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Sustainable technology: Antecedents and outcomes of households' adoption

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ABSTRACT

With the development of cities, environmental concerns have increased with the adoption and development of measures to reduce environmental devastation becoming important. The use of sustainable technologies as a solution, more specifically, smart homes, have gained special attention in reducing energy consumption as one of the sectors with the biggest impact on the environment. Few studies have been done to understand the consumer perspective on the household adoption of sustainable technologies, specifically regarding smart thermostats. Based on a sample of 327 responses and using a quantitative approach through structural equation modelling (SEM), this study aims to understand the relevant dimensions that influence households to adopt smart thermostats, as well as the outcomes of that adoption. The model was estimated using the partial least squares method, and final results suggest the relevance of internal and external motivators, privacy risks, and comfort to the adoption. Moreover, the adoption of sustainable technologies positively impacts two major outcomes: perceived well-being and intention to recommend. Comfort and pro-environmental behaviour also act as moderators for these two outcomes. The model revealed that 10 out of 13 hypotheses were supported, and the findings allow us to understand households' motivation for sustainable technologies adoption, emphasizing their importance in the topic of energy efficiency.

1. Introduction

In recent years, environmental problems have increased and become more present in society due to human influence. Situations such as global warming, ozone layer depletion, loss of biodiversity, scarcity of natural resources, and water, air, and soil pollution, besides being harmful to the environment and sustainability, end up not only negatively impacting human life but also compromising the quality of life and well-being of the future generations [45,64,68]. One of the sectors that most affect the environment is the energy sector. Therefore, it is essential to find a balance for the amount of energy consumed, seeking new energy sources and more environmentally friendly solutions in order to reduce the environmental problems caused by its abusive consumption [43]. The topic of energy efficiency and the reduction of energy from non-ecologically renewable sources has been receiving great attention from researchers, being one of the most effective ways to reduce these problems [53]. During the United Nations Climate Change Conference (COP21), the need for a rapid energy transition was discussed, where the decarbonization of the electricity sector and the improvement of energy efficiency appear, in the Paris Agreement, as essential to promoting sustainability and responding to existing climate change [2].

The need to invest in new technologies and research and find smart solutions that consider the development of sustainability and the well-being of individuals is increasingly a priority [40]. With the strong growth in technological advances, progressively more intelligent devices, interfaces and applications are appearing and making our lives easier [41]. Thus, implementing sustainable technologies can be a strong ally [18]. Since the residential sector accounts for about one-fifth of global energy consumption [6], implementing technological solutions in this sector and developing energy policies that promote and influence the adoption of sustainable technologies at home, such as support programs, or rebates, can accelerate the use of this type of technologies by households, and can consequently, substantially reduce energy consumption by private users from non-sustainable sources. Smart homes have gained special attention in this field, especially on the topic of energy efficiency, being one of the main priority action areas of the European Union (EU) under the Strategic Energy Technology Plan [69]. These contribute not only to decarbonization by reducing the consumption of non-renewable energy but also to improv-

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ing people's quality of life and to more independence from the extraction of natural resources [38]. In this sense, the implementation of efficient and sustainable technologies, for which the smart thermostat is an example, has significantly impacted energy savings and improved energy efficiency [3], hence the importance of exploring this topic further. Within the set of sustainable technologies that can respond to the current environmental problems and help individuals to behave more sustainably, we find the smart thermostat (ST), which will be the focus of this research.

Despite several studies focusing on sustainable technologies, few have been developed specifically from the household customer's perspective [70], integrating the antecedents and outcomes that lead families to adopt domestic sustainable technologies into a single model, essentially in the energy efficiency sector [43]. Most studies are based on general energy behaviours or on individuals who have already purchased heating appliances and not specifically on understanding the antecedents for adoption intention by new customers [21,35]. Regarding smart thermostats, existing studies focus on a functional view of the product (composition, engineering, features, comparison with the regular thermostat) and not on understanding the factors that may influence their adoption by families and the benefits they can gain from it in terms of comfort and well-being [31,58,59]. Hence, having as a motivation to fill this gap in the literature, this study aims to understand the consumer's perspective on adopting sustainable household technologies [67,66]. More specifically, this investigation probes the antecedents, such as motivators, determinants and factors that influence families to adopt sustainable technology smart thermostats (ST) in their homes, as well as the outcomes emerging from this adoption.

The contribution of this research is twofold. The purpose of this study is, firstly, with the results obtained, provides a theoretical contribution to the literature in the field of sustainable technologies and energy efficiency, creating and developing an empirically validated and contextualized research model that integrates the antecedents and outcomes that leads households to adopt sustainable technologies, more specifically, the smart thermostat, in order to contribute to the efficient use of energy. Secondly, from a practical point, it presents a proposal that identifies strategies, improvements and initiatives that professionals in the sustainable technologies and energy sector should incorporate in the future, considering the consumers' perspective, in order to formulate more effective policies that consider energy use efficiently, as well as create effective marketing programs and campaigns, that can motivate consumers to adopt smart thermostats or sustainable household technologies in their homes that meet their needs, rather than less environmentally friendly energy sources.

The structure of this research is as follows. The next section provides a theoretical background regarding the concepts of smart homes and smart thermostats and contains the literature review. Section 3 presents the conceptualized model and the respective research hypotheses to be tested. Section 4 provides the methodology used and describes the sample obtained. In section 5, the data analysis and results from the research are presented. Section 6 contains a discussion of the results, as well as the theoretical and practical contributions, and some limitations and recommendations for future research. Finally, the principal conclusions are presented in section 7.

2. Theoretical background

2.1. Smart homes

With the growth of technology, IoT devices have been gaining the interest of consumers [13]. An exponential growth in their use is expected from the increase in the number of smart homes [8]. A smart home is a modern home equipped with interconnected intelligent devices capable of acquiring information about the environment and its inhabitants [24,38], fulfilling the objectives of comfort and efficiency [46]. Bing et al. (2011) [4] define it as a home environment containing devices and systems automatically controlled through technology. For Ghaffarianhoseini et al. (2016) [22], it is a residence equipped with a communications network, which connects sensors and technological home appliances that can be accessed, monitored or controlled remotely, providing services that meet the needs of individuals. These contribute to the improvement of citizens' domestic environment in several aspects, one of them being in the field of energy efficiency [56]. Various studies have been conducted to examine the acceptance and adoption of smart homes by users, as well as their drivers and possible barriers, using theories such as the theory of planned behavior (TPB), the theory of acceptance model (TAM) or using the image of these technologies [38,49,69,72]. Hence, despite its potential and growth in the global market, some studies have reached the same conclusions. High prices, associated costs, concerns with security vulnerabilities, cyberattacks, and a lack of information and data protection are considered factors that discourage consumer interest and adherence. In contrast, energy and monetary savings are seen as attractive factors [13,55].

2.2. Smart thermostats

In recent years, energy consumption has increased drastically in buildings due to population growth [60] and the coronavirus disease pandemic situation (COVID-19), which intensively increased household energy expenditure [74]. Household appliances are the leading cause of this consumption [7], so the shift to environmentally renewable energy should start with energy consumption at home by adopting more efficient appliances [21]. In the context of energy efficiency, energy efficient heating appliances (EEHA) emerge, responsible for heating a house's environment [43]. The smart thermostat appears in this field as an efficient item of equipment to regulate an environment's heating and air conditioning. The smart thermostat consists of a device that uses innovative technologies to control the temperature at home through IoT devices remotely (e.g. smartphone or web application), based on reactive or predictive occupancy, or by configuring the temperature regulation, allowing to create an organic heating/cooling schedule that adapts to the needs of families, making it possible not only to save on energy bills but also to reduce energy consumption [58,63]. Although the adoption rate of smart thermostats has been growing in residential buildings [33], there are still some gaps. Table 1 summarizes the main recent findings on smart thermostats, where studies that approach theories such as theory of planned behavior (TPB), theory of technology acceptance model (TAM), among others, are presented. Globally, users often mention problems with confusing procedures in programming the device, interfaces with reduced fonts and buttons, unintuitive symbols or abbreviations, difficulty accessing the thermostat's physical location, and concerns about data privacy and security due to the use of presence sensors and geolocation [58,63]. Additionally, users value comfort, ease of use, control, and installation over energy savings and device costs [31].

2.3. Drivers from the literature

2.3.1. Motivational theories

Motivational psychology argues that individuals' behaviours are triggered by motivations, which can be intrinsic or extrinsic [14]. One of the theories used in motivational psychology is the organismic integration theory. This theory examines the level of integra-

Table 1
Studies on Smart Thermostats.

