building occupants are reluctant to adopt Smart Energy Technologies when they are not sure about the potential savings they can achieve using the said technologies (Qiu, Colson, & Grebitus, 2014).

4.1.3 Methods

This study employed qualitative research methods to explore aspects that influence users' thoughts, emotions, and behaviours toward the acceptance and adoption of SETs. While there may be numerous stakeholders involved in the decision-making process in residential building ecosystem, this study concentrates on the personal views of residential building occupants. This study employed a non-probability technique called purposive sampling to recruit interview participants who possess certain characteristics or qualities relevant to the study. In this study, interview participants are those residential building occupants or energy consumers who are above 18 years old, male or female, living in Denmark and possess smart energy technologies. To maintain the same selection criteria used for the initial participants, the interview participants been asked to refer someone from the target population who might be interested to participate. Finally, 21 interview participants took part in both face-to-face and online semi-structured interview.

4.1.3.1 Interview Questions

The interview questions are based in the literature divided into different topics to uncover the residential building occupants' views and experiences including demographic characteristics, energy-saving measures, and barriers and drivers to SETs' adoption. The interview started by providing the participants with an introductory explanation and a concise overview of smart energy technologies (SETs). To enhance interactivity and engagement, pictures smart energy technologies included in the study were presented for better understanding of questions and provide a clear reference point for discussion. Interview questions also include TAM elements and influential factors (e.g. trust, awareness, knowledge, policy and social influence) to SETs' acceptance and adoption found by (Billanes & Enevoldsen, 2022).

Table 19. Profile of interview participants

IP#	Gender	Age	Education	Employment	Residence	Region	Income
IP1	Female	25-34	Post-graduate	Full-time	House/villa	Middle Jutland	Above 40,000kr
IP2	Female	35-44	Bachelor	Full-time	Apartment	Zealand	30,000-39,999kr
IP3	Female	35-44	Bachelor	Full-time	Apartment	Main cities	10,000-19,999kr
IP4	Female	35-44	Diploma	Unemployed	Apartment	Main cities	No income
IP5	Male	35-44	Post-graduate	Full-time	Apartment	South Denmark	Above 40,000kr
IP6	Female	35-44	Post-graduate	Full-time	house/villa	South Denmark	Above 40,000kr
IP7	Female	25-34	Post-graduate	Full-time	Apartment	South Denmark	30,000-39,999kr
IP8	Female	25-34	Post-graduate	Full-time	Apartment	Middle Jutland	30,000-39,999kr

IP9	Female	35-44	Diploma	Full-time	house/villa	South Denmark	30,000-39,999kr
IP10	Female	25-34	Post-graduate	Full-time	house/villa	Middle Jutland	30,000-39,999kr
IP11	Male	25-34	Post-graduate	Full-time	Townhouse	Middle Jutland	30,000-39,999kr
IP12	Male	25-34	Post-graduate	Full-time	Apartment	Middle Jutland	30,000-39,999kr
IP13	Male	25-34	Post-graduate	Full-time	Apartment	Middle Jutland	30,000-39,999kr
IP14	Female	35-44	Post-graduate	Full-time	House/villa	South Denmark	above 40,000kr
IP15	Female	35-44	Post-graduate	Full-time	House/villa	Middle Jutland	30,000-39,999kr
IP16	Female	25-34	Post-graduate	Full-time	Townhouse	Middle Jutland	30,000-39,999kr
IP17	Female	25-34	Post graduate	Full-time	Apartment	Middle Jutland	Above 40,000kr
IP18	Female	35-44	Bachelor	Unemployed	House/villa	South Denmark	No income
IP19	Female	35-44	Post-graduate	Full-time	Apartment	Main cities	Above 40,000kr
IP20	Female	55-64	Bachelor	Full-time	House/villa	Zealand	No answer
IP21	Male	35-44	Post-graduate	Full-time	House/villa	Zealand	30,000-39,999kr

Note: Interview participant#: IP1- interview participant 1; Income: monthly income range before tax, Homeowner and tenant means type of a residential occupant

Interview participants and are both homeowners and tenants, five (5) were male and sixteen (16) were female (shown in Table 19). Majority of the interview participants possess higher education. Interview participants reside in Middle Jutland, Southern Denmark, Zealand and main cities. For the age group, 43% are aged 25-34, 52% are aged 35-44, and 5% are aged 55-64. When it comes to income per month (before tax), 52% of the interview participants earn 30,000 to 39,000kr, 29%

with income above 40,000kr, 9% with income 10,000 to 19,000kr, 4% have no income, and another 4% had no answer. For the types of dwelling, 43% reside in a house/villa, 9% in a townhouse, and 48% in an apartment.

4.1.4 Findings and Analysis

Deductive thematic analysis was employed to analyse the data. Seven steps of performing deductive thematic analysis are: (1) Identifying the pre-defined themes from the literature. (2) Reading transcripts multiple times, familiarizing of the data with its context, taking notes and making initial observations about how the data relates to the predefined themes. (3) Coding the data and applying the predefined themes as codes. (4) Organizing and grouping the similar codes and searched for potential themes or categories. (5) Generating new codes to capture the unique elements. (6) Reviewing how well the data aligns with the predefined themes. Finally, summarizing, and discussing the relationships between the predefined themes and research questions.

4.1.4.1 Ownership and willingness to recommend and adopt Smart Energy Technologies (SETs)

Result shows that due to high increase in gas prices in Denmark, most of the interview participants claimed that their energy bills have increased even though their energy consumption remained unchanged from last year. To address the issues, interview participants started practicing energy-saving measures. Moreover, interview participants were asked about their ownership of SETs to understand if adopting to smart energy technologies is considered as energy-saving practices. Result shows that the common practices to save energy include preparing multiple dishes simultaneously, turning off appliances when not in use, reducing heating temperature, and purchasing SETs such as LED and appliances with an A+ energy efficiency rating. On the other hand, some interview participants were already conscious about their energy consumption and practiced energy-saving measures for years. Additionally, most of the interview participants downloaded an app to monitor energy prices and utilizing appliances during off-peak hours.

When it comes to ownership of smart energy technologies, majority of the interview participants own LED lamps and controlled lighting systems. While others SETs owned by residential building occupants are EVs, solar PV, smart thermostat, smart meters and smart appliances (shown in table 20).

