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Tailored gamification and serious game framework based on fuzzy logic for saving energy in connected thermostats

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A B S T R A C T

Connected thermostats (CTs) often save less energy than predicted because consumers may not know how to use them and may not be engaged in saving energy. Additionally, several models perform contrary to consumers' expectations and are thus not used the way they are intended to. As a result, CTs save less energy and are underused in households. This paper reviews aspects of gamification and serious games focused on engaging consumers. A gamification and serious games framework is proposed for saving energy that is tailored by a fuzzy logic system to motivate connected thermostat consumers. This intelligent gamification framework can be used to customize the gamification and serious game strategy to each consumer so that fuzzy logic systems can be adapted according to the requirements of each consumer. The framework is designed to teach, engage, and motivate consumers while helping them save electrical energy when using their thermostats. It is described the proposed framework as well as a mockup that can be run on a cellphone. Although this framework is designed to be implemented in CTs, it can be translated to their energy devices in smart homes.

1. Introduction

In 2018, as part of its revised Energy Performance of Buildings Directive, The European Commission introduced a "smart readiness indicator" as a means to make building energy smartness more understandable and useful for building users, owners, and tenants. This indicator functions by raising awareness of the benefits of smart technologies and information and communication technologies (ICT) in buildings (IEA, 2018). Technological innovation serves to create new opportunities for progress inefficiency, such as the deployment of connected devices. By the end of 2016, four thoushand million connected devices were in use by households worldwide. Five hunded million smart meters were contracted to be installed, as they can complement connected devices, allowing consumers to adjust energy use in response to changes in energy prices (IEA, 2017). In addition to smart meters and energy devices that have emerged on the market for saving energy in households and buildings, connected thermostats (CTs) have a significant impact on saving energy in HVAC systems. The fundamental goal of an HVAC control system is to keep temperature and air quality within a comfortable range while minimizing energy usage (Soltanaghaei and Whitehouse, 2018). In (Ponce et al., 2018a), a connected thermostat (CT) is defined as an electrical device that links smart homes with smart grids. CTs are thus designed to automatically learn occupants' schedules and turn heating and cooling on or off on the users' behalf (Soltanaghaei and Whitehouse, 2018). The CTs' design makes it possible to consume low energy, increase consumer comfort, and inform users about the energy conditions of the thermostats through mobile device interfaces. Besides, CTs can improve energy efficiency without affecting consumer satisfaction by making automated decisions regarding temperature conditions once they learn consumer's behavior patterns. The interface of the CTs can assist end-users when dealing with complex tasks. However, CTs have not been entirely accepted because their interfaces do not match consumers' expectations (Ponce et al., 2017). The failed expectations on the part of the users are due to several factors: (1) CTs are usually sold as energy-saving devices that control heating and cooling systems.

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However, because end-users operate them differently than intended by the manufacturers and designers, they produce major energy waste (Pritoni et al., 2015); (2) Although CTs can automatically adjust the patterns of electrical consumption to save energy, end users do not use these functions. As a result, the users expect features that decrease the complexity of operating the product and do not feel confident in using the functions; (3) End users are unable to accurately understand the features and advantages of the CTs because they do not know what to expect of these devices; (4) Customers should receive accurate and complete information regarding the relationship between kWh and CO_2 so that they can understand the environmental impact of incorrect operation of a CT (Ponce et al., 2018a); (5) The device is designed only for meeting certain types of expectations, it means that those devices are generally designed for the typical user rather than non-typical user; thus it cannot be entirely or quickly adopted because some end users do not consider saving energy to be their main expectation. Their primary expectation is what they look for when buying an air conditioning system: cost, energy efficiency, performance, durability, reliability, brand, greenness, and aesthetics; (6) If customers do not use an HVAC correctly, then the human-machine interface (HMI) will be unable to support the CT in improving the customers' understanding of energy efficiency (Ponce et al., 2018b, 2017). Table 1 describes the main problems when CTs are deployed and their relationship between the behavior and usability problems. These problems are divided according to a consumer's point of view (problems with consumer behavior or problems in the thermostat). For example, the problem of programming and CT can be considered a usability problem that can be solved by improving the thermostat's design. However, this can also be considered a problem that arises because consumers do not read the thermostat manual. In contrast, saving energy can be classified as a behavior problem; this requires changes in the consumers' habits and thus cannot be solved directly by changing the thermostat's interface.

However, according to (Kashani and Ozturk, 2017), 2/3 of typical home energy usage is based on human habits; thus, efforts to target behavior changes have led to an emerging area of interest called gamification and serious games (SGs), which is a way to engage and educate individuals and support environmental awareness through the use of game design elements (AlSkaif et al., 2018; Johnson et al., 2017). SGs and gamification share a common goal: to shape human actions to improve the user experience, offer motivation, and encourage behavior changes (Beck et al., 2019). To this end, the CT designer must implement changes to motivate customers to use the product and change consumer habits. The use of sensing, smart, and sustainable products (S^3 products) has also been proposed for the design process or for developing social products in smart homes (Méndez et al., 2020b). There are two classes of communication between products and processes. There are two classes of communication between products and consumers: (1) natural society behavior, in which consumer data is obtained from the installed product when it is in operation; and (2) non-natural

Table 1
Primary problems with deployed CTs according to a consumer's point of view.

	Behavior problems (Ponce et al., 2018b, 2017)					
	Users operate the CT different than how the design engineers intended.	Users do not understand the functions. They feel using the CT is complicated.	Users do not know and/or care about the advantages of the CT.	Users are not aware of the environmental impacts.	User is not primarily focused on energy saving.	Users do not know how to use the HVAC system.
Usability problems (Ponce et al., 2018b)						
1. Visibility of the status: The interface neither informs the status nor gives appropriate feedback.	x	x	x	x	x	x
2. Match between system and the real world: It uses system-oriented terms rather than following real-world convention language.	x	x				
3. User control and freedom: User feels controlled by the interface and without freedom.	x	x				
4. Consistency and standards: It does not follow platform conventions.	x	x				
5. Recognize, diagnose, and recover from errors: Messages are displayed in code; users cannot recognize, diagnose, and recover from them.	x	x				
6. Error prevention: it is not carefully designed and develop error problems.	x	x				
7. Recognition rather than recall: the objects, actions, and options are not visible.	x	x				
8. Flexibility and minimalism design: Lack of custom actions. Access and operation are limited to average users.	x	x	x	x	x	x
9. Aesthetics: Dialogues contain irrelevant information.	x	x	x	x	x	x
10. Help and documentation: information is complicated to search and is not focused on the user's task and is extensive.	x	x		x	x	
11. Skills: The interface tries to replace the user's capabilities, background, knowledge, and expertise.	x	x				
12. Pleasurable and respectful interaction with the user: The design is unpleasing and nonfunctional.	x	x				
13. Privacy: The system does not protect personal or private information.	x	x				

behavior, in which, depending on the positive or negative performance of the product, the communication reinforces consumer attitude or considers a habit change. Therefore, by taking advantage of the consumer data on natural society behavior and by using gamification and SG strategies to send stimuli for changing consumer attitude in non-natural behavior communication. In addition (Méndez et al., 2019a; Ponce et al., 2019) propose the use of gamification to save energy by improving user habits for better performance of the CT, whereas SGs make it possible to shape user habits through an educational platform (Coursera, 2017; Giessen, 2015; Moloney et al., 2017).

It is therefore necessary to understand how the user behaves or thinks to propose tailored products for those non-typical users that are not considered when the products are designed and deployed. In this regard, fuzzy logic has been used to model human reasoning through a set of If-Then rules to provide a better user experience (Mata et al., 2019). classified five types of energy end-users based on their personality traits using fuzzy logic (Albadán et al., 2018). implemented a fuzzy logic model with gamification elements in a platform to profile five types of aspirants for personnel selection (Méndez et al., 2020a, 2019b). proposed to use tailored gamified HMI to promote physical activity and social interaction in elderly people by classifying them with personality traits or by tracking their mood via voice and image detection (Méndez et al., 2020a, 2019b).

However, the (Mata et al., 2019; Méndez et al., 2020a, 2020b, 2019a, 2019b) proposals have been developed based on this paper premise, propose a tailored gamified HMI based on fuzzy logic system decision for non-typical and typical user to save energy by shaping user behavior. Before the authors' proposal of using fuzzy logic system decision to display gamification elements in HMI to personalize devices based on each user's characteristics and profile, to the best of the authors' knowledge, it has never been proposed.

Therefore, the relevance of this work is the novel proposal of developing personalized interfaces using gamification elements in a fuzzy logic system decision to promote energy-saving habits in all types of users (typical and non-typical users) considering the personality traits of the user, the kind of role player in gamification and SGs contexts, and the relation with the energy end-user segment and target group. Besides, the framework is designed to detect if the user is getting bored to change the gamification strategy and display other gamification elements.

The remainder of this paper is structured as follows. Section 2 describes the personality and type of energy end-users, as well as ecological behavior models, regarding personality traits with pro-environmental behavior based on the energy end-user segment to find users' engagement in ecological behavior. Section 3 describes gamification and SGs in energy-saving and review state of the art in gamification, SGs, and CTs. The proposed methodology is described in Section 4. As a result of the analysis in Sections 1 to 4, Section 5 proposes a framework to fill the gap between consumer expectations and energy consumption to make the CT a suitable S^3 product. Section 6 presents a mockup of the framework that can be used on a mobile phone. In Section 7, it is described the scope of the framework, its advantages and disadvantages, and the benefits for the user and thermostat designer regarding energy terms. Conclusions and future work are presented in Section 8.

2. Type of users

For the proposed strategy, five types of users are described: (1) personality traits that cannot be changed but help understand users' behavior; (2) energy end-users divided into five customer segments; (3) energy target groups divided into three groups; (4) four types of player in SG; (5) six types of gamification players and their associated personality traits.

2.1. Personality traits

Table 2 depicts a descriptive theory in the field of psychology of five broad and replicable personality traits (McCrae and Costa, 1997) that have been vastly supported and are often referred to as the "Big Five" (Oliver and Srivastava, 1999). These personality traits have demonstrated a close relationship between the personalities of individuals and their behavior in different domains (Paunonen, 2003). Research linking personality and environmental behaviors have produced somewhat mixed results; however, the ability to predict environmental concerns through personality traits appears feasible.

Recent studies have explored different methodologies to predict or link engagement in pro-environmental behavior with the Big Five traits. The results are consistent, demonstrating that with higher levels of agreeableness and openness, there is greater environmental engagement. In contrast, conscientiousness displays little positive influence on environmental engagement; however, it is more likely to be related to environmental concern. Extraversion does not appear to have a significant impact on conduct, while neuroticism shows an unexpected finding. Because individuals with high neuroticism levels tend to be more worried about adverse outcomes, they experience more significant environmental concerns (Brick and Lewis, 2016; Hirsh, 2010; Milfont and Sibley, 2012).

2.2. Energy end-users

Table 3 presents the five customer segments proposed in (Ponce et al., 2017) that are related to energy use based on traditional sector divisions, the economic activity of the customer, and the qualitative evaluation of energy end-users: (1) green advocate energy savers, (2) traditionalist cost-focused energy savers, (3) home-focused selective energy savers, (4) non-green selective energy savers, and (5) disengaged energy wasters.

2.3. Energy target groups

Table 4 illustrates the three groups proposed in (Peham et al., 2014) according to their characteristics, household appliances, user availability, and energy awareness as the main aspects to focus on an energy application.

2.4. Four types of role players in SG environment

(Bartle, 1996) profiled four types of role players in a game that works for the SG environment. Table 5 shows these players and their characteristics.

2.5. Six types of users and their relationship with the Big Five personalities

Table 6 presents the (Marczewski, 2015) Hexad framework based on the (Bartle, 1996) role player. Based on (Bartle, 1996) role player, he proposed six types of player need in a gamification system. Then (Tondello et al., 2016), associated those players with the five personality traits.

2.6. Ecological behavior

To tailor a CT requires knowledge of the type of personality, end-user, market segments, and how they are structured in the energy sector. To design a gamified CT is important to define the most

Table 2
Personality traits and characteristics (Oliver and Srivastava, 1999).

Personality trait	Characteristics	Attitude
Openness (Rothmann and Coetzer, 2003)	appreciation of divergent thinking; new social, ethical, and political ideas, behaviors, and values	curious, imaginative and unconventional
Conscientiousness (Barrick and Mount, 1991)	self-discipline, competence, dutifulness, and responsibility	rational, purposeful, strong-willed, like to follow the rules and have a clear objective
Extraversion (Barrick and Mount, 1991)	energized by social interactions, excitement, and diverse activities	talkative, assertive and optimistic
Agreeableness (Judge et al., 1999)	altruism, modesty, straightforwardness and a cooperative nature	sympathetic to others and tolerant
Neuroticism (Judge et al., 1999)	the tendency to experience negative emotions such as fear and sadness	impulsive, stressful and bad-tempered

Table 3
Energy end-user segments and characteristics (Ponce et al., 2017).