Authors	Topic	Theories	Findings	Data
Koupaei et al., (2020) [31]	Opinions and perceptions of smart thermostats using aspect-based sentiment analysis of online reviews	Confirmatory aspect-based opinion mining	Users do not discuss energy and cost savings features compared to control, ease of use, and installation. Comfort is discussed more than energy efficiency.	26,372 online reviews from Amazon
Stopps & Touchie (2021) [58]	Exploration of thermostat programming, environmental attitudes, and influence of smart controls on energy savings	Based on previous studies about energy savings and programmable thermostats in buildings	ST operation differs from conventional programmable ones. Participant-programmed schedules achieved significant HVAC load reductions compared to no programmed schedule. The use of occupancy-based controls improves energy savings.	54 participants monitored for 1 year with ST installed
Tamas et al., (2021) [59]	Comparing manual, programmable, and smart residential thermostat devices	Usability metrics, in contrast to previous literature	ST were considered more useable than programmable ones. Users desired more feedback concerning energy consumption, and 51 % enjoyed thermostat control through a smartphone application.	51 participants interviewed
Duman et al., (2021) [15]	Home energy management system with an integrated smart thermostat for smart grids response	Theory of Home energy management systems (HEMSs)	Simulation combining ST with HEMS rather than using a conventional thermostat. Important results show a daily cost reduction of 53.2 %, and AC cost is reduced by 24 % compared to conventional thermostats.	Investigation in Istanbul, Turkey, of 6 types of households
Vellei et al., (2021) [65]	Agent-based stochastic model of thermostat adjustments	Theory of Static Fanger's PMV/PPD model	Results highlight the importance of users' thermal comfort needs to understand and model users' interactions with ST for designing, assessing, and controlling demand response strategies.	9,000 user interaction data from Canadian thermostats
Tu et al., (2021) [62]	Multi-country study to understand the role of technology attributes and individual attitudes in the diffusion of smart thermostats	Theory of discrete choice experiment (DCE); previous studies about ST attributes	Heating cost savings, remote temperature control, visualization of energy consumption changes, and expert recommendations are valued by households, privacy concerns reduce remote features acceptance, and a strong environmental identity reinforces environmental attributes acceptance.	5,500 participants from eight European countries
Mamonov & Koufaris, (2020) [37]	Smart thermostats to fulfil higher-order psychological needs	Theory of technology acceptance model (TAM); Theory of planned behavior (TPB)	Performance expectancy has a minor effect on ST adoption intention, and effort expectancy has no effect. A new factor, techno-coolness, was identified as the key to technology adoption, comprising the perceptions that a technology can be fun, make the user feel technologically advanced, and make a home look modern and futuristic.	793 participants from the online labour market Amazon's Mechanical Turk (AMT)

Notes: ST– Smart Thermostat; HVAC – Heating, Ventilating and Air Conditioning; AC – Air Conditioning; PMV – Predicted mean vote; PPD – Predicted percentage dissatisfied.

tion and internalization of values and regulation of the induced behaviour [52]. In the information systems field, the motivational concept of perceived locus of control (PLOC) is widely used [50]. Locus of control emerges from the social learning theory and refers to individual differences in a generalized belief between internal control versus the reinforcement that comes from external control. Moreover, is associated with differences in the functioning of the brain and can be seen as a mediator of involved commitment of the individual in life pursuits [5]. The concept of PLOC can range from external PLOC (feelings of compulsion, that is, one's behavior that is attributed to external authority or compliance, believing that the events in their lives come from uncontrollable forces), internal PLOC (feelings of willingness and volition, where the individual perceive themselves as active agents and the origin of their behaviors, assuming that they can control the events by effort and skill), and introjected PLOC (feelings of misalignment between personal values and perceived social influences) [5,36]. In this context, integrating motivational factors into the final model may be interesting to understand what may motivate households' behaviour in adopting smart thermostats.

2.3.2. Perceived privacy risk

Having IoT devices at home implies that data capture and wireless communications connections are made daily to have the physical and virtual households' objects operational and performing their functions [32]. Furthermore, smart thermostats use presence sensors and geolocation to obtain occupancy information about the house [58]. Hence, it is inevitable that its adoption raises certain privacy and security concerns. These concerns have been prominent in the technology adoption field, where factors compromising individuals' privacy and security influence their adoption intentions negatively [10]. According to Featherman & Pavlou (2003) [17], perceived privacy risk can be defined as the potential loss of control associated with personal information, such as when it is used without one's knowledge or permission. Perceived privacy risk can be also defined as the expectation of losses associated with the release of personal information, suggesting that a factor of awareness, such as trust beliefs, can help to mitigate perceptions of privacy risk and increase consumers' intention to disclose personal information, encouraging them to accept and have intention to adopt a technology when they are apprehensive and skepticism about using it [70,71].

2.3.3. Comfort and Well-being

A characteristic of a smart home is to be able to acquire knowledge about its inhabitants and its domestic environment in order to meet the comfort and efficiency goals desired by the user [46]. Furthermore, some studies on smart thermostats have concluded that their users value comfort more than the energy savings and the costs associated with acquiring the device [31]. In relation to thermal comfort, it can be defined as a condition created in the mind that expresses satisfaction with the thermal environment in which an individual is [11]. Thus, comfort plays an important role where, besides the sustainable considerations and visual aesthetic quality that a sustainable technology can bring to a house, the thermal comfort that an individual feels is also considered one of the crucial considerations for its use and acceptance by households [11]. Hence, understanding the comfort that families perceive when adopting a smart thermostat in their homes can bring interesting insights to the study.

In this context, an individual who feels comfortable and satisfied will have higher perceived well-being. Well-being can be defined as a measure of satisfaction that may be correlated with extrinsic and intrinsic factors of individual life [51]. For Diener (2009) [61], it consists of a life self-evaluation, where pleasant and unpleasant effects are measured. Additionally, well-being can be divided into two concepts, hedonism (or subjective well-being, based on pleasure, happiness and positive emotional states) and eudemonism (or objective well-being, where an actualization of human potential arises) [9]. In practical terms, well-being is the outcome or reward of a particular behaviour, assumed to be positive [54]. Hence, it is expected that the behaviour of adopting and using smart thermostats will lead to rewarding feelings, facilitating daily life as well as contributing to comfort and satisfaction, influencing households' perceived well-being.

2.3.4. Pro-environmental behavior (PEB)

Given the need for global action on climate change, environmental problems could be reduced if people acted more pro-environmentally [1]. Pro-environmental behaviour refers to all possible actions that harm the environment as little as possible and/or safeguard the environment [57], whether these are performed in public (participating in environmental movements) or private (recycling, accepting energy policies, adopting renewable energy systems at home) [1]. It is expected that individuals with environmental concerns, environmental self-identity, and pro-environmental behaviours will readily adopt a sustainable technology and encourage others to do the same. Hence, including a construct related to pro-environmental behaviour (PEB) in the model could be interesting to see its effect on the adoption of a sustainable technology. Several studies have attempted to define PEB according to its multiple dimensions that can be disaggregated depending on the environmental impacts and nature of the study under analysis [34]. Therefore, PEB can be conceptualized into certain dimensions, such as social environmentalism (focusing on the individual's social engagement in conservation actions, such as peer interactions and group memberships), conservation lifestyle (the most common, which typically include everyday household behaviours such as recycling, conserving energy by turning off lights when not needed, using more conscious transportation such as public transport or cycling, and saving water), and environmental citizenship (the least common, being related to civic engagement or political support regarding environmental issues) [34]. PEB is a second-order construct formed by these three concepts. Its inclusion into the final model will bring a more environmentally related perspective to understanding households' use of the smart thermostat sustainable technology.

3. Research model

The proposed research model emerges from the literature to explain the antecedents and outcomes of smart thermostat adoption by households, combining motivational theory, perceived privacy risk, comfort, and the behavioural PEB theory as the antecedents, and well-being and intention to recommend as the outcomes. A motivational theory was added to represent how motivations trigger individuals' behaviours. Subsequently, with the smart thermostat being a technology, it is postulated that perceived privacy risks and trust may play a crucial role, given the inherent concerns with new technologies. When considering the features and functionalities of smart thermostats, comfort may play an important role in their adoption and, consequently, is expected to influence the perceived well-being of households. Also, if the adoption feedback is positive, users will more likely recommend the device to others. PEB theory was also added, given the sustainable aspect, combining environmental concerns with individuals' behaviour.

Additionally, to better understand the role of comfort and PEB in the context of smart thermostat adoption, this work proposes that both constructs will also work as moderators. Socio-demographic parameters such as age and gender and house demographics such as household size were used as control variables [43]. Fig. 1 represents the research model of smart thermostat (ST) adoption, and then the formulated research hypotheses are presented.