Table 20. Ownership of smart energy technologies

IP#	Smart energy technologies
IP1	LED lamps, smart thermostat
IP2	LED lamps, smart appliances
IP3	LED lamps
IP4	Controlled lighting system, and smart appliances
IP5	Smart appliances, LED lamps
IP6	Controlled lighting system, smart HVAC, smart thermostat
IP7	LED lamps, smart appliances
IP8	Controlled lighting system
IP9	Solar PV, LED lamps, HEMs
IP10	LED lamps, smart meters, smart thermostat
IP11	Controlled lighting system, smart thermostat
IP12	LED lamps
IP13	Controlled lighting system
IP14	Smart thermostat
IP15	LED lamps, solar PV
IP16	EV, LED lamps
IP17	LED lamps
IP18	LED lamps, smart appliances
IP19	LED lamps
IP20	LED lamps and EV
IP21	LED lamps, smart washing machine, EV

To understand what interests and preferences, residential building occupants were asked if they are willing to recommend and buy in the future. Result showed that IP12 mentioned that *"If I have to recommend , depends form the person but especially, LED lights to anyone, who has not change yet, that would be because it's an easy an cheap one. But, I will recommend most of them to different people".*

In addition, IP20 recommended to LED and EVs because, *"… any new car will cost money anyway if you go, so might as well spend a little more to get more sustainable and also on the long run, it will be cheaper and cleaner."*

In addition, residential building occupants who perceived LED lamps as cheap and available in the market would like to install more and recommend to others. Moreover, IP16 showed interest in buying smart home appliances *"when we get our own house at some point, like we're saving up* *for that, that would definitely be something like especially the washing machine and the dryer"* while others were interested in buying electric vehicle in the future.

4.1.4.2 Drivers to SETs' adoption

Interview participants were asked about their knowledge of SETs and source of information about SETs. Majority of the interview participants knew smart lighting systems, solar PV panels, and smart appliances. However, very few interview participants were familiar with smart meters, Home Energy Management Systems (HEMs) and Building Automation System (BAS). To understand the knowledge of SETs among residential building occupants, follow up question on how they describe SETs. For instance, IP5 stated *"I know that smart appliance can be connected to my phone and can operate it from there, maybe schedule it, it may be easier..."*

In addition, interview participants also mentioned different sources of information about SETs. For example, there were those who rely on internet when searching for SETs while others go to physical shops to see the products and were influenced by the salesperson. IP21 said, "*when I visit this electronics or shops…there were a lot of advertisement about the LED lights. Actually, I saw in the shop like Silvan."*

Others learned about SETs from YouTube commercials and vlogs, IP1 said *"I got it from YouTube, I think there is a lot from YouTube about different thing"*. Moreover, builders and installers can also help to educate residential building occupants about the benefits of SETs, for instance, IP21 said *"the installation company, they recommend me about the heat pump. Before I change that one. It was a private company."* Similarly, *IP1 said, "I need to consult a company that is working on this or even several, I think."*

Moreover, retailers of SETs can also influence residential building occupant's decision. For example, IP2 stated: *"I would say Power is a very good shop where you can expect like sellers describing you much more precisely and accurately about the product and you know how energy-consuming..."* Furthermore, users of SETs can influence others, for example, IP5: "*Both example, if I would like to buy new EVs, I would see what's in the market and I will also talk to some friends who have EVs to ask about what the things they considered during their purchase."*

Table 21. Sources of knowledge of SETs

- News, consultant, web shops, YouTube
- Shops, apps or google
- Advertisement, internet, supermarket display
- Facebook and colleagues
- Network, internet
- Family, builders
- Campaign posters, advertisement, electricity company, Internet
- Social media, newspaper, internet, friends
- Builders
- Builders, academic institution
- Internet
- Education, internet, friend, experts
- Internet
- Social media, TV
- Internet, friends
- Internet
- Internet
- Internet, family, friends, social media
- Internet
- Family, internet, City council
- Installer, internet, advertisement, friends

During the interview, the participants shared their reasons and opinions on utilizing SETS. Some participants believed that SETs provide convenience, useful in providing security and help them lowering their energy bill. IP3 claimed that: *"LED gives good light and we don't pay that much electricity and I think it's very good."* In addition, IP7 said, *"with LED we can also control the intensity of the light. Like when we are not studying or doing something, we don't need to turn it 100% lighting"*.

In addition, IP6 mentioned about smart lighting, "*it was to reduce energy consumption… because its intelligent system we have an app on our mobile, so for example, if I am just sitting in our sofa and I just want to read something then I just turn on two spotlights on top of me, right. Still am getting light which I need while saving. Second, because I usually travel every year for approximately one month especially in winter, and we are a bit concern that our house is alone and nobody is there."*

Likewise, IP4 said, *"If I have to buy I would prefer with better energy because it is good because I don't have to pay a lot of bill every month. I'd rather prefer one with better energy because it's a one-time investment."*

Similarly, IP5 said, *"I will have to inquire about the cost benefit. How much that it cost and how much does it benefit me. If it will benefit me in the long run, I would definitely install it"*.

Accordingly, IP14 said something about smart lighting, *"I think so, because when they see the benefit and they see that they can save money, of course they will go and try it. I know that most of the people not only around me, but in my also workplace, they trying to use this as smart lighting much more..."*

Aside from lowering energy bill, result shows that concern about the environment can also drive the willingness to adopt SETs. For example, IP20 mentioned; *"So we selected to go for it to go close because we would like to go for lowering consumption and also to as with the price and the prices for the benzin (gas), And so we wanted to go for greener and cleaner environment and we cut off on the cost on the long run."* In addition, IP12 claimed, "*smart meters is very good because we know our consumption"*.

Moreover, awareness about environmental issues can motivate users to buy SETs, for example, IP3 said, *"Maybe the electricity car. I think it is good for the environment because there is no pollution and use more LEDs lights at home instead of using the normal lights."* Some interview participants talked about their good experiences with EVs while some perceived that EVs would be the future trend.

Information coming from a credible source could encourage residential building participants to believe that SETs can help reduce energy bills. For example, IP3 answered, "*Yes, if they say and there is a proof of it then I will consider buying it. What there has to be an authentic proof … because there are many advertisement nowadays, but if there is authentic and there is a reason and proof then of course, I will consider it. I think there should be a research done."* The result shows trust to the policymakers can influence residential building occupant's attitude towards the adoption of SETs.