Energy end-users			
End-user segment	Characteristics	Technology	Energy awareness
Green advocate	Most positive	Interested in new technologies	Most positive
Traditionalist cost-focused	Motivated by cost savings	Limited interest	Extensive overall energy-saving behavior
Home focused	Interested in home improvement efforts	Interested in new technologies	Concerned about saving energy
Non-green selective	Selective energy saving	Focus on set-and-forget inventions	Not concerned
Disengaged	Less motivated by cost savings	Not interested	Not concerned

Table 4
Energy target groups and characteristics (Peham et al., 2014).

Energy target groups				
Group	Characteristics	Household appliances	User availability	Energy awareness
Early adopter	New technology buffs who buy all the latest gadgets	They prefer to buy them on the cutting edge of technology	Anywhere and anytime via smartphone, they use social media communities	They do not care
Cost-oriented individual	Take care of the household and focus on a cost-oriented way of life	Limited interest	They are mostly connected through their smartphone and are social media users	Energy saving is essential, and they try to be sustainable within their abilities
Energy-conscious individual	They try to lead a sustainable way of life	They buy them with a long lifetime and low energy consumption	They use smartphones and are not necessarily active in social media	They care very much

Table 5
Four types of player (Bartle, 1996).

Role player	Characteristics
Achiever	their main goal is to earn points and levels
Explorer	their main objective is to find out as much information as they can gather for the game and the players
Socializer	they love to interact with other players.
Killer	their main target is to impose themselves on others; therefore, to have control over others.

Table 6
Six types of gamification players and their associated personality traits (Marczewski, 2015; Tondello et al., 2016).

User type	Characteristics	Associated personality traits
Philanthropist	They are motivated by a sense of purpose; the associated design elements are collection, trading, gifting, knowledge sharing, and administrative roles.	Extraversion (E), Agreeableness (A), Conscientiousness (C), and Openness (O).
Socializers	Their motivation is the interaction with others to create social connections, similar to (Bartle, 1996) player type. They prefer game elements that include teams, social networks, social comparison, social competition, and social discovery.	Extraversion (E) and Agreeableness (A).
Free spirits	They prefer autonomy as a manner to express liberty and act without external control, similar to the explorer player type (Bartle, 1996). The design elements include exploratory tasks, nonlinear gameplay, easter eggs, unlockable content, creativity tools, and customization	Extraversion (E), Agreeableness (A), and Openness (O).
Achievers	Competence is their primary motivation (Bartle, 1996). They prefer the challenges, certificates, learning new skills, quests, levels or progression, and epic challenges design elements.	Conscientiousness (C)
Players	Competence is their primary motivation (Bartle, 1996). They prefer the challenges, certificates, learning new skills, quests, levels or progression, and epic challenges design elements.	Conscientiousness (C)
Disrupters	They are motivated by forcing positive or negative changes in the system, and it may also be known as the killer player (Bartle, 1996). Thus, the suggested design elements are innovation platforms, voting mechanisms, development tools, anonymity, and anarchic gameplay.	Neuroticism (N)

significant characteristics. For this reason, it is necessary to engage residential customers by leading them to take an active role in energy applications, which can give them the willingness to control their energy behavior and make decisions that can lead to energy savings (Ponce et al., 2019). claim that social factors are fundamental elements that lead to changes in customer habits. In this sense, a smart system manages the HMI adaptation, such as gamification in the interface, to change practices.

(Mata et al., 2019) classified and assigned a level of Ecological Behavior (EB) through an Artificial Neural Network model using fuzzy logic. This model categorizes the personality traits with pro-environmental behavior based on the energy end-user segment (Ponce et al., 2017) to find users' engagement in ecological behavior. The data used to train the system came from 19719 answered surveys of the Big Five Personality Test from the International Personality Item Pool of a public database available in (Psychometrics Project, 2019). The backpropagation algorithm uses Bayesian regularization with an adaptive weight minimization as the top condition. Then, based on the energy end-user segment (Table 3), a radar map is generated regarding the correlation of personality traits to create the rules for the fuzzy system. Fig. 1 shows a radar map of personality correlation with the type of user.

The theory of planned behavior (TPB) is frequently applied to understand energy-related behavior, pro-environmental behavior, and sustainable choices. This model identifies there antecedents of intentions to perform a behavior: (a) attitudes toward the behavior formed form behavioral beliefs, those beliefs outcomes of behavior and the evaluations of those outcomes: (2) subjective norms formed from the normative expectations of others and motivation to comply with such expectation; and (3) perceived behavior control based on beliefs regarding factors that may enable or hinder the behavior (Rai and Beck, 2017). Therefore, Table 7 presents the

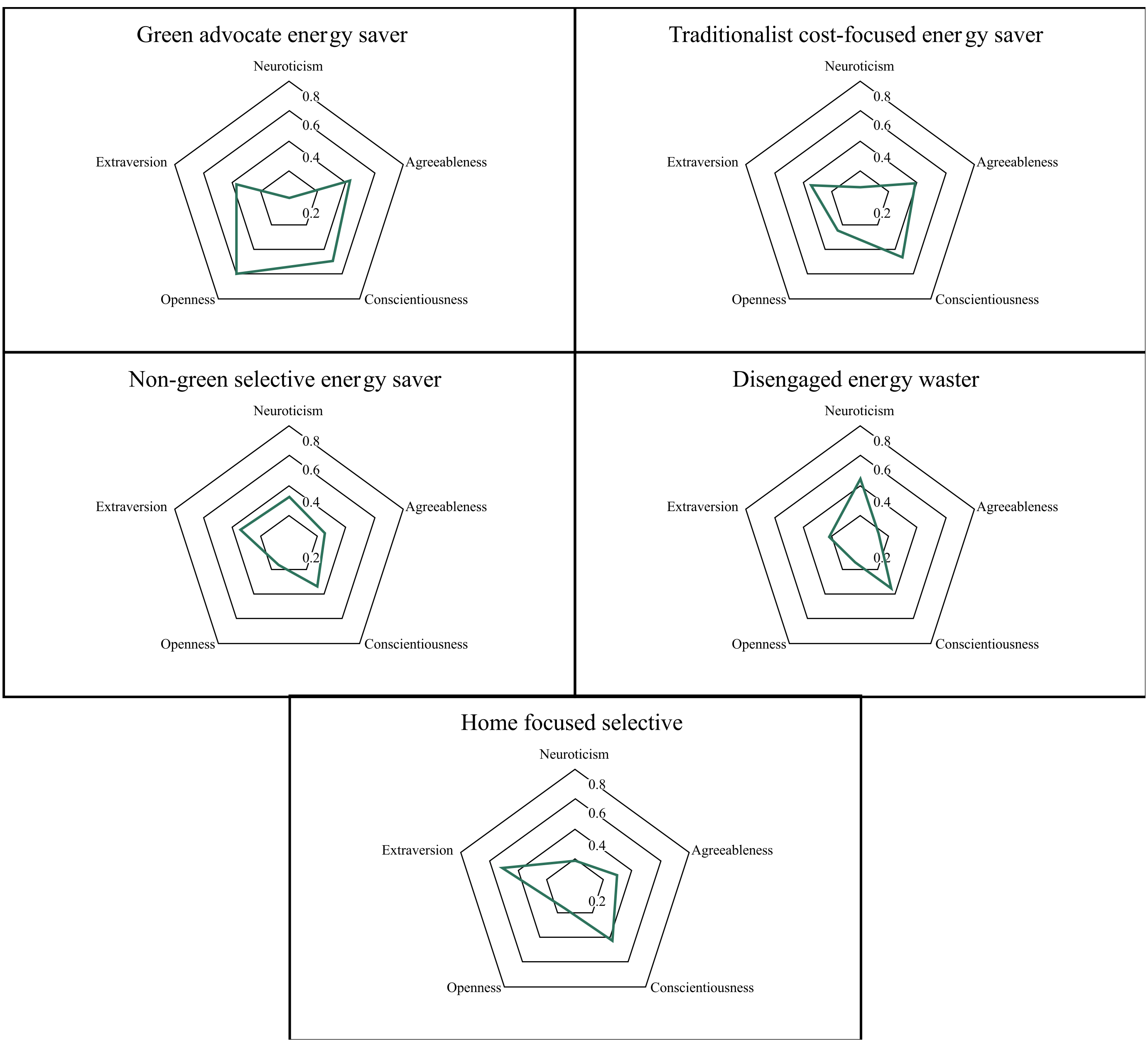


Fig. 1. Radar map of personality correlation with the type of energy end-user segment.

Table 7
Relationship between ecological behavior and the energy target groups.

Ecological behavior relationship (Fig. 1)		Energy end-user segments				
		Green advocate	Traditionalist cost-focused	Home focused	Non-green selective	Disengaged
		Personality traits correlation with the type of energy end-user segment				
Personality trait	**Openness**	0.6	0.25	0.14	0.14	0.1
	Conscientiousness	0.5	0.45	0.41	0.33	0.35
	Extraversion	0.36	0.34	0.5	0.35	0.22
	Agreeableness	0.43	0.38	0.3	0.26	0.15
	Neuroticism	0.03	0.1	0.2	0.33	0.45
		Energy target group and energy user segments relationship				
Energy target groups	**Early adopter**				x	x
	Cost-oriented		x	x		
	Energy-conscious	x				

Table 8
State of the art in gamification and serious games.

Year	Reference	Energy application	Gamification	Serious games
2007	PowerTap (2007)	Power Agent		x
2009	Gustafsson et al. (2009)	Power Explorer		x
2010	(AlSkaif et al., 2018; MIRABEL, 2010)	MIRABEL Project	x	
2012	Geelen et al. (2012)	Energy Battle		x
2013	Peham et al. (2014)	ecoGator	x	
2014	Dorji et al. (2015)	Residence Energy Saving Battle		x
2014	Orland et al. (2014)	Energy Chickens		x
2016	Fijnheer and Van Oostendorp (2016)	PowerSaver Game	x	x
2017	(Barbosa et al., 2017; Casals et al., 2017)	EnergyCat		x
2018	(Game | 2020 Energy, 2018; Ouariachi et al., 2019)	Energy2020		x

Table 9
State of the art in thermostats.

Year	Reference	Home Energy Management	Thermostat	Smart devices
2007	Williams and Matthews (2007)	x	x	x
2009	Vojdani (2008)	x	x	x
2010	Qela and Mouftah (2010)		x	
2015	Pritoni et al. (2015)		x	
2016	Korkas et al. (2016)	x	x	x
2017	Ponce et al. (2017)	x	x	
2018	Baldi et al. (2018)	x	x	x
2018	Soltanaghaei and Whitehouse (2018)		x	x
2018	Ponce et al. (2018a)		x	
2018	Ponce et al. (2018b)	x	x	
2019	Ponce et al. (2019)	x	x	x
2019	Jung and Jazizadeh (2019)	x	x	x

relationships between personality traits, energy end-user segments, and energy target groups with ecological behavior.

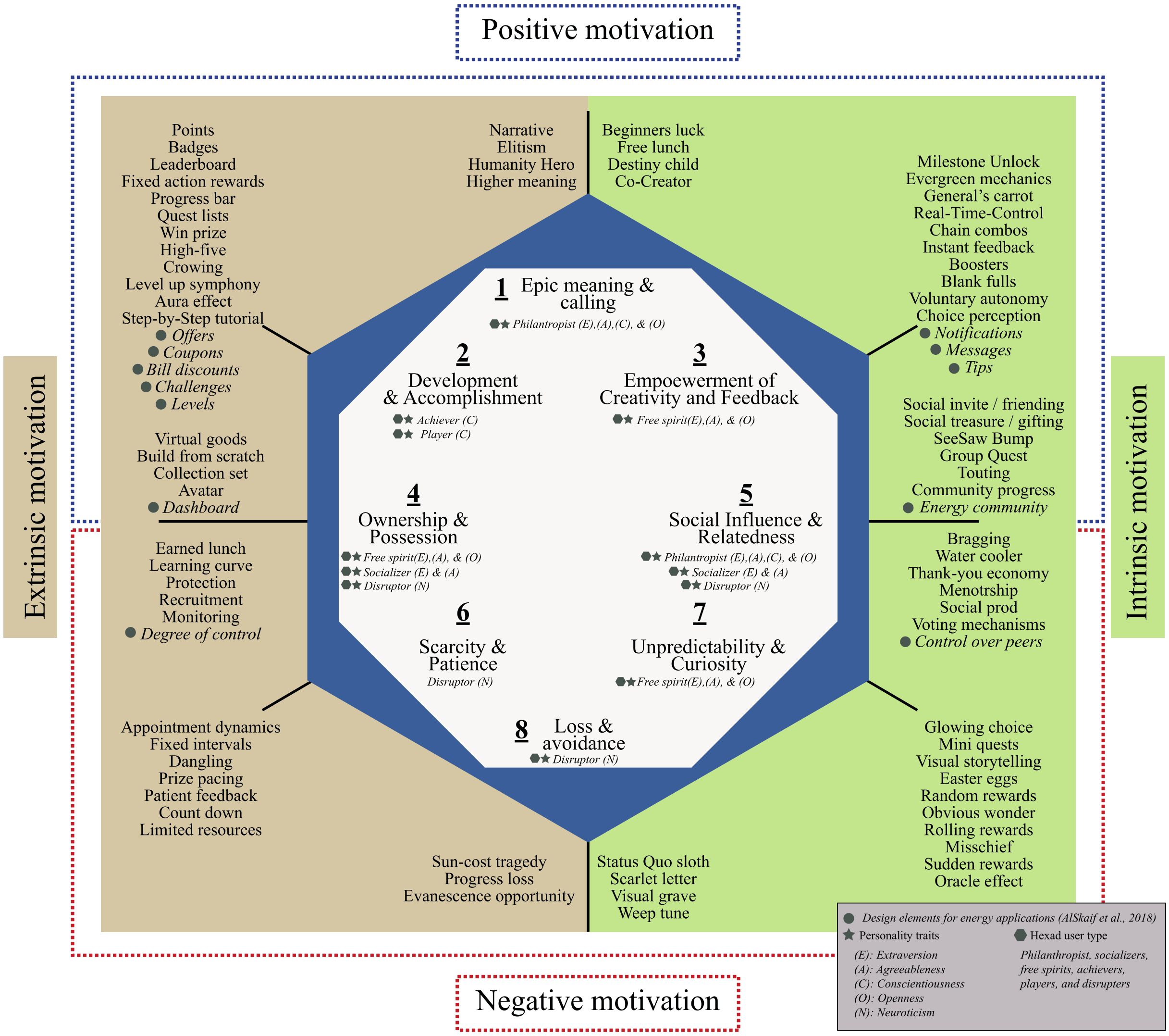
3. Gamification and serious games for energy saving