3.1. Hypotheses development

Internal PLOC refers to feelings of volition where users perceive themselves as the origin of their behaviours. These can be related to inherent enjoyment or based on personal values, goals, and outcomes [36]. If individuals have environmental concerns and ecological awareness, as well as the ability to master the device, or the perception of the benefits they can gain by using smart thermostats, then customers will be more likely to be positively disposed to adopt them [70]. Consequently:

H1: Internal PLOC will positively influence the adoption of ST.

External PLOC is characterized by feelings of compulsion and represents the perceived reasons for the individual's behaviour, which are attributed to an external authority or compliance, so there is no conflict between the user's personal values and the perceived external influences [36]. The individual's behaviour is typically performed to satisfy external demands, so in the case of smart thermostats, if there are recommendations from public institutions or financial incentives, the willingness to adopt the technology is greater [70]. Thus:

H2: External PLOC will positively influence the adoption of ST.

Introjected PLOC is characterized by feelings of misalignment of perceived social influences and personal values and may be related to feelings of guilt, shame, or pressures that may cause individuals to act in a particular way or, on the other hand, bring about feelings of acting and being autonomous [36]. It usually provokes tension and confusion in an individual because it results from the misalignment between their beliefs around a particular behaviour and their self-perceived autonomy. In the case of the smart thermostat, if individuals experience substantial pressure to be environmentally conscientious or feel pressure to adopt the technology and at the same time consider themselves autonomous beings, the resulting confusion may negatively influence them to adopt the technology [70]. Therefore:

H3: Introjected PLOC will negatively influence the adoption of ST.

Perceived privacy risks refer to the potential loss of control over personal information [17]. Technologies that present lower risks of privacy loss will be trusted and, thus, more likely to be used [73]. Trust plays an important role when consumers have little experience with some technology, and their disposition to trust depends on the existing reputation around smart thermostats [71]. Also, concerns about loss of privacy and security will depend on how

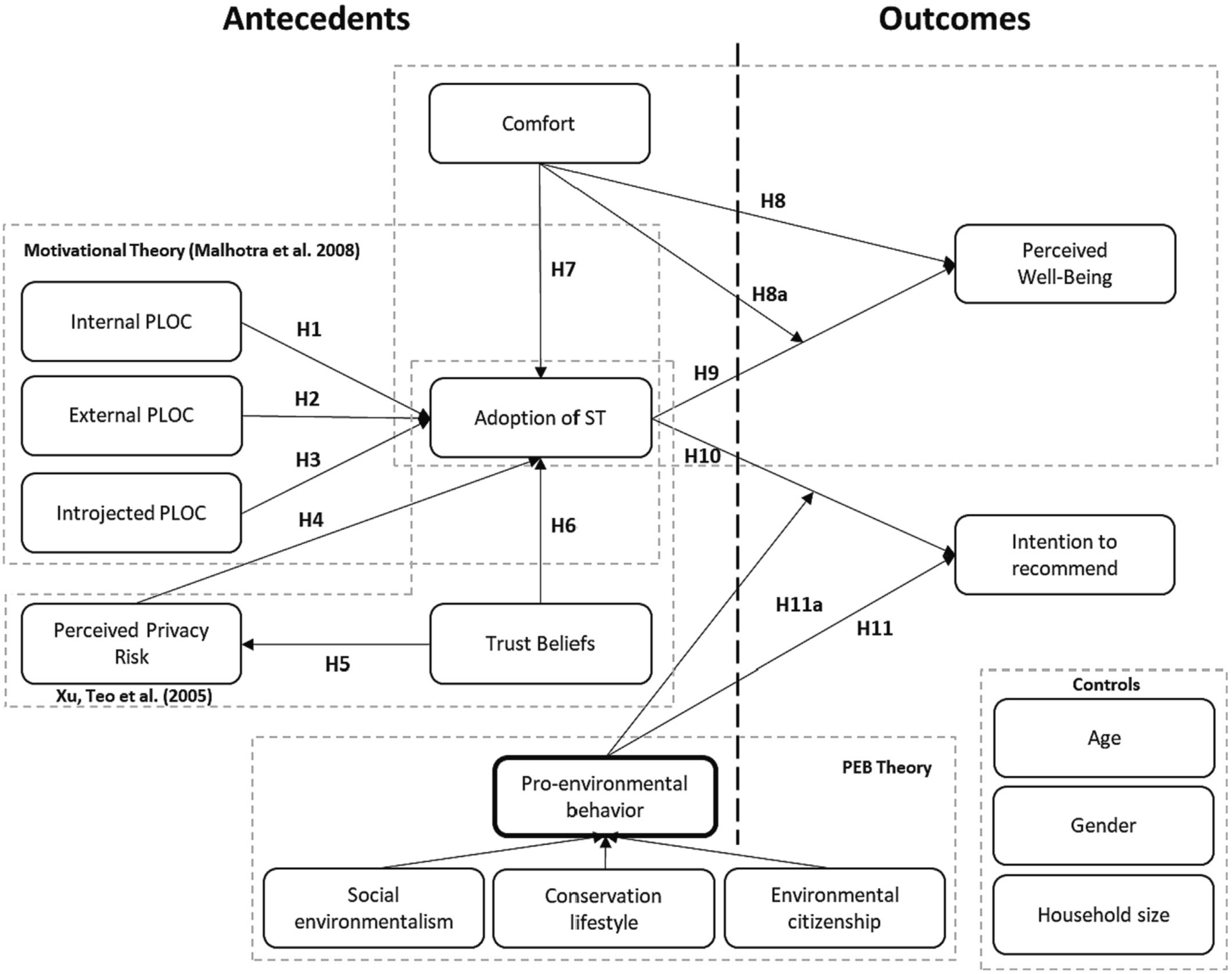


Fig. 1. Research model.

that information is transmitted [73]. If individuals' trust is compromised or they suspect that their privacy and security may be at risk in smart thermostat adoption, that perception will negatively affect them to adopt. Consequently:

H4: Perceived privacy risk will negatively influence the adoption of ST.

H5: Trust beliefs will positively influence perceived privacy risk.

H6: Trust beliefs will positively influence the adoption of ST.

Given that the use of sustainable technologies at home can increase individuals' current levels of comfort, and their being aware of this and prioritizing it, comfort emerges as a primary motivation for families to adopt these types of solutions in their homes [19]. Hence, for higher levels of comfort, the greater families will intend to use these types of technologies and, consequently, adopt a smart thermostat in their homes. Therefore:

H7: Comfort will positively influence the adoption of ST.

The adoption behaviour of smart thermostats implies that families are using this sustainable technology in their homes, which means that they are using the service features that smart thermostats offer to complete the purpose for which they purchased them [54]. In other words, when a household member uses a smart thermostat to control the temperature at home remotely, whether, for heating or cooling, they are using the device they have adopted to achieve a more pleasant temperature in which they feel comfortable, leading them to pursue a state of well-being [54,58]. Thus, we can say that achieving well-being is one of the goals of adopting smart thermostats and that comfort is expected to play an important role as a moderator of this relationship. Additionally, the higher the thermal comfort a family feels in their home environment, the higher their level of satisfaction and tranquillity will be [11] and, consequently, their sense of perceived well-being. Therefore, we hypothesize:

H8: Comfort will positively influence perceived well-being.

H8a: Comfort will moderate the relationship between the adoption of ST and perceived well-being.

H9: Adoption of ST will positively influence perceived well-being.

Recommendation can be defined as a form of post-adoption behaviour [42]. If an individual's feedback is positive about adopting a sustainable technology, then the probability of recommending it to others is high, encouraging more people to adopt that technology. In the smart thermostat context, if consumers become adopters of the smart thermostat technology and have a good experience with it, they are very likely to recommend it to others [44]. Thus:

H10: Adoption of ST will positively influence the intention to recommend the ST.

Pro-environmental behaviour refers to an individual's behaviours aimed at avoiding harm to and/or safeguarding the environment [57]. The more strongly individuals engage in pro-environmental behaviour, the greater the willingness to adopt sustainable technologies instead of using less sustainable products. Therefore, there is a likelihood to adopt smart thermostats and recommend them to others in order to influence others to have pro-environmental behaviours too. Thus, PEB could work as a moderator between adoption and recommendation. Furthermore, positive recommendations have been shown to be quite persuasive and effective in influencing peers' behaviour, which is essential for the continued adoption of a product [42]. Consequently, environmentally concerned individuals are likelier to recommend the smart thermostat technology to others. They may also be interested in having other citizens adopt it to have more people supporting the same goal and encourage change to more sustainable solutions. Therefore:

H11: Pro-environmental behaviour will positively influence the intention to recommend the ST.