IP11 mentioned, *"That's a good question. If it's from the government, I would trust it more, if I get advertisement from the people selling this, it would be that they are just trying to sell it. Than if, it's from government that they make it clear that I can save energy and help the environment then I will be more likely to investigate it more and look for more information."*

Similarly, IP19 mentioned about influence of trust in brand of the product and government policy, *"if we buy something from a popular brand, then we can definitely assure some standard like some level of standard or quality standard we can assure that level of quality standard (...). I believe like there will be some standards or if we are in Denmark then they will definitely, there will be some standards set by government."*

Moreover, curiosity or interest in new technology can also motivate acceptance and adoption to SETs. IP6 said, "*First of all, my husband is a technology freak person and of course I am also from software engineering background so you get to know from internet about new technology on and off …"*

Interview participants who installed controlled lighting systems (e.g. Philips hue) claimed that they installed these systems for convenience, enabling them to control the lights via their smartphones even before entering their homes. For instance, IP8 said, "*I think the main thing for me is that I am able to turn lights off at the other side of the house from my phone and like to many people today I always carry my phone."* Likewise, IP13 said, *"I think it is for convenience, because we can turn all the lights off by talking to the google speaker that we have."*

Residential building occupants seek advice from family or friends when planning to invest on new technology, for example, IP1 said, "*I think I would ask maybe friends or colleagues if they have it"*. IP2 added *"if am using something effective for example, if I install something which makes my electricity bill lower, then definitely I would recommend it to my friends and my colleagues."* Likewise, IP17 said *"Definitely, absolutely as because I see it as an honest review. Uh, you know, considering that they are not trying to sell the product, it's just their honest opinion (…)."*

Policy such as implementing energy saving label program and providing incentives and subsidy can influence SETs acceptance and adoption. IP1 stated, *"if am going to buy something, I think I would choose the one let say A (label)."* In addition, IP1 added, *"Yeah that would really help us* *to implement it if there is that kind of program."* Meanwhile, knowledge of energy efficiency labelling and cost benefit of using SETs can influence adoption to SETs, as IP4 said*: "Here it's very easy, they have for example, if I have to buy freezer it shows the energy mark, it has the energy mark which one it is A+ , A++, B or C. It is easy to choose. It is a bit expensive to buy a better one but I would prefer."* Meanwhile, some participants would want to invest on EV because of the perception that EU rules will be banning gas-powered cars.

Furthermore, participating in energy rating program can also motivate residential building occupants to adopt to SETs, for example, IP15 said : "*The main reason why we chose to have solar panels was when we started to build a house and Denmark there was different energy markings for houses. Moreover, for us to pull up our house energy marking to the highest possible level at that time when it was built. You know, for your energy marking, so we needed some pluses and then we chose to have solar panels, which actually made what our house turn to be highest energy class"*.

Interview participants perceived that ease of use of SETs is important especially for older adults. For example, IP14 said, *"If it's easy to use, they will adopt it or they will use it much more faster than if it's a little bit complicated"* Likewise, IP16 said *"Yeah. So, if you have something where you don't have to consider that much about installation and use when you just plug and play your Tesla then yeah, definitely, yeah."*

In addition, aside from ease of use, the design and performance were mentioned as reasons of buying EVs, for instance, IP16 mentioned *"the EVs Car design and efficiency."* Similarly, IP20 stated, *"the features it's, we know it's clean, it's easy to use. Lesser noise. And very comforting to you were in the drive. And also it's actually safe, for the safety."* Meanwhile, IP21 explained the reasons for buying EV such as about curiosity, perceived usefulness in reducing energy bills and environmental concerns, *"I consider specially 2 and three things. First, I just want to try how it is to drive the electric vehicle. Then Secondly, I just calculate about the expenses. And then suddenly the EV user, it's a less expensive to pay for the electricity. And thirdly, And you will also help the environment so. Actually, I considered when I bought it"*

4.1.4.3. Barriers to SETs' adoption

High upfront cost of SETs affects the residential building occupant's interest to adopt SETs as stated by IP2 *"if they come up with something nice and cheaper format I'm sure not just me but everybody would think about it and try to install it which is much more effective and cheaper."*

Complexity of a technology can also affect acceptance and adoption, for example, some participants argued that smart appliances have many functionalities and residential building occupants only want to focus on what they need and, therefore, not using other functionalities of SETs. IP3 stated, "*The smart ones, they have many functions. We use the normal one and I think it's working so until and unless the normal one is working, I don't think I go to this smart one."* Similarly, IP5 mentioned, *"the new dishwasher we bought just had this feature but I did not want it. I did not demand it, it's not important. Because dishwasher is not something that you run every day at a particular, time and will take your time."*

Result also suggests that residential building occupants take into account both the compatibility between brands and country of origin of SETs. For instance, IP11 said, "*Maybe if it something when I am concern with data safety or the ability to be hacked, probably I feel a bit more safe if it's from Europe …. It's more of a concern that it could work together, its brand that can work with other brands."* IP21 also mentioned about compatibility between brands of smart home appliances*, "The smart energy technology, it helps a lot, reducing the energy consumption, but there is one difficulties for the customer when they want to choose the right appliances. For example, when I try to choose, there was a three or four different kinds of services, and the problem is you don't have the same brands, appliance with the same brands all at your home… I think there should be 1 system which can control different brands with one smart system. So that would be beneficial for the public and it would help a lot to choose these kind of technologies."*

Meanwhile, IP8 is not interested in buying EVs and perceived that EVs is not suitable for long distance drive, "*Not necessarily, no. I think that is mainly because for me what would be relevant for example EVs. And, just because of the amount of, I do have a lot of Kilometre that I drive every day to work and in regards to that an EV just isn't the most convenient option, so no. I'd say no."*

On the other hand, the presence of pre-existing technologies in a household can deter individuals from purchasing new ones. As an illustration, during the interview, IP1 participant stated, *"We already have them in the house since we moved in."* It means that residential building owners do not need buy new appliances when they moved in to new home due because they bought the old appliances of the previous owner while in the case rented apartment, building owners pre-installed or provided most appliances. And, they would only think about buying new when old appliances are broken.

Some residential building occupants are resistant to change their technologies at home. One of the reasons is due to their lifestyle or activities at home. For example, IP1 said *"we have not because our consumption is not so huge."*

Furthermore, house direction can also influence the adoption of SETs as mentioned by IP18, *"House direction not suitable for solar PV."* This suggest that solar PV is not every efficient for a house not facing to the right direction. Likewise, roof design needs to be considered when installing solar PV as mentioned by IP1 "*Yes, this is solar panels (…) our roof need to be changed in some years, maybe in 8 years of 10 years. And if we put them up now, then we have to take it down when we change the roof. So, maybe it's not so cost wise, we don't know exactly. So, our idea is to install them when we have a roof, then we don't need to take it down, not too cheap."*

Home ownership also plays a role in adopting SETs. For example, while some tenants have the decisions to buy their own appliances (e.g. dishwasher, washing machine, dryer and stove) others have limited authority to install home appliances, IP7 mentioned, "*Not buying as such because we are in a rented apartment."*

4.1.5 Discussion

This study explores residential building occupants' perceptions and experiences to identify the drivers and barriers of SETs' acceptance and adoption. The study includes a range of smart energy technologies such as solar PV, smart HVAC, smart lightings, smart thermostat, smart appliances, HEMS, BAS, smart meters and EVs. Results revealed that adoption to SETs is considered as energy-saving measures among residential building occupants. Findings of this study are in accordance to the study of (Billanes & Enevoldsen, 2022) revealing Perceived ease of use (PEOU), Attitudes, trust, knowledge, awareness, policy and social influence positively influence residential building occupants' acceptance and adoption to SETs. The findings of this study also suggest that convenience, curiosity and positive experience could also motivate residential building occupants to invest to SETs.