This section reviews the use of gamification and SGs in the energy field, their main characteristics, and their relationship with the types of users described in the previous section.

3.1. Gamification and energy saving

Gamification is the use of game elements in non-game contexts to improve the user experience and user engagement (Johnson et al., 2017; Lucassen and Jansen, 2014; Peham et al., 2014). In addition, it is "a process of enhancing a service with affordances for gameful experiences in order to support a user's overall value creation" (Huotari and Hamari, 2012) "based on the current consensus game design elements" (Matallaoui et al., 2015). Furthermore, it is the human-focused design process of using game-thinking and game mechanics to engage users and solve problems so that they can be applied to real-world or productive activities. Human-focused design is the process in which instead of optimizing function efficiency within the system, human motivation is optimized (Chou, 2015; Zichermann and Cunningham, 2011). Thus, gamification in energy systems has emerged as a tool for enhancing energy applications by driving customer engagement and energy-related behavior change through targeting a wide set of motives that a customer may have, including economic, environmental, and social incentives (AlSkaif et al., 2018). In (Ponce et al., 2019), the authors propose rewards for consumers by sending stimuli to change consumer behavior.

To design a gamified strategy is essential to understand the components and game elements involved in the development of any application. Several studies have suggested mechanisms for a gamification system (Lucassen and Jansen, 2014). propose five mechanisms (1) progress mechanisms such as popularity/status, competition, scores, badges, leaderboards, achievements, and levels; (2) rewards such as prizes, effort rewards, fixed rewards,



Octalysis core drive (Chou, 2015)	Motivation (Chou, 2015)	Hexad user type (Marczewski, 2015; Tondello et al., 2016)	Role player (Bartle, 1996)	Energy end user segment & target group (Ponce et al., 2017; Peham et al., 2014)
1. Epic meaning and calling	Extrinsic, intrinsic, positive	Philanthropist (E, A, C, & O)*	Socializer	Green advocate & energy-conscious Traditionalist cost-focused & cost-oriented Home focused & cost-oriented Non-green selective & early adopter Disengaged energy waster & early adopter
★ 2. Development and accomplishment	Extrinsic, positive	Achiever & Player (C)*	Achiever	
⬢ 3. Empowerment of creativity and feedback	Intrinsic, positive	Free spirit (E, A, & O)*	Explorer	
▲ 4. Ownership and possession	Extrinsic, positive, negative	Socializer (E & A)* Free spirit (E, A, & O)*	Socializer & Explorer	
● 5. Social influence and relatedness	Intrinsic, positive, negative	Socializer (E & A)* Philanthropist (E, A, C, & O)*	Socializer	
■ 7. Unpredictability and curiosity	Intrinsic, negative	Free spirit (E, A, & O)*	Explorer	
6. Scarcity and impatience	Extrinsic, positive	Disruptor (N)*	Killer	Traditionalist cost-focused & cost-oriented Home focused & cost-oriented Non-green selective & early adopter Disengaged energy waster & early adopter
8. Loss and avoidance	Extrinsic, intrinsic, negative			

*Personality traits: (E): Extraversion; (A): Agreeableness; (C): Conscientiousness; (O): Openness; (N): Neuroticism

Fig. 2. Octalysis framework and its relation with the Hexad framework, role player, and energy end-user segment and target group (Bartle, 1996; Chou, 2015; Marczewski, 2015; Peham et al., 2014; Ponce et al., 2017; Tondello et al., 2016).

monetary rewards, non-monetary rewards, variable rewards, free goods, and virtual rewards; (3) social mechanisms of gifts, altruism, cooperation with friends, rating community submissions, helping a friend, feeling part of a group, differentiation, and controlling over peers due to the increase in users' engagement status; (4) restriction techniques such as punishment for not participating, expiration, scarcity, time constraints, limited resources, and access restrictions; and (5) challenges, collections, promotions, and goals, which can increase brand awareness.

In addition (Chou, 2015; Gonczarowski and Tondello, 2017; Tondello et al., 2016) created a complete framework that analyzed and built strategies around various systems that made games

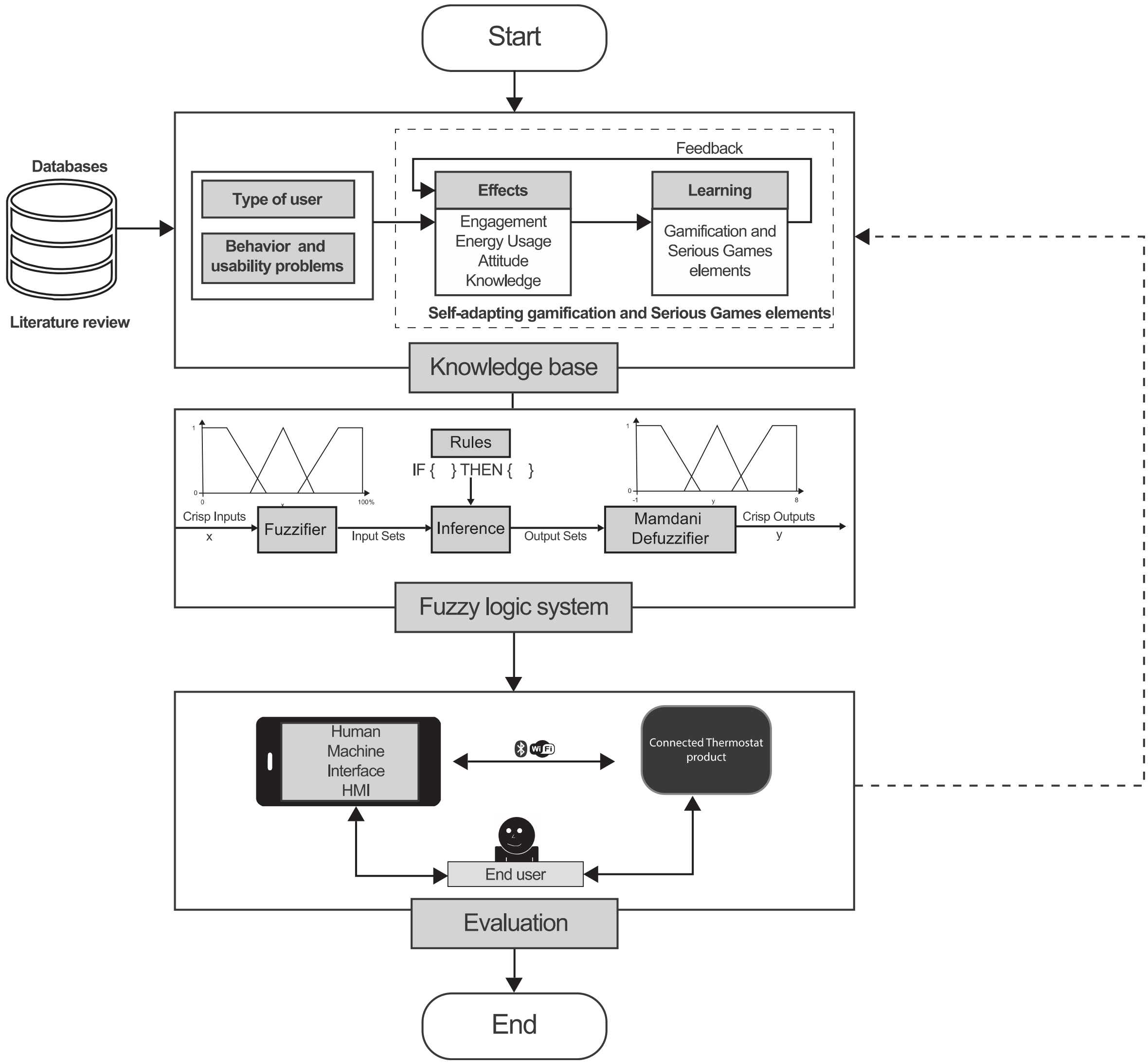


Fig. 3. Diagram of the proposed framework.

engaging. Therefore, this study focuses on the Octalysis (Chou, 2015) and Hexad frameworks (Marczewski, 2015; Tondello et al., 2016).

The Octalysis framework has eight core drives and extrinsic, intrinsic, positive, and negative motivation, which motivate and engage users to continue using a game. Each core has the following significance:

- Core 1. Epic meaning and calling: Users believe that they are doing something greater than themselves and are chosen to take action.
- Core 2. Development and accomplishment: Intern drive for succeeding progressing, developing skills, achieving mastery, and so on.
- Core 3. Empowerment of creativity and feedback: Users become engaged in a creative process when they try different combinations to achieve goals. They also need to see the results of their creativity, receive feedback, and adjust their creativity.
- Core 4. Ownership and possession: the desired core, in which users are motivated because they believe and feel that they own or are in control of something.
- Core 5. Social influence and relatedness: This core has social elements that motivate people, including mentorship, social acceptance, social feedback, companionship, competition, and even envy.
- Core 6. Scarcity and impatience: Users want something just because it is extremely rare, exclusive, or immediately unattainable.
- Core 7. Unpredictability and curiosity: People constantly become engaged because they do not know what is going to happen later; this is the core behind gambling addictions.
- Core 8. Loss and avoidance: Users try to prevent something negative from happening. They feel the urgency to act immediately; otherwise, they may lose the chance to act.

In contrast, the four types of motivations are as follows:

- Extrinsic motivation: People are motivated because they want something they cannot obtain, and obtaining it implies external recognition or even economic rewards.
- Intrinsic motivation: The activity is rewarding on its own without a specific target to achieve.

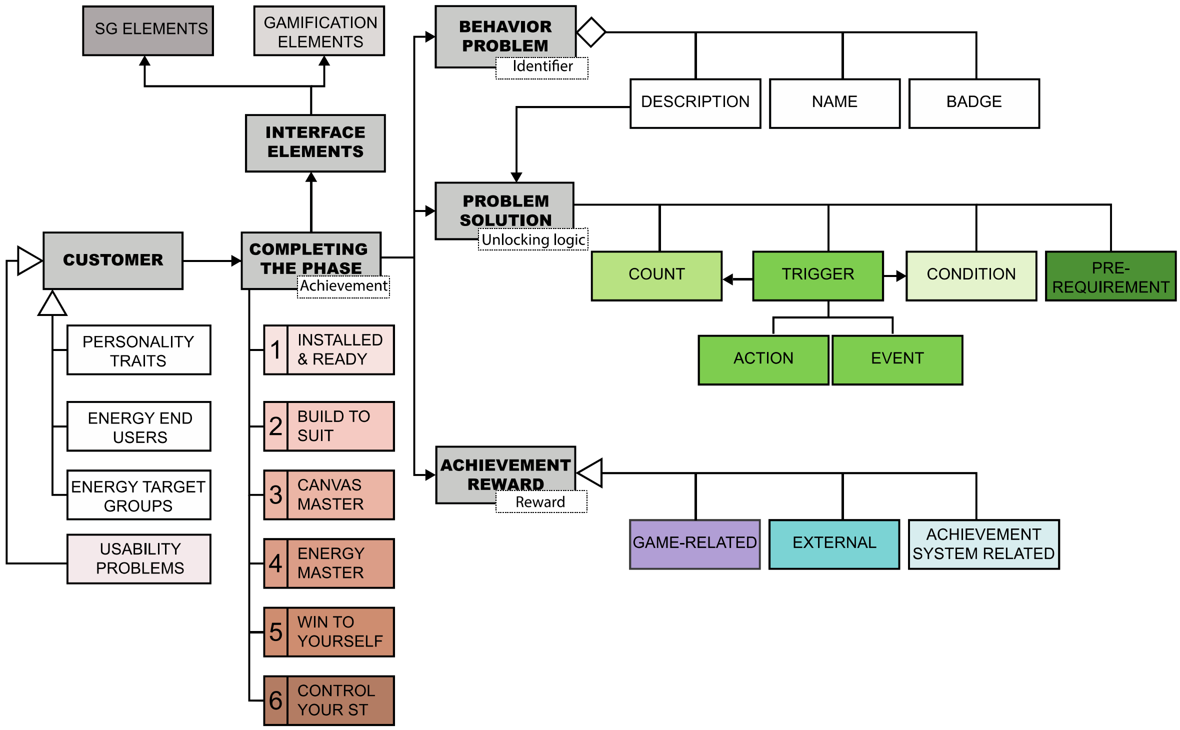


Fig. 4. Gamification and serious game achievement diagram.