H11a: Pro-environmental behaviour will moderate the relationship between the adoption of ST and the intention to recommend the ST.

4. Methods

4.1. Measurement

An online questionnaire was created to obtain the data to be used in the analysis. The selection of the variables and respective measurement items that composed the questionnaire were based on the literature and adapted in order to be consistent with the theme. The survey was conducted online and developed in Portuguese, and most of the questions were measured using a seven-point quantitative scale, ranging from 1 (strongly disagree) to 7 (strongly agree). Regarding the demographic questions, age was measured in years, and gender was measured in a dummy variable, where 1 represented men. All constructs were modelled using reflective indicators, except for perceived privacy risk, which was measured by formative indicators. The items for all constructs that formed the survey and the corresponding sources can be found in Appendix A. Before the respondents answered the questions, an introduction was given explaining the concept of smart thermostat technology to ensure that respondents were aware of the technology under study.

4.2. Data

Firstly, a pilot survey was conducted to polish the questions and receive feedback on the questionnaire content and structure. This test survey obtained 32 responses. Since the results confirmed the preliminary validity and reliability of the measurement instrument, there were no changes to the questionnaire, and the pilot survey data was used in the main survey. The main survey was distributed online, and the audience was primarily members of the Portuguese population. A total of 327 valid responses were collected for data analysis. Common-method bias was analyzed using Harman's one-factor test. Since the first indicator explains 35.3 % of the variance, it means that none of the indicators individually explain the majority of the variance, that is, more than 50 % [47]. In this sense, no significant common method bias was detected. Concerning demographic data, 61 % of the respondents were female. Respondents ranged in age from 18 to 75 years, with the average being 37 years old. 63 % of respondents were academic graduates, having completed a university degree. The sample has an adequate group to test the objective of this study since individuals with a university education typically have a high potential to adopt new technologies [44]. The majority of respondents indicated they were employed (68 %). A question was asked at the beginning of the survey to understand the target audience better. Respondents were asked if they participate in the decision-making process when adopting new technologies in their homes, and 95 % answered affirmatively. The household size was used as a control variable to gauge the house composition. Three was the average number of individuals living in the household.

5. Results

A quantitative approach using structural equation modelling (SEM) was chosen to understand households' adoption of the smart thermostat technology. This procedure consists of a statistical method capable of modelling theoretical concepts through constructs and then connecting the constructs via a structural model to test and estimate their relationships [29], using a combination of statistical data and qualitative causal assumptions [39]. In order to evaluate the hypotheses created, the model was estimated using the partial least squares (PLS) method. This technique is used since we have formative indicators to measure the constructs (which is the case of the perceived privacy risk construct that cannot be directly measured and therefore uses formative indicators to represent it), the data are non-normally distributed [23,26], and the research model is considered complex [29] and has not been tested in the literature before [30], being the case of our research model as explanatory research to understand smart thermostat adoption. Based on all these requirements, PLS is the appropriate method to use since it meets the purpose of this research. Smart PLS 4.0 software was used to run the model and analyze the results [48]. The following subsections describe the methodology further. The measurement model was first examined to assess reliability and validity, and then the structural model was tested.

5.1. Measurement model

A measurement model was conducted to assess reliability and validity to ensure the reflective constructs' internal consistency, convergent reliability, and discriminant validity. Observing Table 2, we can see the mean and standard deviation of the reflective constructs, the composite reliability (CR) and the average variance extracted (AVE). Internal consistency was tested using the CR, and since the results for all constructs are above 0.7, all construct indicators are equally reliable and internally consistent [26,28]. It was also verified that AVE values are higher than 0.5 for all constructs, meaning convergent validity is achieved [20]. The outer loadings should be higher than 0.7 ($\approx \sqrt{0.5}$), and every loading above 0.4 should be excluded to evaluate indicator reliability [12,26,28]. Based on these criteria, item AST3 was eliminated due to a low loading. The others are above 0.7, except for three items (EC3, EC4, IntroP3), that are lower than 0.7 but higher than 0.4 and were therefore retained, as shown in Appendix B [25,28]. Finally, discriminant validity was obtained through the evaluation of three methods. For the Fornell-Larcker assessment, the square root of each construct's AVE should be greater than its highest correlation with any other construct [20], which is verified (Table 2). The second criterion is that the outer loadings should be higher than all of its cross-loadings, that is, greater than the loadings on other constructs [25], as illustrated in Appendix B. The third method is the Heterotrait-Monotrait ratio (HTMT). This technique determines that all the values should be lower than the threshold of 0.9 [27], which is confirmed in Table 3. After the analysis, we can conclude that the reflective constructs are suitable to be used for the assessment of the structural model.

In order to assess the validity of the formative constructs, a measurement model was created to test multicollinearity using the variance inflation factor (VIF) and the significance and relevance of indicator weights [26]. If the VIF values of each indicator are below the threshold of 5, it indicates that we do not have collinearity issues [25], which is confirmed in Table 4, showing VIF values lower than 2.4. Regarding significance, the indicators that do not have significant weights have loadings higher than 0.5. These were maintained, confirming the significance and relevance of the indicator weights. Only PPR3 did not have a significant weight and a loading higher than 0.5 (-0.149). It was therefore dropped. In the end, we can conclude that the formative constructs are reliable.

The second-order construct PEB was also analyzed since it represents a reflective-formative construct. Table 5 presents the formative analysis by assessing the weights' multicollinearity, statistical significance and relevance [26]. The weights here are the result of a multiple regression with PEB as a dependent variable and the formative constructs that composed it as independent variables. All VIF values are lower than 5, indicating no collinearity issues, and regarding weights, all of them are statistically significant; hence they can be used to test the structural model.

5.2. Structural model

Before assessing the structural model and interpreting the results, it was necessary to test the multicollinearity of all constructs based on the variance inflation factor (VIF), which should be lower than 5 [25]. The VIF ranges from 1.000 to 2.584, indicating the inexistence of multicollinearity issues so we can proceed to the interpretation of the results. Fig. 2 presents the structural model and contains the R-squared and the path coefficients. The bootstrapping procedure with 5000 samples [25] was used to assess the significance level of the constructs.

The model explains 59.1 % of the variation in the adoption of smart thermostats. The hypotheses of internal PLOC ($\widehat{\beta}$ = 0.424; $p < 0.01$), external PLOC ($\widehat{\beta}$ = 0.131; $p < 0.05$) and comfort ($\widehat{\beta}$ = 0.155; $p < 0.05$) are statistically significant but introjected PLOC ($\widehat{\beta}$ = -0.029; $p > 0.10$), and trust beliefs ($\widehat{\beta}$ = 0.110; $p > 0.10$) are not. Thus, hypotheses H1, H2 and H7, respectively, are confirmed, but H3 and H6 are not. Perceived privacy risk, although it is statistically significant ($\widehat{\beta}$ = 0.103; $p < 0.10$), has a different influence from what was proposed (not negative). Thus H4 is not confirmed. Regarding perceived privacy risk, the model explains 39.7 % of the variance through trust beliefs ($\widehat{\beta}$ = 0.607; $p < 0.01$), which is statistically significant, meaning that H5 is supported. Concerning perceived well-being, the model explains 63.4 % of the variation, and all variables are statistically significant, namely, comfort ($\widehat{\beta}$ = 0.340; $p < 0.01$), the moderation effect of comfort in the relationship between the adoption of smart thermostats and perceived well-being ($\widehat{\beta}$ = 0.073; $p < 0.05$), and adoption of smart thermostats ($\widehat{\beta}$ = 0.566; $p < 0.01$). Hypotheses H8, H8a and H9 are respectively confirmed. Finally, 65.9 % of the variation in intention to recommend is explained through the adoption of smart thermostats ($\widehat{\beta}$ = 0.779; $p < 0.01$), pro-environmental behaviour (PEB) ($\widehat{\beta}$ = 0.114; $p < 0.05$), and the moderation effect of PEB in the relationship between the adoption of smart thermostats and intention to recommend ($\widehat{\beta}$ = 0.071; $p < 0.10$), which are statistically significant. Thus, hypotheses *H*10, *H*11 and H11a are supported. Overall, of the 13 hypotheses, only three were not confirmed.