4.1.5.1 Drivers to acceptance and adoption of smart energy technologies

Trust can positively influence the acceptance and adoption of SETs. When residential building occupants believe that SETs is safe to use, they are more likely to use them. For instance, residential building occupants perceived that SETs made from Europe are safe to use and simple products like LED lamps have no data security issues. Moreover, trust can be achieved through clear information sharing, success stories, and positive recommendations. Moreover, similar to findings of Berger et al. (2022), reliable sources of information can also shape the attitudes and perceptions toward the acceptance and adoption of SETs among residential building occupants. This suggests that residential building occupants tend to trust more if the information comes from the government, which in turn, increases their interest to investigate more about SETs. Likewise, residential building occupants may trust a well-established brand of SETs. Residential occupants believe that known brands invest in research and development in order to produce high-quality technologies.

Social influence refers to how residential building occupants' behaviours are affected by the actions and opinions of others. Results revealed that positive referrals from friends, family, and colleagues could influence residential building occupants' decisions to adopt smart energy technologies. Results revealed that social influence has a positive influence on residential building occupants' decisions to adopt smart energy technologies. The result indicates that residential building occupants' have greater trust to people they are acquainted with.

Perceived usefulness is the extent to which residential building occupants believe that smart energy technologies will make their lives better. In simpler terms, residential building occupants are more likely to use smart energy technologies if they believe that they will help reduce their electricity bills. Even though SETs may be initially expensive, residential building occupants would still prefer such options, as they perceive SETs would offer cost benefits in the end. Moreover, results reveal that residential building occupants can learn about the energy-saving benefits of using SETs from installers, builders, and salespersons.

Perceived Ease of Use (PEOU). The result shows that residential building occupants would prefer to adopt SETs if they believe it as easy to use indicating that user-friendliness of SETs drive the successful acceptance and adoption of SETs. For instance, the ease of use of EVs and ease of use were cited as reasons to adopt these technologies.

Attitudes. Having good feelings about using SETs would encourage adoption of these technologies. For instance, results indicate that residential building occupants who had good experience using smart lightings have positive attitudes toward buying more SETs and would recommend SETs to others. Positive attitudes toward SETS can be enhanced through educational campaigns and positive reviews highlighting the benefits of using SETs.

Knowledge and awareness about the benefits and features of SETs have positive effects on perceptions of the usefulness and willingness to adopt SETs. Findings showed that most of residential building occupants are capable of recognizing and describing functions of solar PV, EVs, smart home appliances and smart lightings but few were familiar with smart meters, BEMs and HEMs. Increasing awareness through educational programs about SETs, workshops, online resources, and public awareness campaigns can bridge knowledge gaps and empower potential users to make informed decisions. Moreover, the residential building occupant's awareness about environmental issues can also serve as a motivating factor for individuals to purchase SETs. For instance, intention of buying electric vehicles (EVs) is due to perception that EV has positive impact on the environment.

Government policies such as providing incentives and subsidies can positively drive the acceptance and adoption of SETs. In response to the study of (Berger et al., 2022) the result shows that residential building occupants would consider buying SETs if there is a program offering incentives or subsidies for SETs. Furthermore, similar to study (Su, 2019) result shows that government programs that enhance knowledge on energy efficiency labelling and the cost benefits associated with using SETs can also influence the adoption. Moreover, the EU energy policies promoting clean energy and reducing emissions such as the idea of banning fossil fuel cars in few years can influence residential building occupants' decisions to invest in electric vehicles (EVs). Additionally, the intention to improve the energy rating of a residential building can also encourage an individual's decision to invest in SETs. In Denmark, implementing energy efficiency policy and program to motivate homeowners to install solar PV to elevate their house energy rating is an effective approach. For example, result shows that homeowner installed solar PV to achieve the highest energy rating for their house.

Curiosity. The findings showed that one reason for adopting Smart Energy Technologies (SETs) was the residential building occupants' curiosity and willingness to embrace new technologies in residential buildings. Individuals with high interest in new technologies want to remain informed and therefore actively find information about the latest releases, updates, and advancements in their field of interest. SETs offer advanced features and functionalities appealing to residential building occupants who have keen interest in new technologies. The findings educational background and professional background could influence residential building occupant's interest in new technology.

Positive experience. Moreover, residential building occupants tend to recommend and adopt SETs when they have positive experience or satisfying engagements with these technologies. The interests of residential building occupants to recommend and install more LEDs have increased after they experienced positive changes in their electricity bills. Additionally, having confidence in the efficiency of SETs in reducing energy usage due to favourable past experiences has a beneficial impact on the purchasing choices of people residing in residential buildings.

Convenience can also influence residential building occupants to adopt SETs. Residential building occupants who installed controlled lighting systems allowed them to control their lights remotely through their smartphones even when far from home. By developing SETs that suitable into residential building occupants' daily lives can enhance user-friendliness of SETs and would results to increased adoption rates.

4.1.5.2 Barriers to acceptance and adoption of smart energy technologies

Complexity of a technology can hinder the residential occupants' acceptance and adoption. Result reveals that residential building occupants prefer simple and practical technology and consider extra features of smart home appliances to be irrelevant to their specific needs. In addition, residential building occupants prefer SETs that can seamlessly integrate and compatible with other brands of SETs.

High upfront cost. Moreover, in alignment with the finding of (Curtius, 2018) residential building occupants emphasized the reluctance to purchase SETs due to high upfront cost of SETs such as solar PV, smart home appliances and EVs. This explains why a majority of the interview participants opted for affordable SETs such as LED lamps or controlled lighting system.

Pre-existing technologies. Similar to findings revealed by (Shin et al., 2018), this study revealed that the presence of pre-existing technologies or appliances can discourage SETs acceptance and adoption. For example, when moving to a new house residential building occupants acquire appliances from previous owners while in a rented apartment the building owners typically provide or pre-install most of the appliances. The statement suggests that pre-existing technologies in a household can discourage residential building occupants from buying new ones. In this case, residential building occupants do not feel the need to buy new appliances unless the existing ones defective or broken.