- Positive motivation: The activity is engaging because it lets the user feel successful, happy, and powerful.
- Negative motivation: The activity is engaging because the user is constantly in fear of losing something.

Moreover, researchers of energy applications researchers suggest that a gamified application should consider the following: (1) information provision, such as statistics, data-driven messages, and tips, which can give residential customers a clear view of their energy-related behavior and allow them to understand how their actions impact the amount of electricity they use; (2) a reward system based on the customers' energy consumption comportment, effort, and impact, which can incentivize users to take specific actions and increase satisfaction; (3) social connections that can make energy applications more fun and appealing to residential customers, for example, in the form of social competition, collaboration, or energy community, (4) an interactive interface that users can perceive as useful, easy to use, enjoyable, and exciting; (5) a performance status that makes it possible to follow the progress of customers through points, badges, and levels to change the way in which they behave and interact with a specific application; and (6) feedback according to the users' psychological and behavioral outcomes (AlSkaif et al., 2018; Beck et al., 2019).

The (Fijnheer and Van Oostendorp, 2016) steps were proposed for the PowerSaver energy game, and it works as a guideline for designing a household energy game by measuring the practical effects (knowledge, attitude, energy usage, and engagement) to develop a game and dashboard prototype. However, these steps can be improved with a methodology that considers its implementation in physical products, for instance, by saving energy through smart devices and continuously measuring a user's activity. In addition, instead of only using fictional scenarios to test user improvement, the improvements can be examined with real situations, such as comparing users' performance by displaying their amount of energy and money saved in real-time.

3.2. Serious games and energy saving

SGs refer to games designed for primarily non-entertainment purposes with an explicit and carefully thought-out educational purpose. A correct balance between entertainment and education to allow games not to be intrusive or cease being intrinsically motivating is required. Therefore, regardless of whether SGs are analog or digital, they exhibit characteristics such as a goal-oriented nature with specific rules or a feedback system, competitive comparative elements, and element challenging activities, choices, and fantasy elements. They have been found to be effective for the following reasons: (1) the player is immersed in the gaming experience and receives feedback from the other participants; (2) the games provide information in a ludic way so that the players feel active; (3) on a large scale, they permit further investigation into the intervention's effectiveness strategy in influencing behavior (Coursera, 2017; Giessen, 2015; Moloney et al., 2017).

According to (Madani et al., 2017), energy SGs have the following characteristics:

- Theme: The main focus of the game, which is an energy game theme.
- Player's role: The identity of the character that a player assumes in the game (Achiever, explorer, socializer, and/or killer (Bartle, 1996)).
- Game objective: The specific result that a player must achieve to complete the game.
- Number of players: The number of players that can join the game.
- Participants: The group of players, such as students, professionals, and stakeholders.
- Type of game: The classification of each game (board game, card game, digital game, online game, hybrid simulation including the previous types).
- Graphics: 2D or 3D game.

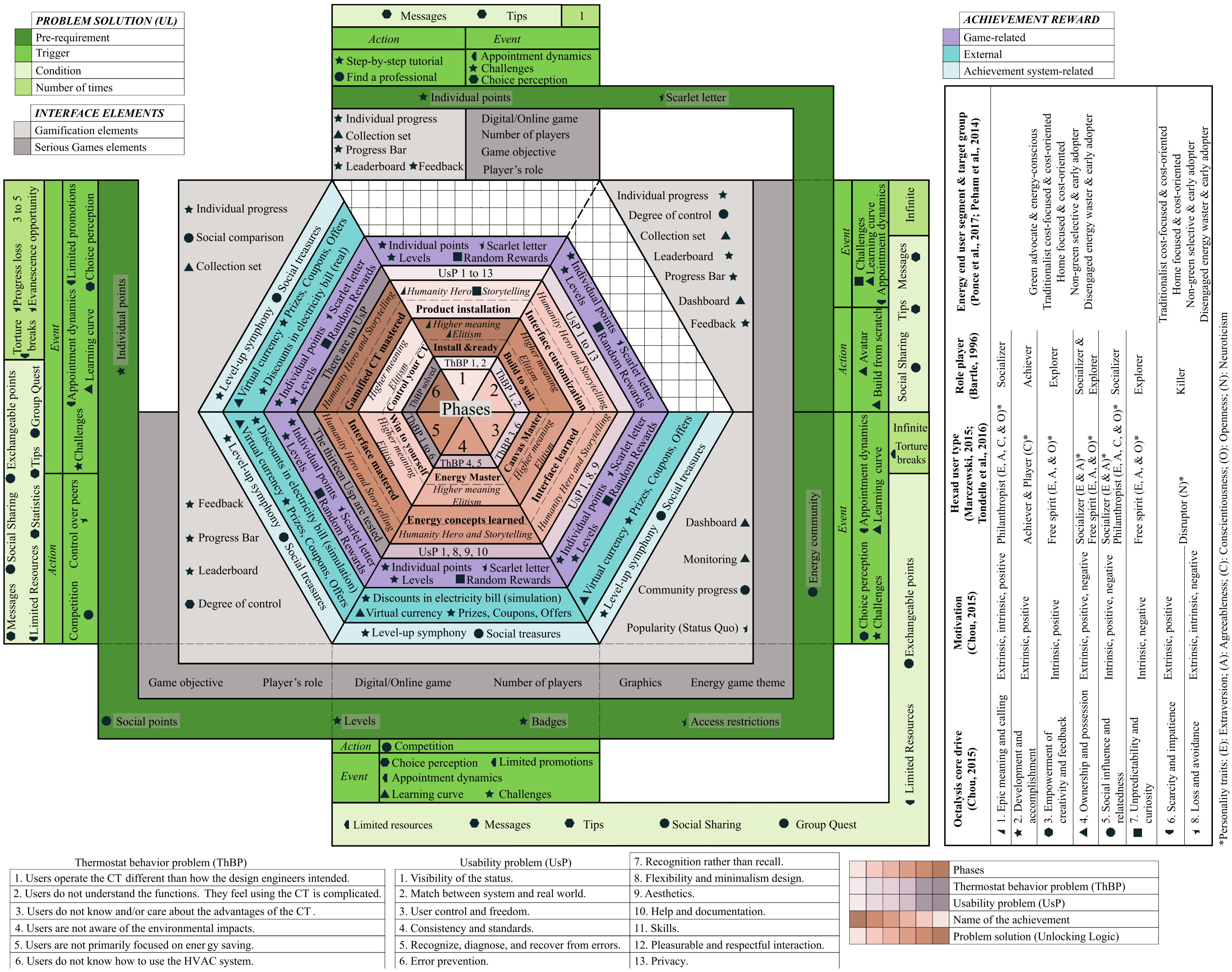


Fig. 5. Elements involved in the smart thermostat interface.

- Availability: How the game is obtained or purchased.

3.3. *State of the art in gamification, serious games, and connected thermostats*

Table 8 presents state of the art in gamification and SGs related to energy, in particular, efficiency, consumption, and sustainability. In addition, Table 9 shows state of the art in CTs since 2007 when CTs were proposed as a controllable vent for zone heating/cooling. As the literature review demonstrates and to the best of the authors' knowledge, there is no evidence of an application that fits with gamification and SG concepts for the behavior and usability problems observed in CTs, besides for the one proposed by the authors in (Méndez et al., 2019a), in which suggestions were based on using gamification elements excluding the SG elements. The proposal was made based on this work. Many energy applications involving SGs teach users how to be aware of energy consumption. The closest gamification game that pertains to energy awareness in households is ecoGator. However, this application only helps users achieve energy efficiency, not control, or become immersed in the functions of a smart device.

Subsections 3.1. and 3.2. show gamification and SG categories from the literature. As this paper is not focused on developing a new gamification framework, Fig. 2 shows the collected information from Section 2 and Subsections 3.1 and 3.2. This figure, due to its completeness, takes a basis for the Octalysis framework (Chou, 2015). The eight-core drives, the game mechanics, and their motivations are related with the six gamified users types and their personality traits (Bartle, 1996), the four SG role players (Bartle, 1996), and the most common gamification elements in energy applications (AlSkaif et al., 2018) to propose any gamified application.

4. Methodology

Step 1: Knowledge base phase: this step collects information provided by questionnaires, longitudinal, or transversal studies obtained from literature review and databases. This information is related to the energy end-users, their behavior, and usability problems, as well as the associated effects with the most common gamification and serious game elements in energy applications. Therefore, for this work, it is considered the type of user described in Section 2, in addition to the behavior and usability

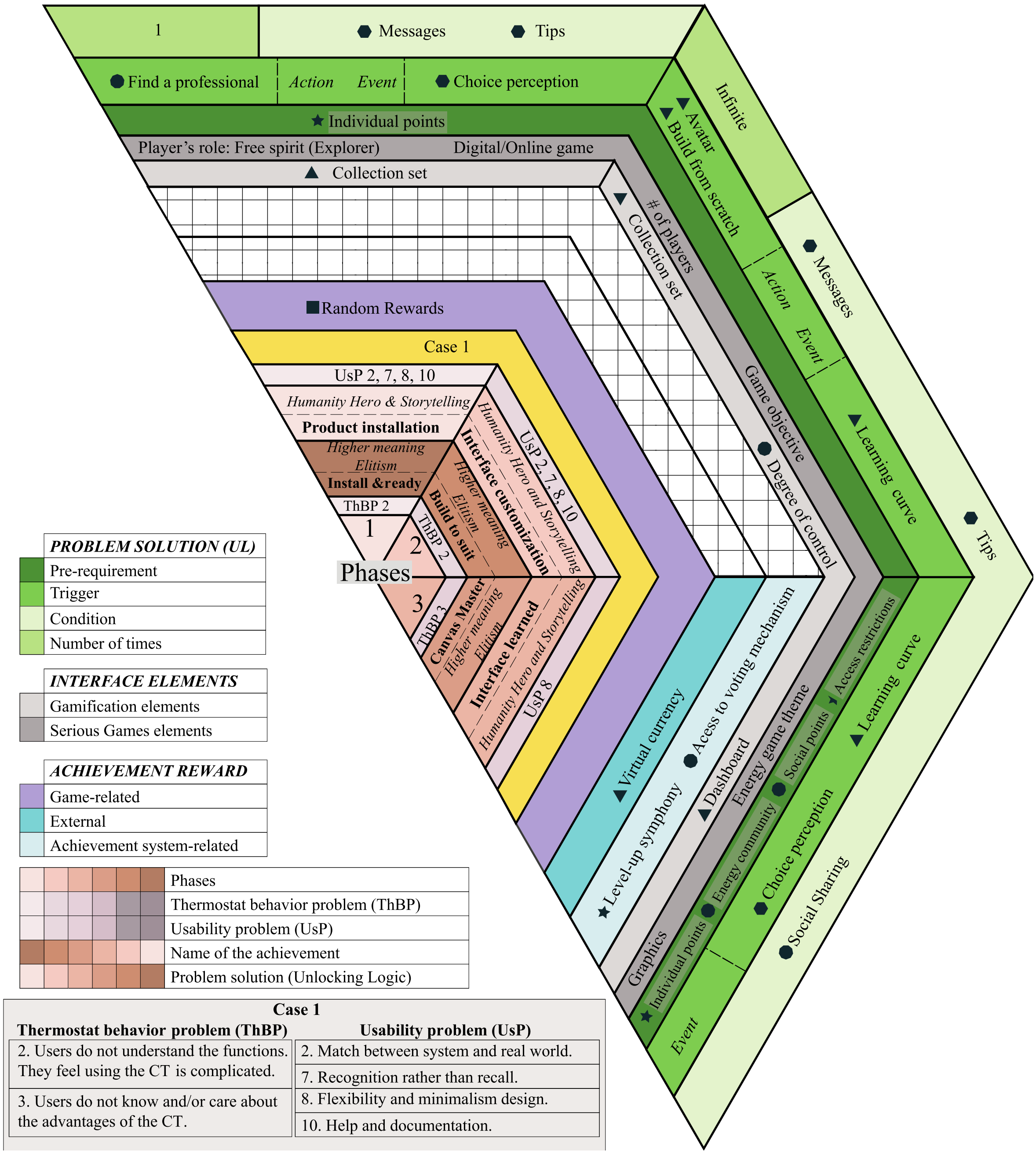


Fig. 6. Case 1 diagram.

problems explained in Table 1, the gamification elements in Fig. 2, and the four effects attributed to a successful energy game (knowledge, attitude, energy usage, and engagement (Fijnheer and Van Oostendorp, 2016)). As a result, these elements can self-adapt to keep the user continuously learning, engaged, and motivated while saving electrical energy when using the CTs.