Concerning the control variables, the majority are not statistically significant ($p > 0.10$), meaning that, in general, age, gender, and the number of elements that constitute the households do not have a significant impact on our dependent variables. Therefore, they are not related to households' antecedents, adoption, and outcomes of smart thermostat adoption. The exceptions are household size controlling the perceived privacy risk and perceived well-being, making sense since all the individuals of the households may not have the same perception of these two factors. Age, controlling the adoption of smart thermostats and perceived well-being is also expected since younger people are usually more engaged in adopting new technologies [44], seeking more technological solutions to improve their well-being.

6. Discussion

Given environmental concerns and the need for a rapid energy transition, the necessity to move toward more sustainable solutions and energy-efficient appliances is increasing. The results of this research enable an understanding of what may motivate households to adopt a sustainable technology in their homes, such as smart thermostats, as well as the benefits they can gain from this adoption, filling a gap that has not yet been reported in other studies.

6.1. Theoretical implications

This research concludes that factors such as internal and external motivations, perceived privacy risk and comfort influence the adoption of smart thermostats, except for the introjected PLOC motivation and trust beliefs. Regarding perceived privacy risks,

Table 2
Mean, standard deviation, CR and Fornell-Lacker table.

Constructs	Mean	SD	CR	InterP	EP	IntroP	TB	AST	Comf	PWB	IR	SE	CL	EC
InterP	4.723	1.616	0.913	**0.824**										
EP	3.987	1.648	0.924	0.597	**0.843**									
IntroP	3.632	1.756	0.923	0.550	0.661	**0.842**								
TB	4.568	1.433	0.963	0.683	0.546	0.506	**0.930**							
AST	5.106	1.426	0.941	0.719	0.546	0.429	0.627	**0.917**						
Comf	5.116	1.470	0.918	0.628	0.447	0.361	0.599	0.575	**0.888**					
PWB	4.534	1.595	0.950	0.758	0.614	0.558	0.686	0.736	0.642	**0.908**				
IR	4.986	1.527	0.930	0.768	0.536	0.507	0.672	0.799	0.661	0.757	**0.904**			
SE	3.978	1.882	0.843	0.250	0.197	0.297	0.146	0.156	0.167	0.257	0.209	**0.802**		
CL	5.416	1.525	0.869	0.334	0.213	0.189	0.217	0.294	0.295	0.283	0.359	0.528	**0.830**	
EC	3.631	1.993	0.824	0.187	0.234	0.266	0.103	0.180	0.126	0.204	0.194	0.622	0.374	**0.739**

Notes: The diagonal elements (bold) are the square root of AVE. InterP – Internal PLOC; EP – External PLOC; IntroP – Introjected PLOC; TB – Trust Beliefs; AST – Adoption of ST; Comf – Comfort; PWB – Perceived well-being; IR – Intention to recommend; SE – Social environmentalism; CL – Conservation Lifestyle; EC – Environmental citizenship.

Table 3
Heterotrait-Monotrait ratio (HTMT).

	InterP	EP	IntroP	TB	AST	Comf	PWB	IR	SE	CL	EC
InterP											
EP	0.658										
IntroP	0.626	0.747									
TB	0.746	0.577	0.552								
AST	0.801	0.588	0.479	0.675							
Comf	0.719	0.492	0.412	0.660	0.646						
PWB	0.836	0.663	0.620	0.731	0.795	0.709					
IR	0.869	0.583	0.573	0.733	0.890	0.753	0.831				
SE	0.309	0.254	0.374	0.174	0.188	0.230	0.313	0.269			
CL	0.404	0.244	0.223	0.250	0.348	0.358	0.329	0.432	0.688		
EC	0.215	0.303	0.354	0.164	0.216	0.155	0.243	0.254	0.877	0.454	

Notes: InterP – Internal PLOC; EP – External PLOC; IntroP – Introjected PLOC; TB – Trust Beliefs; AST – Adoption of ST; Comf – Comfort; PWB – Perceived well-being; IR – Intention to recommend; SE – Social environmentalism; CL – Conservation Lifestyle; EC – Environmental citizenship.

Table 4
Mean, standard deviation, weights, loadings and VIF of formative construct.

Items	Mean	STD	Weights	Loadings	VIF
PPR1	3.954	1.478	0.216^{**}	0.078	1.954
PPR2	3.911	1.555	-0.294^{***}	−0.156	2.066
PPR4	4.232	1.517	0.432^{***}	0.823^{***}	2.396
PPR5	4.263	1.526	0.063	0.662^{***}	2.151
PPR6	4.309	1.576	-0.198^{**}	−0.007	1.835
PPR7	4.453	1.646	0.293^{***}	0.115	1.642
PPR8	4.425	1.519	0.576^{***}	0.878^{***}	1.579

Notes: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.10$; PPR – Perceived Privacy risk.

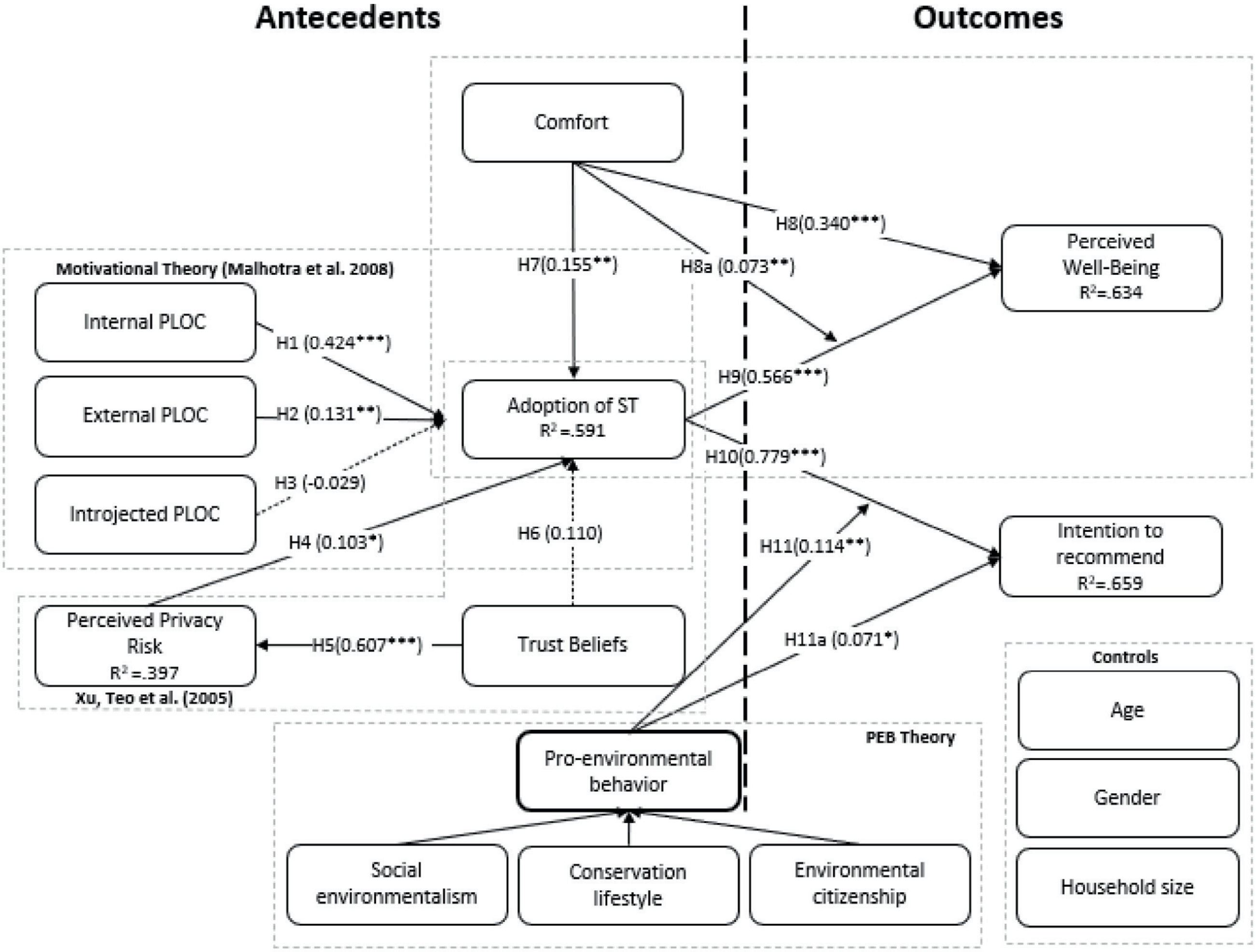
Table 5
Measurement model for second-order formative construct.