Resistance to change. This study found similar results to (W. Li et al., 2021) that resistance to technological change among residential building occupants can hinder the acceptance and adoption to SETs. For residential building occupants having home activities that do not require a significant change in their technologies, investing in SETs may not bring substantial improvements in their lifestyle. Moreover, the perception of consuming less energy is another reason of resistance to change technologies.

House design. Result indicates a connection between the direction or orientation of a house and solar PV. This suggests that solar PV may not be efficient if house roofs are not directly facing the sun. Similarly, result also shows that roof design can affect the decisions to invest on solar PV.

Not owning a house inhibit the adoption of SETs. Homeowners have more authority to install SETs than tenants, who have limited power to do so. Despite being aware of smart home appliances, tenants are unable to install SETs because of their rental agreements.

4.1.6 Conclusion and recommendation

This study emphasizes the importance of engaging residential building occupants in the energy transition goal. The valuable insights about the factors that guide residential building occupants to adopt or reject SETs, could guide relevant stakeholders such as policymakers and technology providers when developing strategies that address barriers, enhance motivations, and promote widespread adoption of these energy-efficient technologies.

Positive reviews and recommendations from trusted sources like family, friends, colleagues, or the government can encourage residential building participants to adopt SETs. In contrast, the negative experience of using SETs within social circles could discourage residential building occupants from buying and adopting them. In addition, social media, word-of-mouth, newspapers, physical shops are prefect channels for spreading information about SETs.

Perceived usefulness (PU), perceived ease of use (PEOU), Attitudes, knowledge and awareness, trust, policy, curiosity, social influence, positive experience were identified as drivers to residential building occupants' acceptance and adoption of SETs. On the other hand, high upfront cost could be one of the main reasons for low acceptance and adoption to SETs like EVs, solar PV or smart home appliances. Smart lightings such as LED lamps and controlled lightings are the most common SETs owned by residential buildings. The widespread adoption of smart lighting system could be due to its affordability and presence even in the physical shops in Denmark. In addition, complexity, resistance to change, pre-existing technologies, not owning a house or property and house design can also hinder the acceptance and adoption of SETs in residential buildings.

Furthermore, to overcome these barriers, this study suggests collaboration of housing associations, local utilities, environmental groups, city government to provide educational and awareness campaigns regarding the benefits of SETs, the types of SETs' available and how to access them, targeting not only residential building occupants but also builders, installers and engineers. Moreover, technology providers can provide online information and tutorials to help residential building occupants, installers, and builders understand the installation process, functionalities and benefits of SETs, which in turn, enhance the perception of ease of use and perceived usefulness of SETs among residential building occupants. Furthermore, encouraging residential building occupants to form local communities, such as a local housing community group can be useful for sharing information and experiences among each other about SETs. Lastly, offering incentives and subsidies can make SETs more affordable and attractive for residential building occupants.

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5 Overview of the Acceptance and Adoption of Smart Energy Technologies (SETs) in residential buildings

The final chapter of this PhD dissertation combines and reflects on key findings from the four journal articles in relation to three research questions. It aims to provide a detailed understanding of drivers and barriers to the acceptance and adoption of Smart Energy Technologies (SETs). Furthermore, this dissertation also presents conclusion and recommendations while outlining limitations and suggesting areas for further studies.

5.1. Key Findings

This section presents the key findings on the residential occupants' willingness to adopt SETs, as well as the drivers and barriers for adoption decisions.

5.1.1 Willingness to adopt SETs

In response to Research Question 2: *Are residential building occupants willing to adopt SETs,* this sub-section compares the empirical studies (quantitative and qualitative) with the literature. Studies by (Berardi, 2013; Cristino, Lotufo, Delinchant, Wurtz, & Faria Neto, 2021; Gimpel, Graf, & Graf-Drasch, 2020; Wilson, Hargreaves, & Hauxwell-Baldwin, 2017) indicate low adoption rates for SETs. This study aligns with what literature has already reported about the low familiarity and adoption of SETs. Empirical results of this study also highlight that the intention to adopt SETs varies by technology, with lower adoption rates for HEMS and BAS compared to slightly higher rates for technologies like smart lighting. Studies in (Jia, Xu, Fan, & Ji, 2018; Schaffer & Brun, 2015) revealed the influence of home ownership, income and types of dwelling on residential building occupants' intention to adopt SETs (e.g. solar PV, heating system). Moreover, through quantitative and qualitative results, this study suggests the importance of knowledge and awareness, and affordability of SETs in enhancing adoption intention among residential building occupants.

5.1.2 Drivers to the acceptance and adoption of smart energy technologies

This sub-section addresses Research Question 1*: What factors influence the acceptance and adoption of smart energy technologies?* and Research Question 3: *Why do residential building* *occupants decide to adopt or reject smart energy technologies, and how do they make these choices?*

TAM elements. This study adopted the Technology Acceptance Model (TAM) and elements from other models such as TAM2 and UTAUT. Original TAM, proposed by Davis (1989), includes elements such as Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), which influence Attitudes and Behavioral Intention to use a technology. A study in (Whittle, Jones, & While, 2020) shows that PEOU and PU are crucial for individual's intention to adopt Home Energy Management Systems (HEMs). Additionally, Fleiß, Hatzl, and Rauscher (2024) claim that PEOU and positive Attitudes influence adoption of SETs. Literature implies that PU has inconsistent effect on BI compared to PEOU and Attitudes. Moreover, the quantitative results support the literature by showing that PEOU ($\beta=0.159$, $p<0.001$) and Attitudes ($\beta=0.151$, $p<0.001$) significantly predict BI, whereas PU ($\beta=-0.002$, $p=0.904$) does not significantly influence BI. Qualitative findings reveal that residential building occupants are inclined to invest in SETs such as smart lighting, smart appliances, smart thermostat as they perceived them as useful and easy to use.

Policy. A study by (Zhou & Brown, 2017) reveals that policies (e.g. subsidy and programs) can help overcome barriers to SETs' adoption. The quantitative result in this study supports the literature, revealing the positive influence of government policies such as subsidy ($\beta=0.117$, $p<0.001$), and program ($\beta=0.118$, $p<0.001$) on residential building occupants' intentions to adopt SETs. Likewise, qualitative study results showed the impact of incentives and energy-saving program in overcoming challenges related to high upfront cost and limited knowledge. Overall, the empirical findings support the literature's emphasis on government policy as a driver of SETs adoption by highlighting the role of incentives and programs.