In this phase, the Octalysis and Hexad frameworks (described in Fig. 2) plays the leading role because of the game mechanics considered in every core drive associated with the type of gamification user help to test the elements that keep the user interested (Chou, 2015; Tondello et al., 2016). Thus, it is proposed to use the extrinsic factors that are suggested in energy applications as they are tangible and measurable, and they seek to achieve external recognition and economic rewards as well as positive motivation to make users feel successful, happy, and powerful (AlSkaif et al., 2018; Beck et al., 2019).

Step 2: Fuzzy logic phase: In this phase, the fuzzy logic type 1 system decision is used to determine which gamification and SG elements must be displayed in the HMI that best fit each type of consumer. This step proposes the tailored interface for the typical and non-typical user.

Step 3: Evaluation phase: The natural society behavior and non-natural behavior in (Ponce et al., 2019) evaluate the interactions between the consumer data that stem from CT and

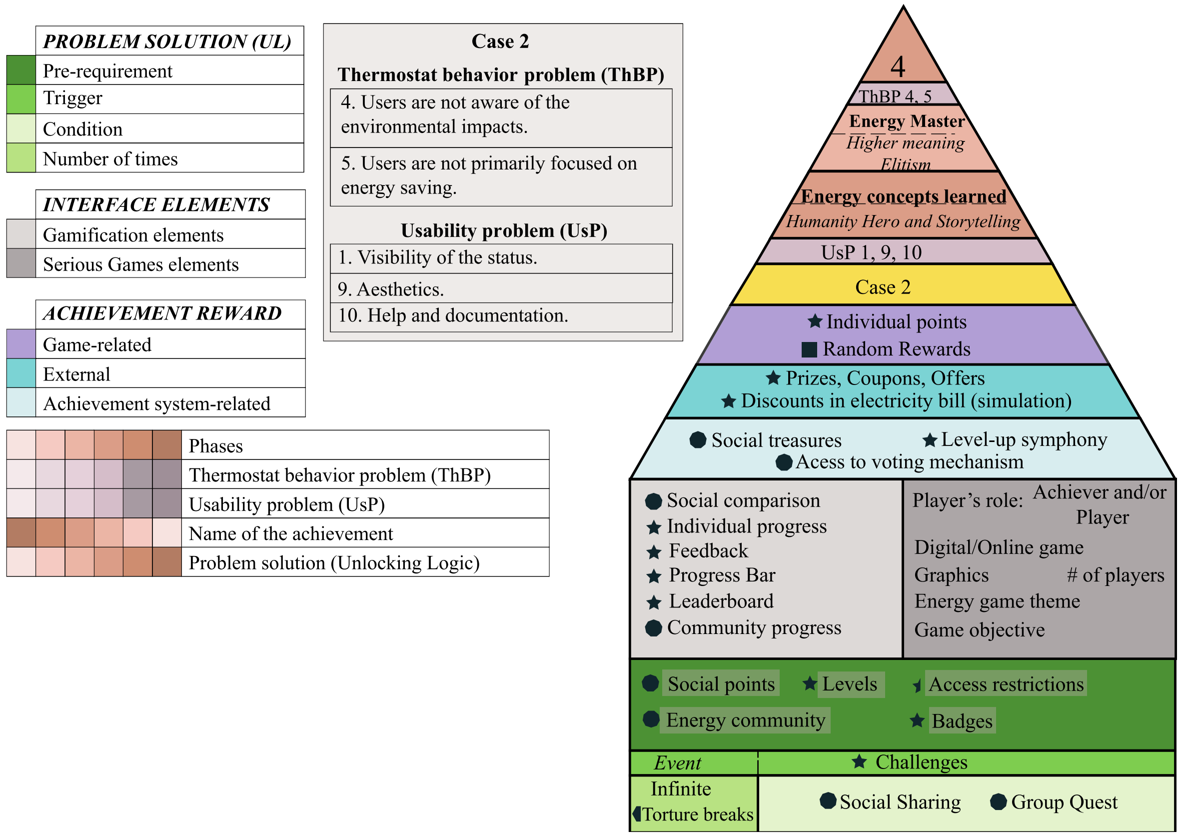


Fig. 7. Case 2 diagram.

the users' conducts changes. If the users continue to behave with no changes, then it is necessary to change the output values of the fuzzy logic; thus, the application provides feedback to the knowledge base to rerun the process.

5. Proposed framework

Fig. 3 illustrates the three-step framework proposed for the development of an S^3 product that aims to bridge the gap between the information provided by the CT, the user's expectations, and the environmental impact through an HMI.

5.1. Knowledge base phase

To become engaged in the energy application, the consumers (users) must complete several stages. This leads them to increase their energy awareness and knowledge (AlSkaif et al., 2018) by mastering the application through gamification and SG elements and produces a solution to the behavior and usability problems.

Fig. 4 presents a diagram derived from the achievement structure (Hamari and Eranti, n.d.; Matallaoui et al., 2015; Stieglitz et al., 2016), which, in addition to the identifier, unlocking-logic, and reward components, has an interface elements component and a customer component. The customer component pertains to the different types of users according to their personality traits, energy end-users, and energy target groups. Each achievement phase is proposed to solve the usability problems detected in the use of CTs. The interface of an interactive system influences the users' decisions, expectations, and motivations; thus, the interface should be useful, easy to use, and designed to be enjoyable and exciting (AlSkaif et al., 2018). The problem solution unlocking logic (UL) aims to solve the behavior problems displayed in Table 1 and, depending on the phase, immerse the users in real and fictional scenarios so that they can understand energy concepts and how the CT operates. The users can interact with elements that commonly appear in a CT interface, such as the system mode, humidity, indoor temperature, weather, quick changes, voice control, manual temperature adjustment, and menu options (ecobee, 2016).

Fig. 5 demonstrates that every element presented in the achievement diagram is followed by gamification and/or SG elements that provide the user with game-like techniques to allow them to feel real ownership and purpose when they become engaged with tasks (Peham et al., 2014). The Customer element contains three large groups categorized according to personality, energy end-users, and energy target; however, this group is not static and can self-adapt. Thereafter, to perform each Completing the Phase achievement, the user must solve the Thermostat Behavior Problem Identifier by completing the problem solution UL to finally be awarded with an Achievement Reward. The application thus requires Interface Elements that have a positive effect on and increase customer engagement (AlSkaif et al., 2018; Peham et al., 2014).

a) Thermostat behavior problem identifier: This is the visible part that transmits the information presented to the player about the achievement that makes the identifier unique, playing an essential role in creating the experience of an achievement meta-game (Hamari and Eranti, n.d.; Matallaoui et al., 2015; Stieglitz et al., 2016). For example, the

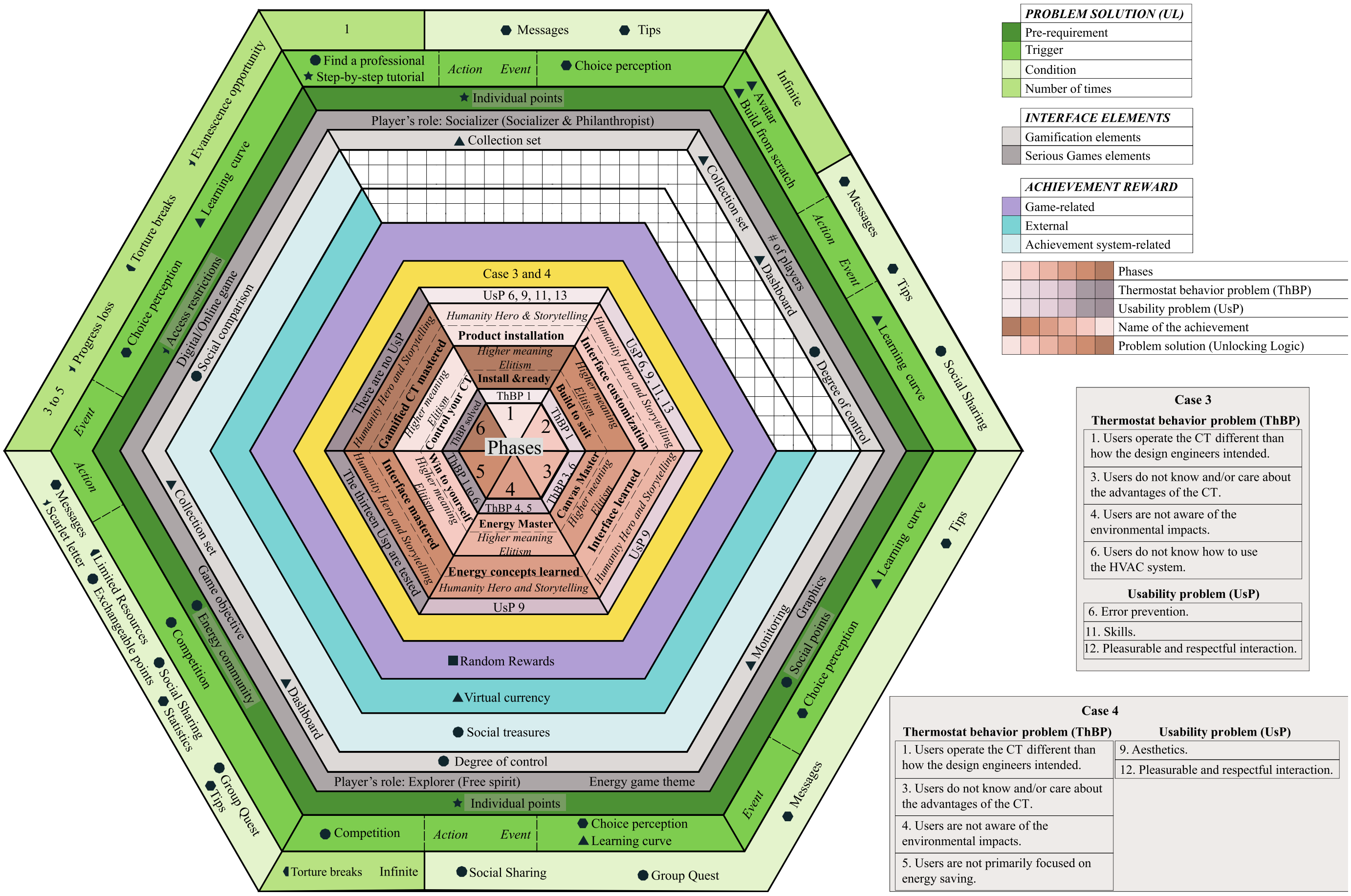


Fig. 8. Case 3 and 4 diagrams.

2020 Energy game has three identifier scenarios: energy saving, energy efficiency, and renewable energy. Every situation has several tasks to complete; thus, the user must play all scenarios to win (Game | 2020 Energy, 2018).

- **Description of the game objective:** this has operational rules that describe what the player must do. According to (Chou, 2015), including gamification elements such as Humanity, Hero, or Storytelling makes users feel that they are part of a community in which their skills are helpful for achieving tasks.
- **Name of the achievement:** This sets a theme for Completing Phase achievement. A narrative element inside the achievements name is useful for engaging users so that they can understand why their help is essential for the success of the task. In addition, the elitism element encourages users to feel that being part of the game is something that makes them unique and that only a few individuals have access to the game (Chou, 2015).
- **Badge:** This usually has two forms: unlocked or locked achievement (Hamari and Eranti, n.d.).

b) Problem solution UL: This defines what is required from the user and from the game state for the achievement to be completed (Hamari and Eranti, n.d.; Stieglitz et al., 2016).