		VIF	Weights
PEB	Social environmentalism (SE)	1.956	0.396^{***}
	Conservation lifestyle (CL)	1.393	0.407^{***}
	Environmental citizenship (EC)	1.640	0.417^{***}

Notes: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.10$; PEB – Pro-environmental behavior.

trust beliefs have a significant influence on that. In the case of perceived well-being and intention to recommend, the adoption of smart thermostats has an important influence, where both are moderated by comfort and pro-environmental behaviour, respectively. It was found that comfort moderates the relationship between the adoption of smart thermostats and perceived well-being, and pro-environmental behaviour moderates the relationship between the adoption and intention to recommend. Therefore, our research model extends the existing literature review on households' adoption of sustainable technologies, especially regarding smart thermostats, presenting the antecedents and outcomes that motivate smart thermostat adoption by households and enhancing the importance of understanding the role of the outcomes of this adoption for a continuous consumer engagement in sustainable technologies and environmental behaviours, in order to address energy efficiency. Overall, our model explains 59.1 % of the variation in the adoption of smart thermostats, 39.7 % of the variance in perceived privacy risk, and concerning the adoption outcomes, 63.4 % and 65.9 % on the variance of perceived well-being and intention to recommend, respectively. As mentioned earlier, 10 out of the 13 hypotheses were supported in our research model (Table 6).

The adoption of smart thermostats is positively impacted by internal PLOC, external PLOC, perceived privacy risk and comfort, with internal PLOC being the factor with the strongest impact ($\widehat{\beta} = 0.424$). This means that individuals are mainly driven by internal motivations and their own desires and that they are probably environmentally conscious or have a perception of the benefits they can gain by adopting this technology in their homes and thus have the desire to acquire the devices. All these hypotheses are supported except perceived privacy risks that, although statistically significant at $p < 0.10$, do not negatively influence the adoption of smart thermostats, as we suggested previously in our study ($\widehat{\beta} = 0.103$; $p < 0.10$). Thus our formulated hypothesis that perceived privacy risks negatively influence the adoption of smart thermostats is not supported. Given the positive signal on $\widehat{\beta}$, practically means that perceived privacy risks positively influence the adoption. This may happen since trust beliefs positively influence perceived privacy risks. Trust beliefs have a significant positive influence on perceived privacy risks, meaning that individuals trust the information provided by the companies that sell smart thermostats, trusting in the usage of the product. Then it is expected that concerns with risks are low and the impact of perceived privacy risks on adoption is positive and not negative since technologies that present lower risks of privacy loss will be trusted and thus more likely to be used [73], leading to the adoption of smart thermostats and not the opposite, because there are no significant concerns related to risk since, by an indirect relationship, families trust the device. To evidence this indirect relation, the mediating effect was tested (Table 7), where we can observe that perceived privacy risks mediate trust beliefs and adoption. Finally, the adoption of smart thermostats is not impacted by introject PLOC motivation, having a negative path coefficient and p-value > 0.10 ($\widehat{\beta} = -0.029$; $p > 0.10$), meaning that the resulting confusion between social pressures and households' personal values [36] does not influence the adoption decision of smart thermostats and is also not impacted by trust beliefs. We have already seen that although it does not directly influence adoption, it indirectly affects it since



Notes: * $p<0.10$; ** $p<0.05$; *** $p<0.01$

Fig. 2. Structural model.

Table 6
Hypotheses conclusions.

Hypotheses	Independent V.	Dependent V.	Sign suggested	Findings	Result	Conclusion
H1	Internal PLOC	Adoption of ST	Positive	$(\widehat{\beta} = 0.424;\ p < 0.01)$	Positive and statistical sign.	Supported
H2	External PLOC	Adoption of ST	Positive	$(\widehat{\beta} = 0.131;\ p < 0.05)$	Positive and statistical sign.	Supported
H3	Introjected PLOC	Adoption of ST	Negative	$(\widehat{\beta} = -0.029;\ p > 0.10)$	Non-significant	Not supported
H4	Perceived Privacy Risk	Adoption of ST	Negative	$(\widehat{\beta} = 0.103;\ p < 0.10)$	Positive and statistical sign	Not supported
H5	Trust Beliefs	Perceived Privacy Risk	Positive	$(\widehat{\beta} = 0.607;\ p < 0.01)$	Positive and statistical sign.	Supported
H6	Trust Beliefs	Adoption of ST	Positive	$(\widehat{\beta} = 0.110.;\ p > 0.10)$	Non-significant	Not supported
H7	Comfort	Adoption of ST	Positive	$(\widehat{\beta} = 0.155;\ p < 0.05)$	Positive and statistical sign.	Supported
H8	Comfort	Perceived Well-Being	Positive	$(\widehat{\beta} = 0.340;\ p < 0.01)$	Positive and statistical sign.	Supported
H8a	Comfort	Adoption × Perceived WB	Moderation	$(\widehat{\beta} = 0.073;\ p < 0.05)$	Positive and statistical sign.	Supported
H9	Adoption of ST	Perceived Well-Being	Positive	$(\widehat{\beta} = 0.566;\ p < 0.01)$	Positive and statistical sign.	Supported
H10	Adoption of ST	Intention to recommend	Positive	$(\widehat{\beta} = 0.779;\ p < 0.01)$	Positive and statistical sign.	Supported
H11	PEB	Intention to recommend	Positive	$(\widehat{\beta} = 0.114;\ p < 0.05)$	Positive and statistical sign.	Supported
H11a	PEB	Adoption × Intention to rec.	Moderation	$(\widehat{\beta} = 0.071;\ p < 0.10)$	Positive and statistical sign.	Supported

perceived privacy risks act as an important mediator between trust beliefs and the adoption of smart thermostats.

Concerning perceived well-being, it is positively influenced by comfort and the adoption of smart thermostats. There is also the moderation effect of comfort between adopting smart thermostats and perceived well-being. All the hypotheses are supported. The adoption of smart thermostats has the biggest impact ($\widehat{\beta}$ = 0.566), which is normal since perceived well-being emerges as an outcome of this adoption, implying that individuals adopt the device because they want to benefit from its consequences.

Table 7
Mediating effect.

Effect of	Indirect effect (a*b)	Direct effect (c)	Sign (a*b*c)	Interpretation	Conclusion
TB -> PPR -> AST	0068*	0.106*	+	Complementary mediation	H6a supported

Notes: ***p < 0.01; **p < 0.05; *p < 0.10; TB – Trust Beliefs; PPR – Perceived Privacy risk; AST – Adoption of ST.

These findings also underline that the use of sustainable technologies at home can increase the current comfort levels of individuals [19]. Thus, the higher the levels of thermal comfort the household feels in their environment, the higher their state of satisfaction and, consequently, their perceived well-being [11].

Last but not least, the intention to recommend is positively influenced by the adoption of smart thermostats and pro-environmental behaviour and the moderation effect of pro-environmental behaviour between the adoption of smart thermostats and the intention to recommend, thus supporting our hypothesis. Like perceived well-being, the intention to recommend also appears as a major outcome emerging from the adoption of smart thermostats, where adoption strongly impacts the intention to recommend ($\widehat{\beta}$ = 0.779). These findings make sense since if consumers become adopters of smart thermostat technology and have a good experience, then the possibility of recommending it to others is high [44]. Also, if the individuals have strong environmental concerns and embrace pro-environmental behaviours, it is normal that this will positively impact the intention to recommend the device to others and influence more individuals to also have pro-environmental behaviours. In other words, the higher their engagement in pro-environmental behaviour, the more willing they are to adopt sustainable technologies such as smart thermostats and therefore recommend them to others to influence their peers to use environmentally friendly technologies [42].

Regarding the moderating effects, Fig. 3 shows that the relationship between the adoption of smart thermostats and perceived well-being is stronger in individuals with high comfort levels than those with low comfort levels. Additionally, pro-environmental behaviour not only explains the intention to recommend but also moderates the relationship between the adoption of smart thermostats and the intention to recommend. Fig. 4 shows that the relationship between the adoption of smart thermostats and the intention to recommend is stronger in individuals with high pro-environmental behaviour than individuals with low pro-environmental behaviour.

Our model includes four dependent variables, namely the adoption of smart thermostats, perceived privacy risks, perceived well-being, and intention to recommend, investigating the direct and indirect effects on each variable, as well as two moderator effects and one mediating effect. Also, the last two variables - perceived well-being and the intention to recommend, arise as important outcomes of smart thermostat adoption. They provide more holistic research into the antecedents and outcomes of households' adoption of smart thermostats, compared with other studies that usually only study the adoption of technology individually and the direct relations.