Trust. A study by Tak, Becerik-Gerber, Soibelman, and Lucas (2023) highlights the importance of trust in adoption decisions of smart home technologies. Moreover, a quantitative finding of this dissertation found the positive influence of trust ($\beta=-0.042$, $p=0.025$) on the acceptance of SETs. Moreover, the qualitative insights showed that trust in SETs is developed through the influence of government programs and reputable brands that encourages positive attitudes towards investing in them.

Social influence, an element from Unified Theory of Acceptance and Use of Technology (UTAUT), through social recommendations shows positive effect on individuals' adoption decisions (Guerreiro, Batel, Lima, & Moreira, 2015; Gøthesen, Haddara, & Kumar, 2023). Both quantitative and qualitative findings support the literature, for instance, quantitative study reveals the significant role of social influence ($\beta=0.145$, $p<0.001$) on residential building occupants' intentions to adopt SETs. Qualitative findings showed that personal experience, such as seeing SETs installed at friend's home, and recommendations about the benefits of SETs promote adoption intention. Qualitative findings identified trusted sources that influence adoption intention including family, friends, government, and technology providers.

Knowledge and Awareness. Studies by Alkawsi, Ali, and Baashar (2020) and (Badri-Harun, Shaari, Jaafar, & Julayhe, 2017) reveal the positive influence of knowledge and awareness on SETs adoption. Similarly, a study in Taso, Ho, and Chen (2020) indicates the influence of awareness of environmental problems on attitudes toward using smart meters. In other words, this study implies that awareness on the negative impact of one's actions may lead to a more favorable attitude toward adopting sustainable practices or technologies. In response to the literature, quantitative result supports the literature revealing the positive influence of knowledge ($\beta=0.206$, $p<0.001$) and awareness ($\beta=0.123$, $p<0.001$) of the benefits of SETs on intention to adopt SETs among residential building occupants. Similarly, the qualitative findings highlight that familiarity with SETs and awareness of environmental benefits may lead to more favorable attitudes toward adopting SETs.

Additional factors. Qualitative result extends the literature by highlighting other factors that drive the acceptance and adoption of SETs including curiosity, convenience, and positive experience. For instance, options to control smart home appliances and smart lighting remotely via smartphones can also influence the acceptance and adoption. The positive experience in reducing electricity bills from using LED lamps encourage intention to install energy-efficient lighting system. And the high interest or curiosity in smart technologies reveals positive attitudes toward installing SETs.

5.1.3. Barriers to adoption of SETs

This sub-section presents the barriers to SETs adoption, identified through both quantitative and qualitative studies and compares these findings to the existing literature. These barriers to adoption of SETs include high upfront cost, house ownership, limited knowledge and awareness, pre-existing SETs, complexity and house design.

High upfront cost. Literature suggests that high battery cost and high price for EVs hinder the widespread adoption of EVs (She, Qing Sun, Ma, & Xie, 2017; Vassileva & Campillo, 2017). Literature also reveals the residents' concerns of high installation cost, maintenance and repair of smart home technologies especially those with lower income and tenants (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013). The quantitative results support these findings, showing that residential building occupants are reluctant to adopt SETs as they perceived them (e.g. EVs) as expensive. Consistently, qualitative findings revealed that residential building occupants often prefer more affordable options like LED lamps. On the other hand, the high cost of SETs influences positive attitudes towards investing, as some residents perceived that high initial costs indicate sustainability. Qualitative findings, for instance, revealed that while investing on EVs require high upfront cost, some residential building occupants believe that it will lead to greater long-term savings and environmental benefits.

House Ownership. As was found in Jia et al. (2018), the types of dwelling (rented vs. owned) significantly influences the willingness to adopt energy-efficient technologies. For instance, tenants are reluctant to adopt energy-efficient technologies (e.g. air conditioners) as they don't perceived them as useful, especially if they might move out soon (Jia et al., 2018). Quantitative study supports the literature, revealing that "not owning a house or apartment" as one of the reasons for not investing on SETs. Moreover, qualitative findings also support the literature, showing that even though tenants know about the benefits of SETs, rental agreements hinder adoption. This rental agreement limits their control over their living space.

Limited awareness and knowledge. A study in Dutt (2020), reveals that limited technical and practical information from technology provider may discourage adoption to SETs. The quantitative findings support the literature, revealing that residential building occupants are reluctant to adopt SETs due to limited knowledge on benefits of SETs. Qualitative finding further explained that residential occupants are generally unfamiliar with SETs and their benefits, particularly smart meters, Home Energy Management Systems (HEMS), and Building Automation Systems (BAS). The qualitative and quantitative findings confirm and extend the literature's insights and indicate the need for increased knowledge and awareness about benefit of using SETs.

Additional Barriers. A study of Shin, Park, and Lee (2018), which indicate that pre-existing home appliances can hinder the adoption of SETs, particularly among younger users. Likewise, qualitative results revealed that apartments furnished with appliances would limit the options for investing in new ones. Qualitative study finds that some new homeowners might keep appliances from previous occupants to save money and time. Furthermore, complexity and house design also influence adoption of SETs. Complexity in using and integrating smart energy technologies (SETs), for instance, qualitative finding showed that residential building occupants often find smart home appliances with complicated features less interesting because they prefer simple and user-friendly options. Furthermore, qualitative result shows that house design and orientation also a challenge. For instance, effectiveness of solar PV depends on optimal sunlight capture, therefore, houses with poor orientation or design features encounter significant challenges in adopting solar PV systems.

5.2 Conclusion and recommendations

This dissertation investigates the willingness to adopt SETs among residential building occupants and examines the influential factors to the acceptance and adoption of Smart Energy Technologies (SETs). This study confirms a low willingness to adopt SETs, with varying levels of willingness differs in the type of SETs. The rationale behind these decisions is influenced by various factors. Identified factors hindering acceptance and adoption of SETs include high upfront cost, lack of knowledge, home ownership, pre-existing technologies, complexity and house design. Additionally, the study highlights the positive influence of Perceived Ease of Use (PEOU) and Attitudes, along with the mixed effect of Perceived Usefulness (PU) on SETs' acceptance. Furthermore, this study emphasizes the role of government policies, social influence, trust, awareness, knowledge, curiosity, convenience, and positive experiences in shaping adoption decisions. Based on these insights, some recommendations are proposed:

- Offer financial incentives (e.g. subsidies, low-interest loans) to alleviate the cost challenges of SETs especially for the low-income households and tenants. For example, providing a portable SETs or agreements that allow tenants to benefit from energy-saving technologies without permanent installation.

- Initiate programs to enhance knowledge about the climate impacts of excessive use of energy and the benefits of using SETs via social media (e.g. Youtube), community meetings, physical shops, etc.
- Utilizing recommendations from government or reputable brands and showcasing positive reviews from SETs' users to improve trust on SETs among residential building occupants. For example, creating platforms for sharing experiences and recommendations to build trust in SETs.
- Government policies or programs that encourage SETs' providers to design user-friendly technologies that can be integrated seamlessly with existing home technologies to reduce complexity and foster adoption.