- **Trigger:** This element defines an action done by a user or an event.
  - o **Action:** This is what the user must do. The players explore the game to ensure that the conditions match and then trigger the action themselves (Bartle, 1996).
- **Event:** A system-invoked event takes place by playing in a way in which the conditions match the conditions described in the Completing the Phase achievement task (Hamari and Eranti, n.d.; Matallaoui et al., 2015; Stieglitz et al., 2016).
  - o **Condition:** This includes the requirements for the prevailing game state of existing, as well as the historical events within the game session that must occur before the trigger takes place. Questions are answered, including when, where, in what time frame, and with whom the trigger should take place; that is, what the trigger is based on.
  - o **Pre-requirement:** Global requirements for the game setting that do not affect the game session. These can be the selection of the game mode, difficulty, character class, or playing during a determined season.

c) Achievement reward: Users are rewarded with a cue for unlocking the achievement. Usually, these achievements are visible to players (AlSkaif et al., 2018; Barbosa et al., 2017; Bartle, 1996; Casals et al., 2017; Chou, 2015; Dorji et al., 2015; ecoGator, 2016; Fijnheer and Van Oostendorp, 2016; Game | 2020 Energy, 2018; Geelen et al., 2012; Hamari and Eranti, n.d.; Matallaoui et al., 2015; Ouariachi et al., 2019; Stieglitz et al., 2016).

- **Game-related:** Players earn points toward the maximum achievement points possible as a manner to dispose and accumulate high-value rewards (Bartle, 1996).

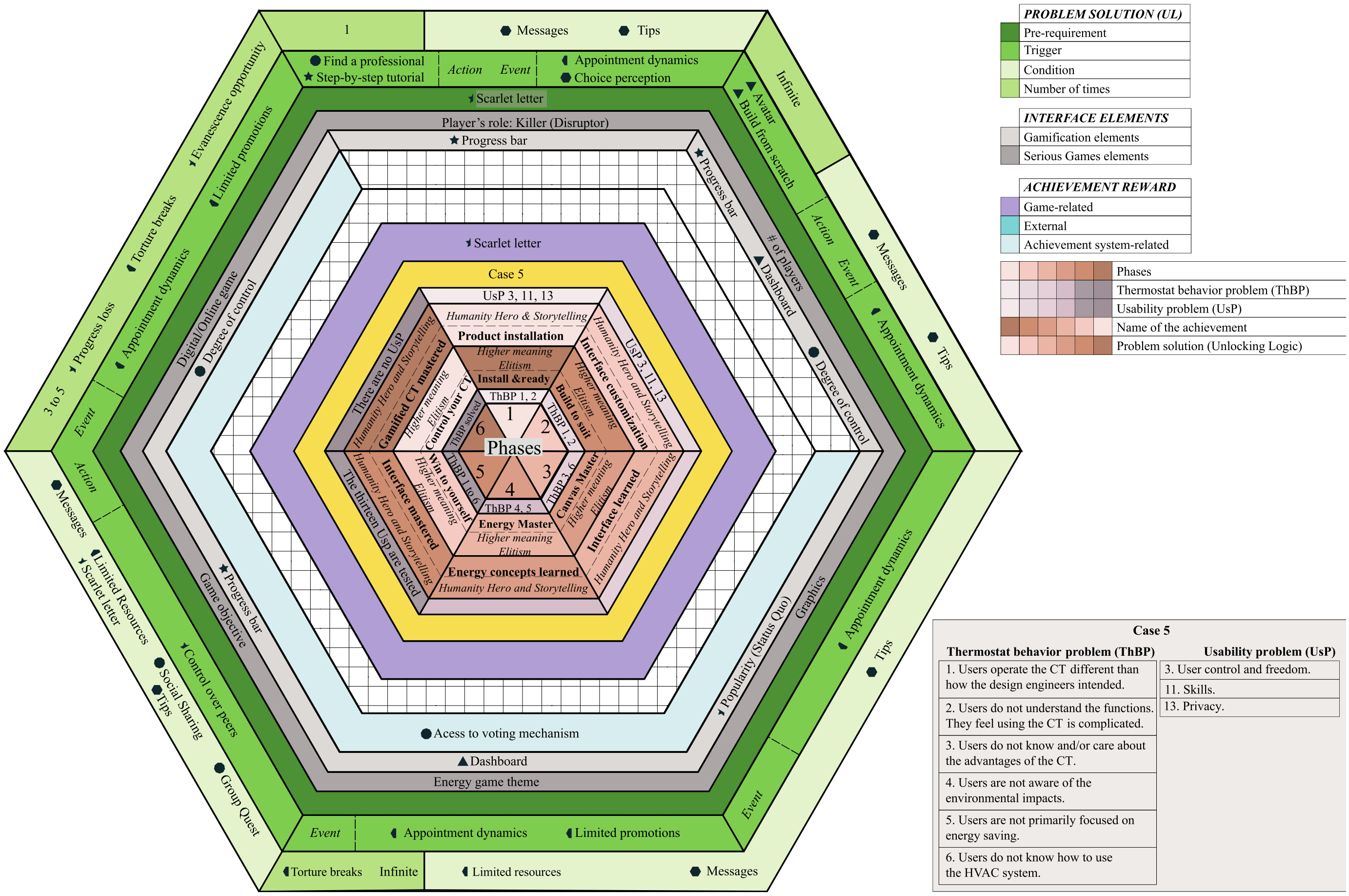


Fig. 9. Case 5 diagram.

- **External:** Rewards are external to the achievement system and the game itself (e.g., users are rewarded with a shopping coupon).
- **Achievement system based:** Rewards related to the achievement system, (e.g., by unlocking a given achievement, the user fulfills the conditions for unlocking another type of achievement).

d) Interface elements: The interface influences the users' motivation. An attractive user interface is required with stimulation visuals and exciting interaction concepts (AlSkaif et al., 2018; Barbosa et al., 2017; Casals et al., 2017; Chou, 2015; Dorji et al., 2015; ecoGator, 2016; Fijnheer and Van Oostendorp, 2016; Game | 2020 Energy, 2018; Geelen et al., 2012; Hamari and Eranti, n.d.; Matallaoui et al., 2015; Moloney et al., 2017; Ouariachi et al., 2019; Stieglitz et al., 2016).

- SG: This option is available from step 1 to step 5, the Install and ready, Build to Suit, Canvas Master, the Energy Master, and the Win to yourself achievements. The users learn six thermostat behavior problems. Any serious energy game requires objective, energy game theme, an identity of the player's role based on the Hexad Framework, and its association with the personality trait (Marczewski, 2015; Tondello et al., 2016), and the (Bartle, 1996) role player. This type of game displays the option of on-line or off-line mode, and the group or single-mode to promote socialization or imposition with the others (Bartle, 1996; Dorji et al., 2015; Geelen et al., 2012; Huotari and Hamari, 2012).

Gamification: The gamification elements display to the users the options to monitor the thermostat status to have a degree of control, to receive feedback, to show popularity. The interface displays a leaderboard to track his/her progress and community progress and collection set to display all the badges and rewards achieved. The Dashboard is displayed from step 2 to six and is mandatory for all the typical and non-typical user. The progress bar element appears in all the phases and for all the types of costumers.

5.1.1. *Proposed cases for knowledge base*

To better explain the goals in this study, it is examined five types of users and how tailored gamification and SG mobile application can help customers become engaged, change their behavior, and save energy. To use the application is not required to pass all the phases. This means that a user can be in My Real Interface mastered without achieving Phases 3, 4, or 5. However, the main principle of this structure is that customers understand the functionalities and capabilities of the CT and how improving energy consumption can lead to economic, social, and environmental benefits. The concept of having several phases is that the users master each and can, at the final stage, deeply understand how to manage their CTs to save energy.

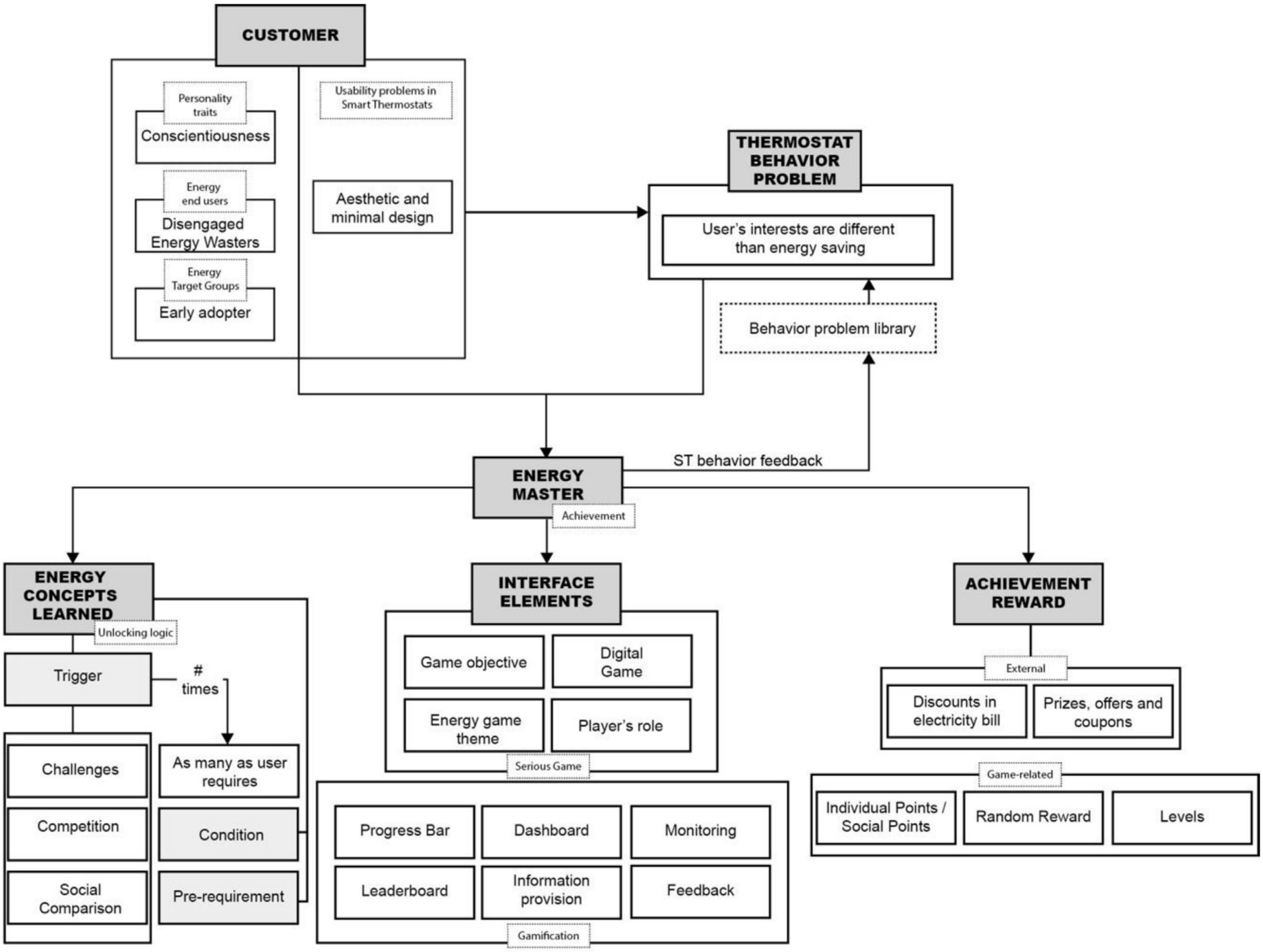


Fig. 10. Energy saving strategy diagram.

5.1.2. Case 1 (Fig. 6)

a) Type of user: The user is pro-environmental but does not know how to use an ST. The user has the following features:
  - Openness, green advocate, and energy-conscious.

b) Usability problem: Help and documentation, flexibility and minimalism design, match between system and real-world, and recognition rather than recall.

c) Behavior problem in the CT: The user does not understand the functions of the CT; the user believes that CT is complex. The user does not know about the advantages of using a CT.

d) Problem solution suggested: product installation, interface customization, and interface learned.
  - These steps are designed to help users better understand how to use their thermostats. First, the users must customize their CT interface according to the method in (Ponce et al., 2017). Then, by applying SG techniques in the Interface Learned, the application displays users' CT customized canvases as a game so that they can learn how to use every button and understand the implications of taking actions regarding energy consumption. Once the users understand the CT display, they can comprehend how to use the Real Interface to interact with their thermostats and observe the consequences of every action they take.

e) Achievement Reward: Game-related.
  - Rewarding users based on their conduct, effort, and impact, can incentivize them to take specific actions and increase their satisfaction (AlSkaif et al., 2018). This can take place through points, achieving levels, or even by providing, for example, smiley faces to users who improve their average or are at the top (Gonczarowski and Tondello, 2017).
  - Interface elements:
  - As discussed in (Ponce et al., 2018b), end-users often do not understand programmable thermostats and are not motivated to overcome difficulties in programming them; thus, they have low expectations for the performance of the CTs. To motivate users to learn how to use the thermostats is necessary to have an interface in which the primary system has contact with the end-users through tailored, interactive tips, information, and data-driven messages that can give users a clear view of how their actions impact the amount of energy they waste and how they can have improved engagement and active participation (AlSkaif et al., 2018).