6.2. Practical implications

This paper highlights important findings for more effective formulation of energy policies and marketing campaigns based on the empirical model results. From a policy standpoint, the results suggest that financial incentives, such as support programs or rebates, are an effective way to accelerate the diffusion of smart thermostats since it has been proven that external motivations drive adoption by individuals. These strategies can help achieve energy efficiency, meeting the climate goals set by the EU for reducing energy expenditures from non-renewable energy sources. From a business perspective, our findings suggest that companies should consider comfort-conscious and environmentally concerned consumers to increase the sales of smart thermostats. Additionally, as shown, perceived well-being and the intention to recommend are important outcomes of smart thermostat adoption. Developing device features that can stimulate households' well-being and guarantee positive user feedback are important drivers for consumer engagement and continuous use of smart thermostats. Positive recommendations have been shown to be very persuasive and effective in influencing other customers, thus increasing adoption [42]. At the same time, suppliers should consider marketing strategies that transmit trust to the user, paying particular attention to

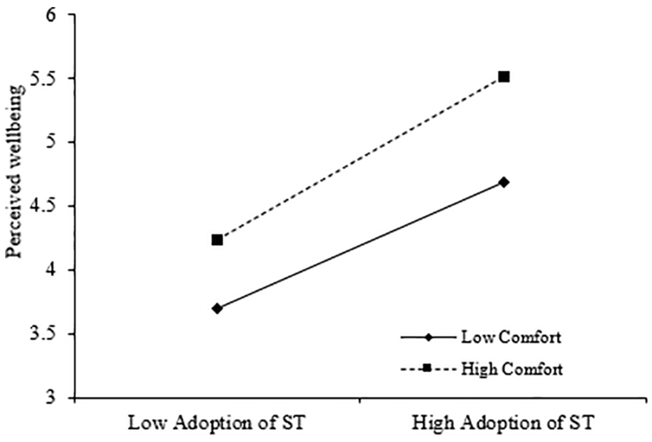


Fig. 3. Moderation effect of comfort on the relationship between adoption of ST and perceived well-being.

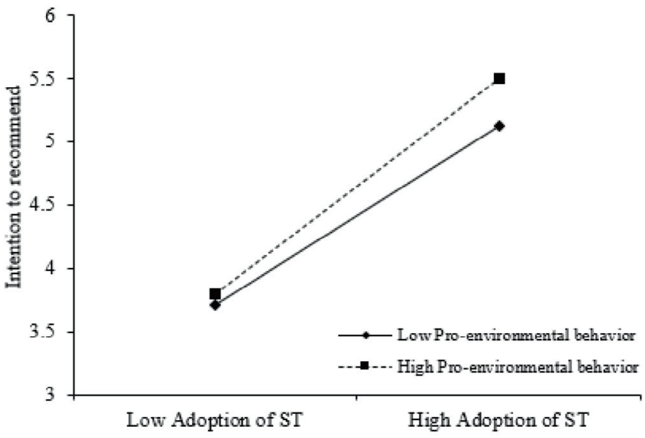


Fig. 4. Moderation effect of pro-environmental behaviour on the relationship between adoption of ST and intention to recommend.

consumer privacy concerns. These may be particularly relevant for emerging technology applications, given the privacy risk concerns that may involve detailed user profiles, temperature preferences, and geolocation, as otherwise, these concerns may compromise users' trust and, therefore, reduce the acceptance of remote functionalities and these types of technologies in the home environment. Overall, the presented results can help energy consultants and organizations, as well as smart thermostat manufacturers and vendors, create effective policies, device improvements and marketing programs that motivate household consumers to adopt smart thermostats, using energy more efficiently in their homes.

6.3. Limitations and recommendations for future research

Despite the relevance of the theoretical and practical contributions, some limitations were identified in the course of this analysis. A limitation is that this research was mainly carried out in Portugal. Since temperature regulating devices are widely used in countries with more extreme temperatures (heating appliances for colder countries and cooling appliances for warmer countries), it would be interesting to expand the geographical horizons by applying this model to data from other countries, essentially where these types of appliances are used more, and even extend the comparison between countries. Furthermore, given the relevance of this topic for the environmental sector and the need for a rapid energy transition, it would be a good contribution if other countries develop a similar analysis. Another limitation is the fact that this work was only conducted for household adoption of smart thermostats. It could be interesting to do the same work but with other types of sustainable technology household appliances or even the adoption of smart thermostats or similar appliances in other buildings, such as companies or shopping centers. Additionally, since this research followed a more motivational and behavioral approach regarding the use of the smart thermostat technology, it could be interesting to follow an approach more focused on the physical and operational aspects of the device, considering, for example, the price perception of energy and sustainable technologies. Equally interesting would be the use of moderators in further research, not only related to environmental concerns and comfort but others, since there are few studies in the literature where moderators are used in the energy efficiency field and sustainable technology adoption context of households.

7. Conclusion

With the prevalent environmental devastation and increasing energy expenditure, and on the other hand, the growth of new technologies, it has become essential to combine these factors in order to reduce environmental problems, with the use of sustainable technologies emerging as a solution. As shown in the literature, the residential sector is the one that comprises the largest energy consumption and that most contributes to the increase of energy expenditures from non-renewable energy sources. Therefore, the adoption of sustainable technologies at home has occupied the interest of investigators more and more. Smart thermostats emerge as a sustainable household technology, consisting of a device that allows families to control the temperature at home (heating/cooling) through IoT devices, as well as control their energy expenditure, being the technology under analysis in this research. To study the adoption of this technology by households, we describe and create a new model where two perspectives were addressed, namely the antecedents and the outcomes of the adoption, representing a novelty in the literature concerning studies on technology adoption by households and smart thermostats. The model was empirically evaluated based on a sample of 327 responses and, overall, of the 13 hypotheses, only three were not confirmed, namely introjected PLOC and trust beliefs having p-values > 0.10, and perceived privacy risk that, although it is statistically significant ($\widehat{\beta}$ = 0.103; $p < 0.10$), has a different influence from what was proposed (not negative). As such, our model explains 59.1 % of the adoption of smart thermostats. Findings of this research concludes the relevance of internal and external motivators, as well as comfort to smart thermostat adoption, trust beliefs to overcome perceived privacy risks, perceived privacy risks as a mediator between trust beliefs and adoption, and especially the extreme importance of smart thermostat adoption to two major outcomes: perceived well-being and the intention to recommend, explained by 63.4 % and 65.9 %, respectively. Two important moderators were also found to be relevant. Comfort highlights the premise that the greater the individual's thermal comfort, the greater the individual's well-being, and if satisfied, the more convinced they will be of the decision to adopt smart thermostats at home, and pro-environmental behaviour the assumption that individuals with greater environmental concerns are more likely to engage in environmental behaviours and therefore, recommend it to others so more people will engage in more environmentally friendly solutions, investing in a more sustainable lifestyle. Overall, our results allow us to understand households' motivation to adopt sustainable technologies, emphasizing their importance in energy efficiency, and support future effective policies and marketing campaigns to develop strong strategies that lead to energy reduction and more sustainable behaviours.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A – Measurement Items.

Construct	Item	Measurement items	Sources
Internal PLOC (InterP)	InterP1	I would use smart thermostats because I want to help protect the environment.	[70]
	InterP2	I would use smart thermostats because I personally like using this type of technology.	
	InterP3	I would use smart thermostats because I think they are personally important to me.	
	InterP4	I would use smart thermostats because I want to learn how to use them.	
	InterP5	I would use smart thermostats because I enjoy using this type of technology.	
External PLOC (EP)	EP1	I would use smart thermostats because they are recommended by my energy supplier.	[70]
	EP2	I would use smart thermostats because they are recommended by governmental institutions.	
	EP3	I would use smart thermostats because using them offers me financial incentives.	
	EP4	I would use smart thermostats because the European Union recommends using them.	
	EP5	I would use smart thermostats because I can avoid price peaks in peak load times.	
Introjected PLOC (IntroP)	IntroP1	I would use smart thermostats because I would feel bad if I did not.	[70]
	IntroP2	I would use smart thermostats because people who are important to me think that I should use them.	
	IntroP3	I would use smart thermostats because it is trendy to be green.	
	IntroP4	I would use smart thermostats because people who influence my behaviour think that I should use them.	
	IntroP5	I would use smart thermostats because people whose opinions I value prefer that I use them.	
Perceived Privacy Risk (PPR)	PPR1	Giving my personal information to smart thermostats would have too much uncertainty associated.	[70]
	PPR2	It would be risky to disclose my personal information to smart thermostats.	
	PPR3	Using smart thermostats could lead to a loss of my privacy because my energy consumption data could be used without my knowledge.	
	PPR4	My personal data won't be used for any purposes not related to smart thermostats.	
	PPR5	My personal data that is gathered due to the usage of smart thermostats would not be sold to third-party providers.	
	PPR6	I am concerned about the data security of smart thermostats.	
	PPR7	Internet hackers might take control of my payment and consumption data if I used smart thermostats.	
	PPR8	The databases that are used to save my consumption data are protected against unauthorized access.	
Trust Beliefs (TB)	TB1	Smart thermostats seem competent and effective in handling my personal information that I would provide.	[71]
	TB2	Smart thermostats would keep my best interests when dealing with my personal information.	
	TB3	Smart thermostats would fulfil their promises related to customers' personal information.	
	TB4	Smart thermostats are, in general, trustworthy regarding the usage of my personal information.	
Adoption of Smart Thermostat (AST)	AST1	I assume that it is a good idea to use smart thermostats.	[70]
	AST2	I think that it is reasonable to use smart thermostats.	
	AST3	All in all, I think it is a bad idea to use smart thermostats.	
	AST4	I like the idea of using smart thermostats.	
Comfort (Comf)	Comf1	Thermal comfort in warmer seasons (air velocity, humidity, and temperature).	[11]
	Comf2	Thermal comfort in cooler seasons (air velocity, humidity, and temperature).	
	Comf3	Air quality (smells, irritants, outdoor air, and ventilation).	