Implementing these strategies can help overcome barriers and promote the widespread adoption of SETs, improving energy efficiency and sustainability in residential buildings.

5.3 Limitation and Future Studies

This dissertation advances our knowledge in SETs' acceptance and adoption but there are some limitations. *First,* the focus on Denmark means the findings may not be applicable to other countries with different economic, social, or regulatory conditions. *Second,* by relying solely on the Technology Acceptance Model (TAM) and some elements from TAM2 and UTAUT, the study might not cover other relevant factors and considerations. *Third,* the research is confined to residential buildings, limiting its applicability to other types of buildings (e.g. commercial buildings). *Fourth,* while the study considered the relationship between income and types of dwelling on adoption intention, it does not explore the influence of other important socio-demographic factors (age, gender and education). *Finally,* even though the study employed both numerical and qualitative methods, each has its own weaknesses. These weaknesses may affect might affect how thorough and useful the study's results are in different situations.

To address the limitations, future studies should explore several areas. For instance, employing case studies on specific Smart Energy Technologies (SETs) in real-world settings can provide a better understanding of the effect of Perceived Usefulness (PU). Additionally, conducting studies in different regions of Europe will help determine if empirical results in this study are consistent across various contexts. Finally, monitoring changes in adoption patterns as SETs evolves will help in understanding how these advancements in SETs influence decisions.

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6. Appendix

6.1 Online survey questionnaire

Welcome to this survey on users' acceptance and use of smart energy technologies. It has been designed as part of a PhD project at Aarhus University and it should take no more than 5 minutes to complete. Your responses are anonymous and will never be linked with you personally. In addition, you have the right to withdraw from the survey at any time. Thank you for your participation.

1. How familiar are you with the following technologies?

	Very familiar	Somewhat familiar	Slightly familiar	Not familiar
Heating, ventilation, air conditioning (HVAC) systems	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Photovoltaic solar panels	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Smart lighting technologies (e.g. LED lights)	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Smart home appliances (e.g. smart dishwasher, dryer, smart washing machine)	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Smart thermostat	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Home energy management systems (HEMS)	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Building Automation systems	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Smart meters	(1) ❑	(2) ❑	(3) ❑	(4) ❑
Electric cars	(1) ❑	(2) ❑	(3) ❑	(4) ❑

2. Which among the following would you consider as smart energy technology? (check all that apply)

(1) ❑ Heating, ventilation, air conditioning (HVAC) systems

(2) ❑ Photovoltaic solar panels

(3) ❑ Smart lighting technologies (e.g. LED lights)

(4) ❑ Smart thermostat

(5) ❑ Home energy management systems (HEMS)

(6) ❑ Building Automation systems

(7) ❑ Smart meters

(8) ❑ Electric cars

(10) ❑ None of the above

(11) ❑ Others (specify)_____

3. Do you own any of the following smart energy technologies? (check the box that applies)

	Yes	No, but I plan to buy one in the next 12 months	No and I do not plan to buy one in the next 12 months
Heating, ventilation, air conditioning (HVAC) systems	(1) ❑	(2) ❑	(3) ❑
Photovoltaic solar panels	(1) ❑	(2) ❑	(3) ❑
Smart lighting technologies (e.g. LED lights)	(1) ❑	(2) ❑	(3) ❑
Smart home appliances (e.g. smart dishwasher, dryer, smart washing machine)	(1) ❑	(2) ❑	(3) ❑
Smart thermostat	(1) ❑	(2) ❑	(3) ❑

	Yes	No, but I plan to buy one in the next 12 months	No and I do not plan to buy one in the next 12 months
Home energy management systems (HEMS)	(1) ❑	(2) ❑	(3) ❑
Building Automation systems	(1) ❑	(2) ❑	(3) ❑
Smart meters	(1) ❑	(2) ❑	(3) ❑
Electric cars	(1) ❑	(2) ❑	(3) ❑

4. (If you do not own a smart energy technology) What is your reason for not buying?

(1) ❑ It's expensive

(2) ❑ I'm not sure it can help me

(3) ❑ I'm just not interested

(4) ❑ I am not confident using it

(5) ❑ Other (specify) _____

5. How do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
I believe that smart energy technologies are useful for lowering my electricity bill	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I think using smart energy technologies would be easy	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
I like the idea of using smart energy technologies	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I intend to buy smart energy technologies in the near future	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

6. How do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
With government subsidies and tax incentives, I will be interested to use smart energy technologies	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Government policies and programs on energy savings will motivate me to use smart energy technologies	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I feel that smart energy technologies are safe to use	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I am aware about the benefits of using smart energy technologies	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Opinions of my family and friends influence my choice and decision to use smart energy technologies	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Having knowledge about the benefits of using smart energy	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
technologies, motivates me to use smart energy technologies					

7. Please select your age group

(1) ❑ 18 to 24

(2) ❑ 25 to 34

(3) ❑ 35 to 44

(4) ❑ 45 to 54

(5) ❑ 55 to 64

(6) ❑ 65 and above

8. What is your sex?

(1) ❑ Male
(2) ❑ Female
(3) ❑ Other
(4) ❑ I would rather not say

9. What is your occupation?

(1) ❑ Employed (fulltime)
(2) ❑ Employed (part-time)
(3) ❑ Self-employed
(4) ❑ Unemployed
(5) ❑ A student
(6) ❑ Retired
(7) ❑ Others (please specify) _____

10. What is your educational background?

(1) ❑ Primary school
(2) ❑ Secondary school up to 16 years
(3) ❑ Diploma or further education

(4) ❑ Bachelor or undergraduate
(5) ❑ Post-graduate degree
(6) ❑ Prefer not to say

11. In what region in Denmark do you live?

(1) ❑ Nordjylland
(2) ❑ Midtjylland
(3) ❑ Sjælland
(4) ❑ Syddanmark
(5) ❑ Hovedstaden

12. Which of the following best describe where you live?

(1) ❑ House or villa
(2) ❑ Apartment
(3) ❑ Town house residence
(4) ❑ Rural property
(5) ❑ Other (please specify) _____

13. Which of these describes your monthly (before tax) income?

(1) ❑ Under 9,999 kr
(2) ❑ 10,000-19,999 kr
(3) ❑ 20,000- 29,999 kr
(4) ❑ 30,000- 39,999kr
(5) ❑ 40,000kr and above
(6) ❑ Prefer not to say

6.2 Interview Questions

Introduction: purpose of the interview is to explore the SETs users' knowledge, perceptions, and willingness to buy SETs. Smart energy technologies are energy-efficient technologies installed in buildings that can improve energy efficiency and reduce energy consumption. Examples of smart energy technologies, Solar PV, smart lighting (LED), smart thermostats, smart HVAC systems, smart appliances, smart meters, BAS, HEMS, and EVs.