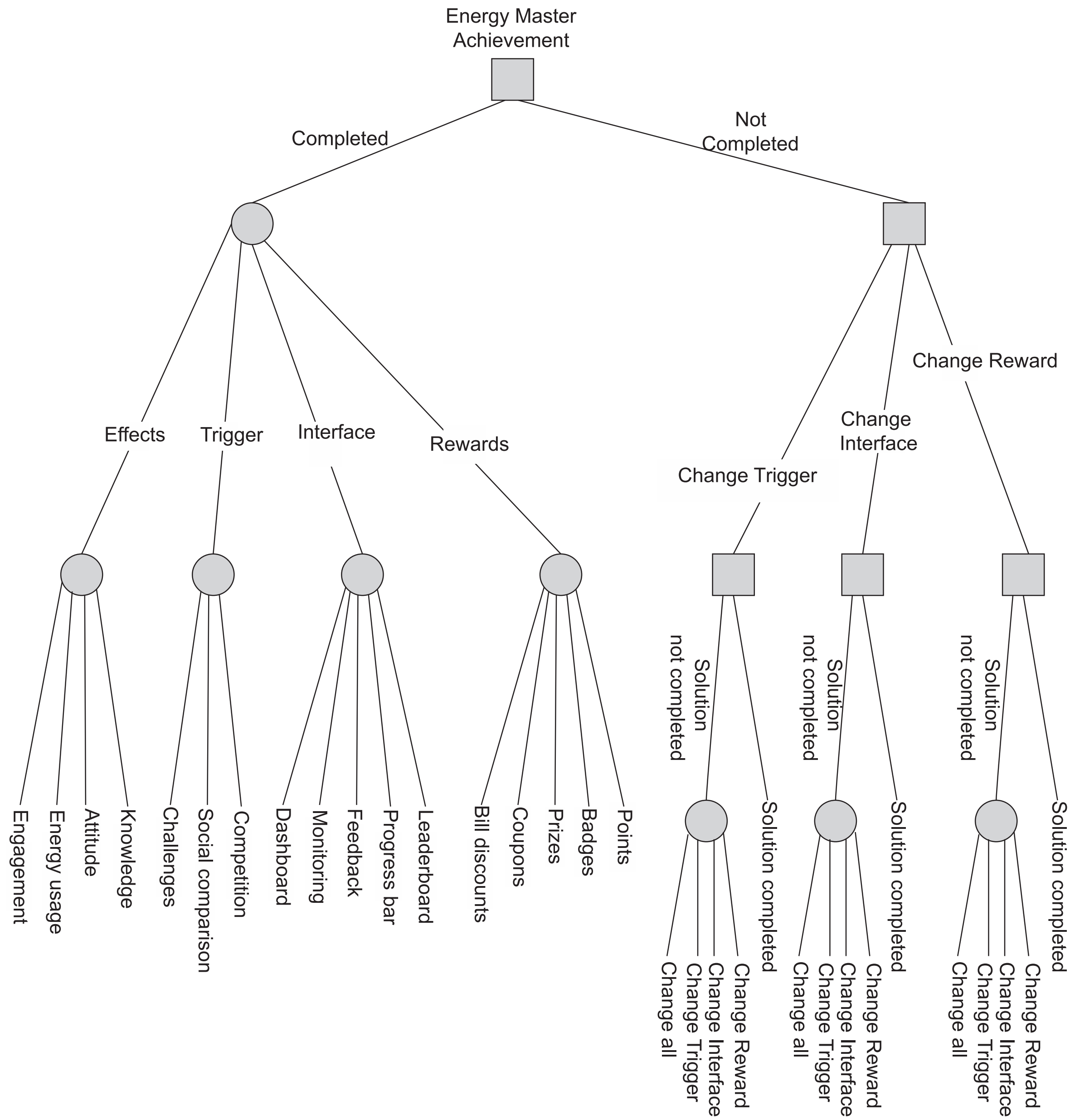


Fig. 11. Decision tree.

Table 10
Energy Master achievement completed Case 2a.

Energy Master achievement completed							
Effects		Trigger		Interface elements		Rewards	
Engagement	H	Challenges	H	Dashboard	H	Points	H
Energy usage	L	Social Comparison	M	Monitoring	H	Badges	H
Attitude	M	Competition	H	Feedback	H	Prizes	H
Knowledge	H			Progress bar	H	Coupons	L
				Leader-board	H	Bill dis-counts	L

- Users can follow their progress through the dashboard, leaderboard, progress bar, message box, and notifications about their performance. These elements are used to motivate individuals to be at the top and achieve the Win-State of completeness, as (Chou, 2015) proposes. In addition, using a dashboard can prompt users to constantly

Table 11
Energy Master achievement completed Case 2b.

Energy Master achievement completed							
Effects		Trigger		Interface elements		Rewards	
Engagement	L	Challenges	M	Dashboard	M	Points	M
Energy usage	M	Social Comparison	M	Monitoring	M	Badges	M
Attitude	M	Competition	M	Feedback	M	Prizes	H
Knowledge	H			Progress Bar	L	Coupons	M
				Leader-board	M	Bill Dis-counts	M

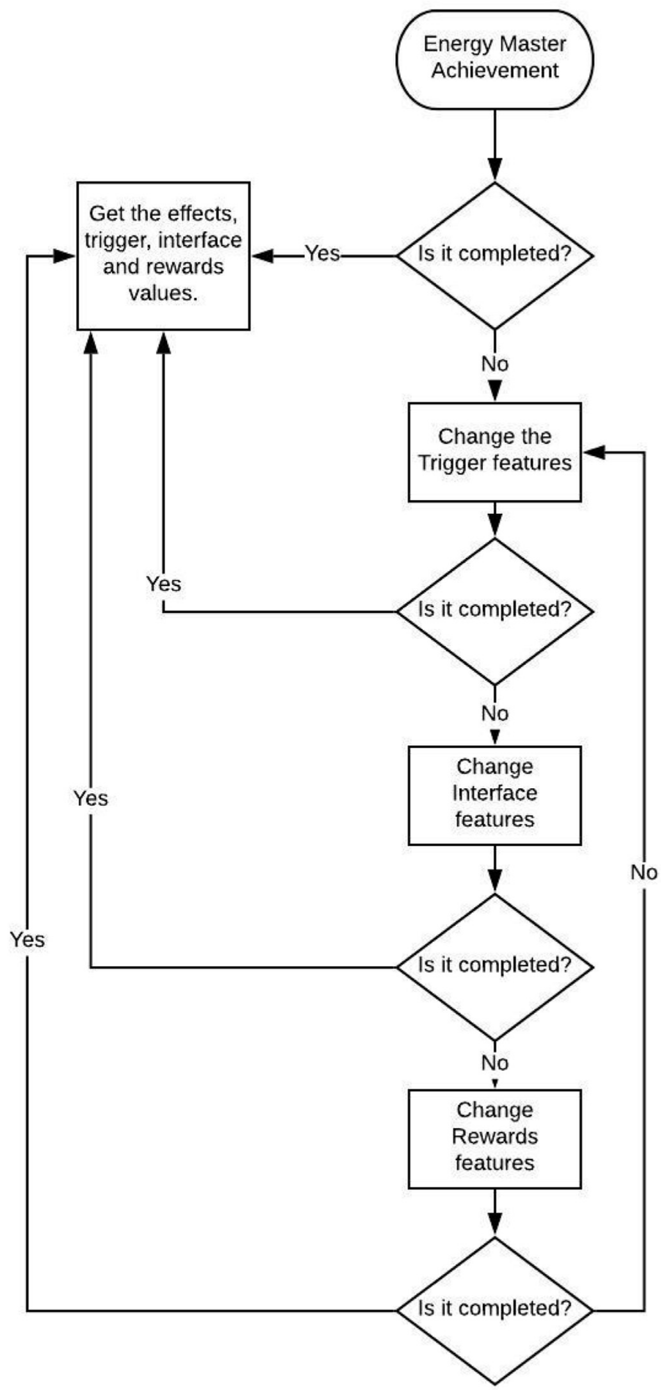


Fig. 12. Energy Master achievement not completed diagram.

monitor the progressive output of the CT development. The use of a leaderboard serves to make users feel optimistic about accomplishing the task and act with urgency so they can increase their status.

- Using a digital game of the user's CT interface can help users understand how the CT operates.

5.1.3. Case 2 (Fig. 7)

a) Type of user: The user is at the cutting edge of technology, understands the CT functions, but is not familiar with saving energy. The user has the following features:
   - Conscientiousness, disengaged energy waster, and early adopter.

b) Usability problem: Aesthetics, visibility of the status, and help and documentation.

c) Behavior problem in the CT: Users' interests are different from energy saving, and they are not aware of their environmental impact.

d) Problem solution suggested: Energy concepts learned.
   - Educational information for a deeper understanding of saving energy that leads to a sustainable lifestyle helps users identify basic concepts of energy consumption and provide useful forms for reducing daily consumption. This information can be presented as tips and hints, and in the end, the user can be quizzed on the content.
   - Social competition, collaboration, and energy community are key components for success (AlSkaif et al., 2018). The best way to motivate households to consume less energy is through a chart that compares their consumption with that of their neighbors (Chou, 2015).
   - Applying the gamification mechanisms collected in Table 7 can provide incentives that are in the customer's interest by demonstrating, for instance, the social and environmental outcomes resulting from a new energy consumption habits, or by compensating them with rewards in proportion to the effort they provide in a certain application (Prochaska and Velicer, 1997).
   - In (Geelen et al., 2012), feedback about energy consumption is an effective way to enable individuals to modify their conduct. The feedback must be provided frequently and over a long period of time and should allow users to see the consequences of their actions.

e) Achievement Reward: Game-related, external.
   - In (AlSkaif et al., 2018; Ponce et al., 2019), the authors propose an electricity discount as an incentive for improved consumption behavior.
   - Individual and Social Points or by giving a number of credits proportional to a customer's effort that can be redeemed within the game economy for valuables or points that can be traded with other users in the

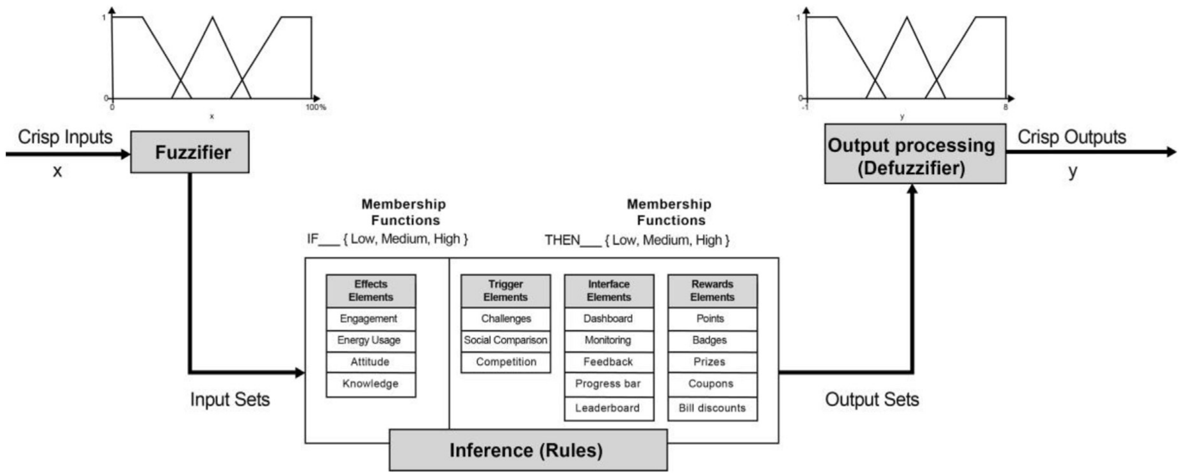


Fig. 13. Algorithm structure.