Appendix A – Measurement Items. (*continued*)

Construct		Item	Measurement items	Sources
Perceived well-being (PWB)		PWB1	Smart thermostats would satisfy my overall household needs.	[16]
		PWB2	Smart thermostats would play a very important role in my social well-being.	
		PWB3	Smart thermostats would play a very important role in my leisure well-being.	
		PWB4	Smart thermostats would play an important role in enhancing the quality of life in my household.	
Intention to recommend (IR)		IR1	I will recommend to my friends to adopt smart thermostats.	[42]
		IR2	If I have a good experience with smart thermostats I will recommend friends to adopt one.	
		IR3	I would recommend smart thermostats to someone who seeks my advice.	
Pro-environmental behavior (PEB)	Social environmentalism (SE)	SE1	Talked to others in my community about environmental issues.	[34]
		SE2	Worked with others to address an environmental problem or issue.	
		SE3	Participated as an active member of a local environmental group.	
	Conservation lifestyle (CL)	CL1	Recycled paper, plastic and metal.	
		CL2	Conserved water or energy in my home.	
		CL3	Bought environmentally friendly and/or energy-efficient products.	
	Environmental citizenship (EC)	EC1	Voted to support a policy/regulation that affects the local environment.	
		EC2	Signed a petition about an environmental issue.	
		EC3	Donated money to support local environmental protection.	
		EC4	Wrote a letter in response to an environmental issue.	

Appendix B – Loadings and cross-loadings.

	InterP	EP	IntroP	TB	AST	Comf	PWB	IR	SE	CL	EC
InterP1	**0.726**	0.375	0.304	0.456	0.525	0.536	0.500	0.587	0.189	0.386	0.168
InterP2	**0.869**	0.473	0.382	0.600	0.667	0.494	0.614	0.636	0.218	0.263	0.164
InterP3	**0.843**	0.547	0.568	0.597	0.582	0.528	0.716	0.659	0.228	0.264	0.197
InterP4	**0.880**	0.523	0.488	0.596	0.642	0.600	0.688	0.715	0.183	0.294	0.127
InterP5	**0.794**	0.547	0.534	0.554	0.528	0.428	0.600	0.560	0.215	0.174	0.115
EP1	0.433	**0.804**	0.626	0.405	0.390	0.325	0.496	0.414	0.215	0.141	0.230
EP2	0.419	**0.842**	0.612	0.348	0.348	0.279	0.440	0.328	0.211	0.145	0.236
EP3	0.490	**0.864**	0.517	0.482	0.453	0.378	0.515	0.419	0.094	0.151	0.172
EP4	0.536	**0.899**	0.632	0.497	0.481	0.386	0.545	0.473	0.217	0.210	0.243
EP5	0.584	**0.799**	0.438	0.516	0.563	0.463	0.554	0.559	0.118	0.222	0.132
IntroP1	0.478	0.587	**0.807**	0.447	0.348	0.271	0.485	0.422	0.242	0.137	0.231
IntroP2	0.461	0.626	**0.904**	0.439	0.372	0.305	0.506	0.422	0.275	0.150	0.236
IntroP3	0.411	0.381	**0.645**	0.386	0.334	0.279	0.339	0.407	0.162	0.177	0.194
IntroP4	0.468	0.554	**0.915**	0.408	0.360	0.330	0.480	0.425	0.286	0.181	0.226
IntroP5	0.489	0.610	**0.908**	0.439	0.385	0.327	0.522	0.452	0.274	0.149	0.226
TB1	0.620	0.495	0.419	**0.907**	0.617	0.597	0.620	0.617	0.134	0.235	0.075
TB2	0.637	0.506	0.478	**0.945**	0.578	0.564	0.642	0.608	0.131	0.192	0.086
TB3	0.663	0.507	0.461	**0.943**	0.597	0.562	0.651	0.655	0.130	0.195	0.098
TB4	0.619	0.524	0.524	**0.926**	0.538	0.505	0.639	0.620	0.149	0.186	0.124
AST1	0.691	0.525	0.395	0.578	**0.942**	0.550	0.713	0.740	0.117	0.269	0.140
AST2	0.615	0.536	0.405	0.547	**0.910**	0.490	0.655	0.672	0.175	0.261	0.219
AST4	0.668	0.444	0.383	0.597	**0.899**	0.539	0.654	0.783	0.140	0.279	0.141
Comf1	0.568	0.426	0.319	0.559	0.529	**0.917**	0.592	0.606	0.159	0.266	0.100
Comf2	0.531	0.400	0.325	0.508	0.463	**0.888**	0.540	0.568	0.157	0.282	0.142
Comf3	0.571	0.365	0.319	0.526	0.534	**0.858**	0.575	0.584	0.131	0.239	0.096
PWB1	0.713	0.571	0.484	0.637	0.709	0.603	**0.917**	0.720	0.221	0.294	0.199

(*continued on next page*)

Appendix B – Loadings and cross-loadings. (*continued*)

	InterP	EP	IntroP	TB	AST	Comf	PWB	IR	SE	CL	EC
PWB2	0.649	0.557	0.601	0.618	0.565	0.508	**0.875**	0.613	0.296	0.248	0.210
PWB3	0.694	0.561	0.529	0.608	0.656	0.553	**0.924**	0.689	0.227	0.229	0.182
PWB4	0.696	0.544	0.439	0.630	0.724	0.651	**0.917**	0.719	0.202	0.255	0.157
IR1	0.724	0.571	0.578	0.621	0.699	0.550	0.737	**0.890**	0.234	0.313	0.188
IR2	0.643	0.382	0.299	0.568	0.726	0.639	0.631	**0.878**	0.124	0.306	0.134
IR3	0.716	0.501	0.500	0.632	0.742	0.602	0.687	**0.942**	0.209	0.353	0.203
SE1	0.248	0.107	0.146	0.156	0.202	0.256	0.224	0.272	**0.787**	0.554	0.435
SE2	0.234	0.206	0.304	0.146	0.123	0.144	0.259	0.184	**0.900**	0.459	0.520
SE3	0.104	0.161	0.270	0.035	0.037	−0.022	0.120	0.024	**0.708**	0.228	0.558
CL1	0.218	0.080	0.077	0.107	0.194	0.205	0.164	0.269	0.380	**0.839**	0.243
CL2	0.301	0.230	0.146	0.219	0.250	0.226	0.258	0.318	0.420	**0.790**	0.333
CL3	0.306	0.211	0.235	0.209	0.282	0.297	0.276	0.305	0.505	**0.861**	0.349
EC1	0.225	0.192	0.177	0.173	0.248	0.164	0.180	0.223	0.518	0.410	**0.825**
EC2	0.174	0.172	0.153	0.085	0.177	0.152	0.192	0.229	0.500	0.365	**0.856**
EC3	0.063	0.202	0.263	0.069	0.031	0.002	0.141	0.048	0.400	0.155	**0.586**
EC4	0.036	0.134	0.245	−0.074	0.003	−0.008	0.068	−0.002	0.414	0.081	**0.652**

Notes: InterP – Internal PLOC; EP – External PLOC; IntroP – Introjected PLOC; TB – Trust Beliefs; AST – Adoption of ST; Comf – Comfort; PWB – Perceived well-being; IR – Intention to recommend; SE – Social environmentalism; CL – Conservation Lifestyle; EC – Environmental citizenship.

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