BACKGROUND QUESTIONS

- Gender:
- Region:
- Age group:
- Types of dwelling:
- Income per month before tax
- Education

KNOWLEDGE AND AWARENESS OF SETS

- *(To understand what types of SETs they know or installed at home, also to understand if SETs are visible to potential users, to understand how aware they are about SETs)*
- How is your current energy bill, compare to last year? What do you think is the reason for rise or fall of your bill? What do you do to reduce energy consumption? Does it work?
- How much do you know about SETs (show some pictures)?
- Can you name any smart energy technology you know? What do you know about it? (show some pictures)
- What smart energy technologies do you own at home? Why did you decide to buy SETs?

  Could you tell me your experience of (example using EVs)
- Considering the product, you bought (EVs), which features are most important to you?
- Does the SET that you have bought meet your expectations?
- What do you think are the benefits of using SETs? Can you describe your experience using the SETs?
- Do you think the SETs you installed at home are beneficial for you? (PU) Can you tell me what is the benefit of using SETs (*e.g. smart meters*)? (knowledge and awareness)
- Are you aware of government programs that encourage the public to use SETs? (e.g. EU energy labeling measure on home appliance A+, or A++)
- Who would you seek advice if you need to buy new technologies for your house? Is it friends, experts, family or just yourself?
- How did you learn about SETs? Alternatively, where did you get information about SETs? (Source of information) (e.g. TV commercial, radio, Facebook)

- Do you know any of your friends or colleagues who installed SETs at their homes?
- In your opinion, why would an energy consumer buy SETs?

PERCEPTIONS OF USING SETs

- In your opinion, what would be the difference between SETs and not smart energy technology in terms of features, benefits and functions? For example, the differences of using smart meters compare to traditional meters, EV vs normal car
- Do you consider about purchasing more SETs in the future? *Why and why not? Which one?(BI)*
- Do you think that using of SETs (LED) will meet your expectations? Why? (Attitudes)
- What will be your motivation or reason for buying SETs in the future? For example, for buying solar PV?
- Does it matter where SETs are produced, for example would you prefer to buy smart appliances if made in Europe than made in the US? Why? (trust)
- What are the things do you consider when buying SETs
- By considering the adoption of SETs, do you think it is important for you to trust in the competence or credibility of those who developed SETs? Why? (trust)
- Do you think that the adoption of SETs would help reduce your energy consumption? Yes/no. If yes, would consider using SETs believing that it could reduce your energy consumption. *(PU)*
- Do you think that subsidy or incentive from government/ utilities would encourage you to use SETs? *(policy/subsidy)*

- Do you think that seeing you by family and friends using SETs could encourage them to use SETs? *(SI)*Why?
- Do you think having a government programs or policies about SETs would enhance awareness and knowledge of SETs? Why and why not? Do you have any suggestion on what program or policy would that be? *(policy/programs)*
- Do you think that people would be encouraged to buy SETs if they believed it is easy to user-friendly? *(PEOU)*
- Would you recommend SETs to others? If yes, *which SETs would you recommend? Why? (SI)*

Thank you for participating in this interview!

6.3 Invitation letter for semi-structured interview

Subject: Invitation to participate in a PhD project on smart energy technology acceptance and adoption

Hello interview participant,

My name is Joy Billanes, PhD Fellow at the Centre for Energy Technologies, Department of Business Development and Technology Aarhus University in Herning. My research interest lies in the acceptance and adoption to smart energy technologies among residential building occupants. As part of my studies, I am looking for someone to help me explore my research topic.

The interview is about energy consumer's perception and experience of adopt smart energy technologies (SETs). This will be an online or face-to-face interview for 20-30 minutes. With your consent, interviews will be audio-recorded and will be deleted once the recording has been transcribed. All research data, including audio recordings and any notes, etc. will be encrypted/password-protected. Research data will only be accessible by the researcher and the research supervisor to publish research article or a future research project.

If you would like further information about my research or have any questions or concerns, please do not hesitate to contact me.

Email: joybil@btech.au.dk

Best regards,

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AARHUS UNIVERSITY

6.4 Co-author statements

6.4.1 A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption/ Billanes J. & Enevoldsen P.

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AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Joy Dalmacio Billanes

This declaration concerns the following article/manuscript:

Title:	A Critical Review: Ten Influential Factors to Technology Acceptance and Adoption
Authors:	Billanes J. & Enevoldsen P.

The article/manuscript is: Published

If published, state full reference: J Billanes, P Enevoldsen. *"A critical analysis of ten influential factors to energy technology acceptance and adoption"*. 2021. Energy Reports, 6899-6907

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No

The PhD student has contributed to the elements of this article/manuscript as follows:
A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	A
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	A

In case of further co-authors please attach appendix

Signatures of the co-author
Date: 14.08.2023

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

6.4.2 Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark/ Billanes J. & Enevoldsen P.

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Declaration of co-authorship*

Full name of the PhD student: Joy Dalmacio Billanes

This declaration concerns the following article/manuscript:

Title:	Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark
Authors:	Billanes J. & Enevoldsen P.

The article/manuscript is: Published

If published, state full reference: J Billanes, P Enevoldsen *"Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark"*. 2022. Energy and Buildings 276, 112524.

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations? No

The PhD student has contributed to the elements of this article/manuscript as follows:
A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	A
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	A

Signatures of the co-authors

Date	Name	Signature
	Peter Enevoldsen	[signature]

In case of further co-authors please attach appendix

Date: 14.08.2023

[signature]
Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

6.4.3 Examining the path to smart energy technology adoption in residential buildings/ Billanes J. & Enevoldsen P.

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Declaration of co-authorship*

Full name of the PhD student: Joy Dalmacio Billanes

This declaration concerns the following article/manuscript:

Title:	Examining the path to smart energy technology adoption in residential buildings
Authors:	Billanes J. & Enevoldsen P.

The article/manuscript is: Submitted

If published, state full reference:

If accepted or submitted, state journal: Energy efficiency

Has the article/manuscript previously been used in other PhD or doctoral dissertations? No

The PhD student has contributed to the elements of this article/manuscript as follows:
A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	A
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	A

Signatures of the co-authors

Date	Name	Signature
	Peter Enevoldsen	[signature]

In case of further co-authors please attach appendix

Date: 14.08.2023

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.