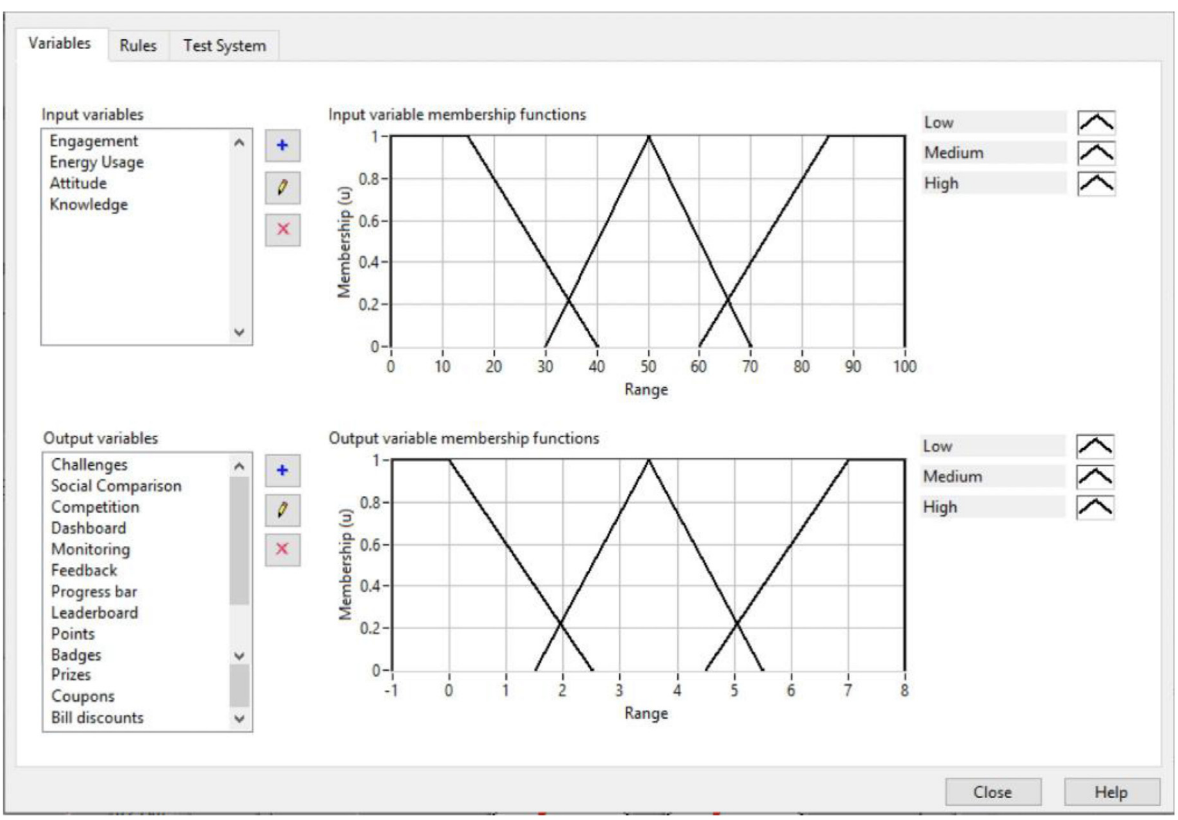


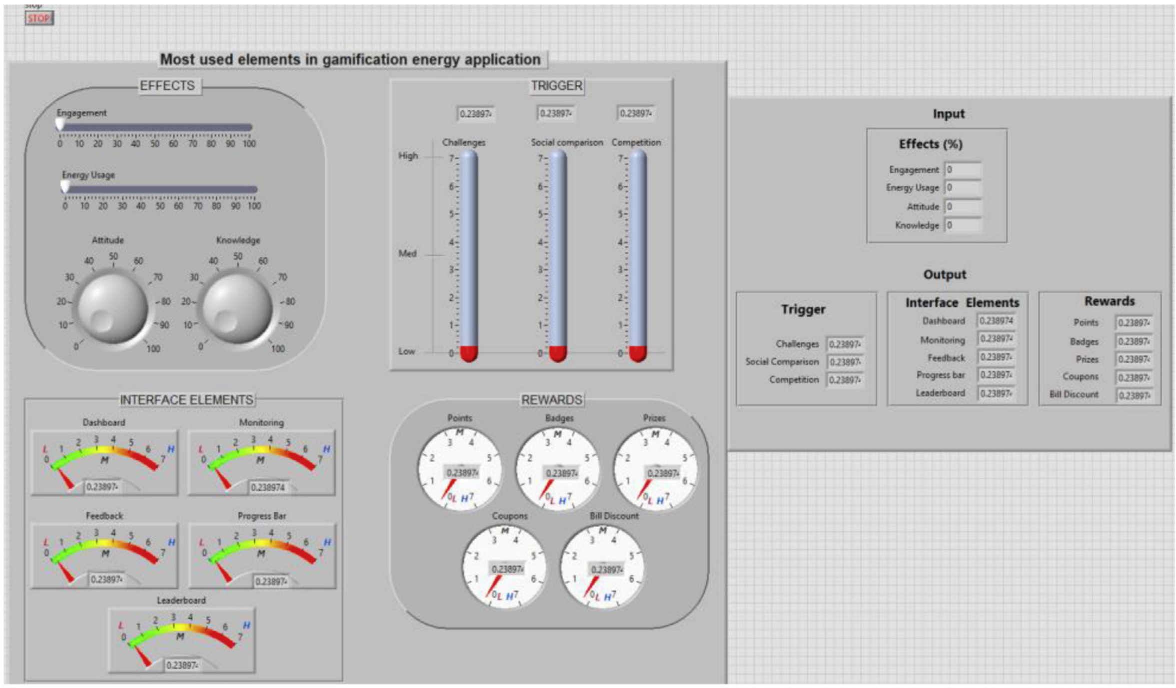
Fig. 14. Membership functions for the Energy Master achievement.

application. Exchangeable points can allow users to trade individuals outside of the gamified system (AlSkaif et al., 2018; Chou, 2015).

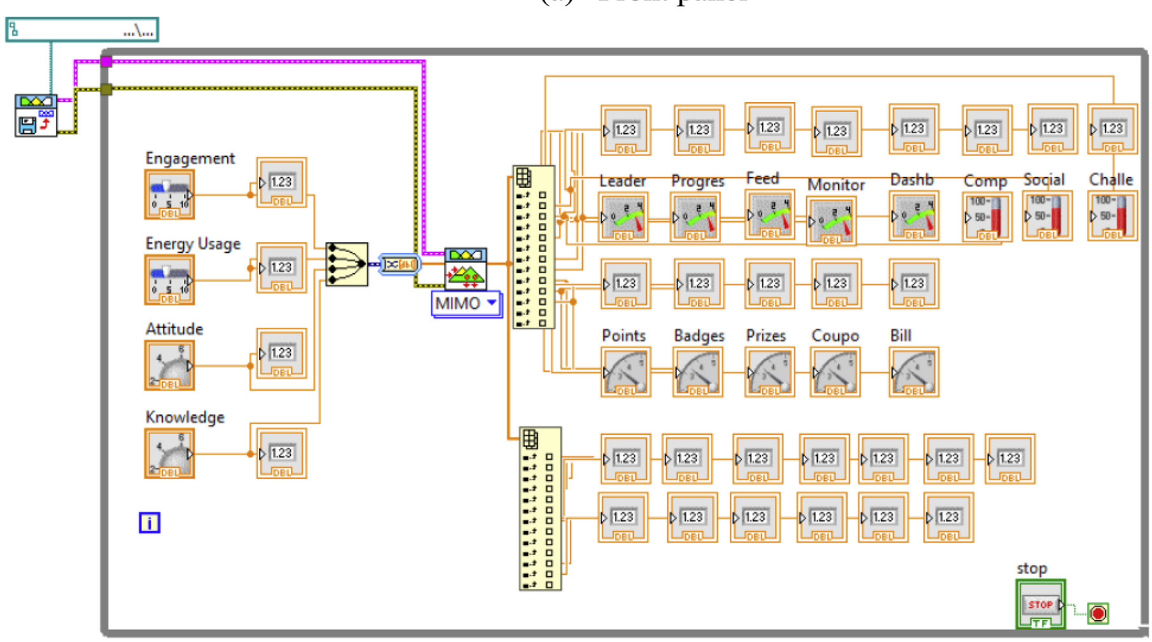
- Prizes, offers, and coupons are occasionally the main reasons to continue (AlSkaif et al., 2018; Geelen et al., 2012).

f) Interface elements:

- The dashboard, leaderboard, progress bar, message box, and notifications about the customers' performance (AlSkaif et al., 2018; Peham et al., 2014).
- Statistics that allow customers to compare their performance with that of other customers (AlSkaif et al., 2018; Peham et al., 2014).



(a) Front panel



(b) Block diagram

Fig. 15. Proposed fuzzy logic system to test the application (front panel (a) and block diagram (b)).

- Providing users with items, characters, and badges of a Collection Set can prompt them to want to collect them all and complete the set (Moloney et al., 2017).

5.1.4. Case 3 (Fig. 8)

a) Type of user: The user wishes to learn how to use a thermostat and become a pro-environmental user. The user has the following features:
   - Agreeable, home-focused, and cost-oriented.

b) Usability problem: Skills, error prevention, and pleasurable and respectful interaction with the user.

c) Behavior problem in the CT: The users' operation is different from the operation intended by the CT engineers. Users do not understand the functions or know and/or care about the advantages of a CT. Users are also unaware of the environmental impact and do not use the HVAC correctly.

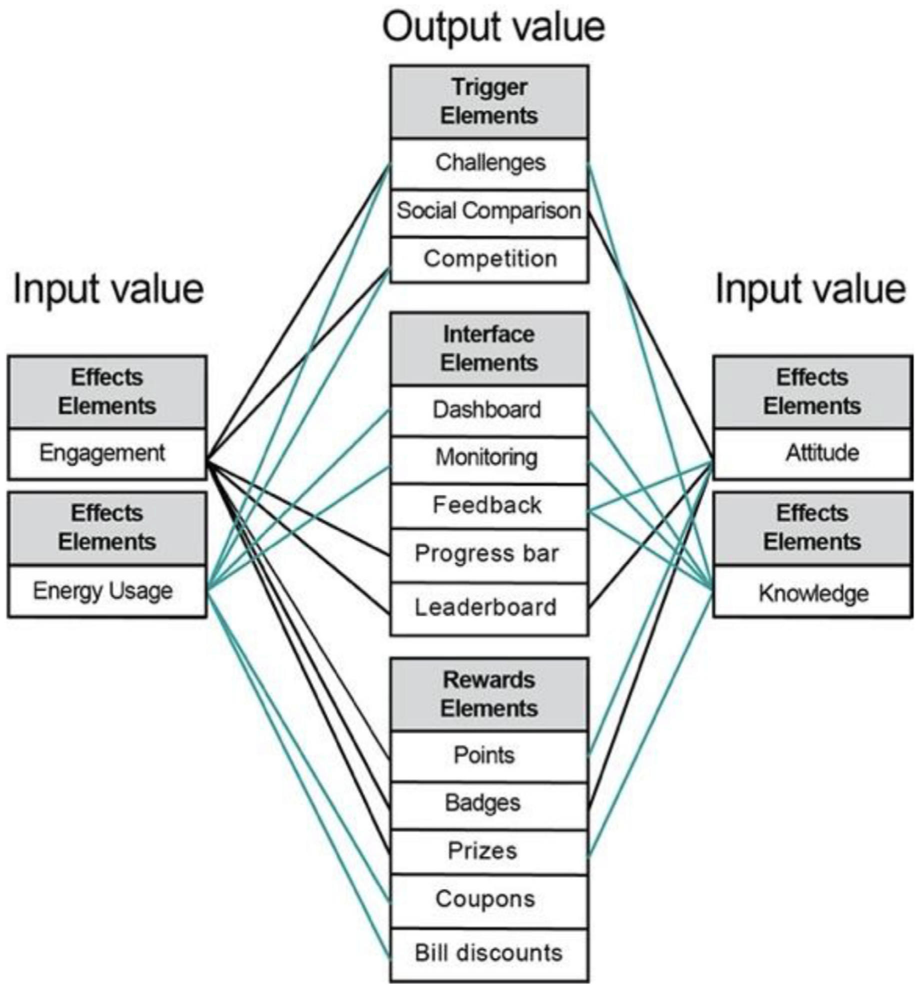


Fig. 16. Proposed input-output relationships.

d) Problem solution suggested: Product installation, Interface customization, Interface learned, Energy concepts learned, Interface mastered, and Gamified CT mastered.
   - Since the problems require a deep understanding of every step of the game, the proposal is to teach users the skills needed to understand the application.

e) Achievement Reward: All are related to the six phases.
f) Interface elements: All are related to the six phases.

5.1.5. Case 4 (Figs. 6 and 9)

a) Type of user: These users are motivated by cost savings, know about HVAC systems, but do not wish to be green users. They bought their CT for social motives and want the product to save energy for themselves. The user has the following features:
   - Extraversion, non-green selective, and early adopter.

b) Usability problem: Aesthetics and pleasurable and respectful interaction with the user.
c) Behavior problem in the CT: The users' operation is different than the operation intended by engineers. Users do not care about the advantages of CT, and their interests are not to save energy. Users are not aware of their environmental impact.
d) Problem solution suggested: Product installation, Interface customization, Interface learned, Energy concepts learned, Interface mastered, and Gamified CT mastered.
   - Users must complete the Product Installation phase before becoming engaged. In this step, the CT manual provides the users with step-by-step guidance to install the product through the mobile application. Once in the application, the game instructs the users to create a personalized profile and thermostat interface. The users can then learn the options that are displayed even if they are not interested and just wish to gain cultural knowledge. In addition, the game provides the users with rewards and demonstrates that by understanding how the CT operates, the more economic benefits they can achieve. Although the CT can help improve energy usage, it is important for the users to learn which options can help them save more energy and to not become upset if their expectations are not fulfilled.

e) Achievement Reward: All are related to the six phases tailored to the customer.

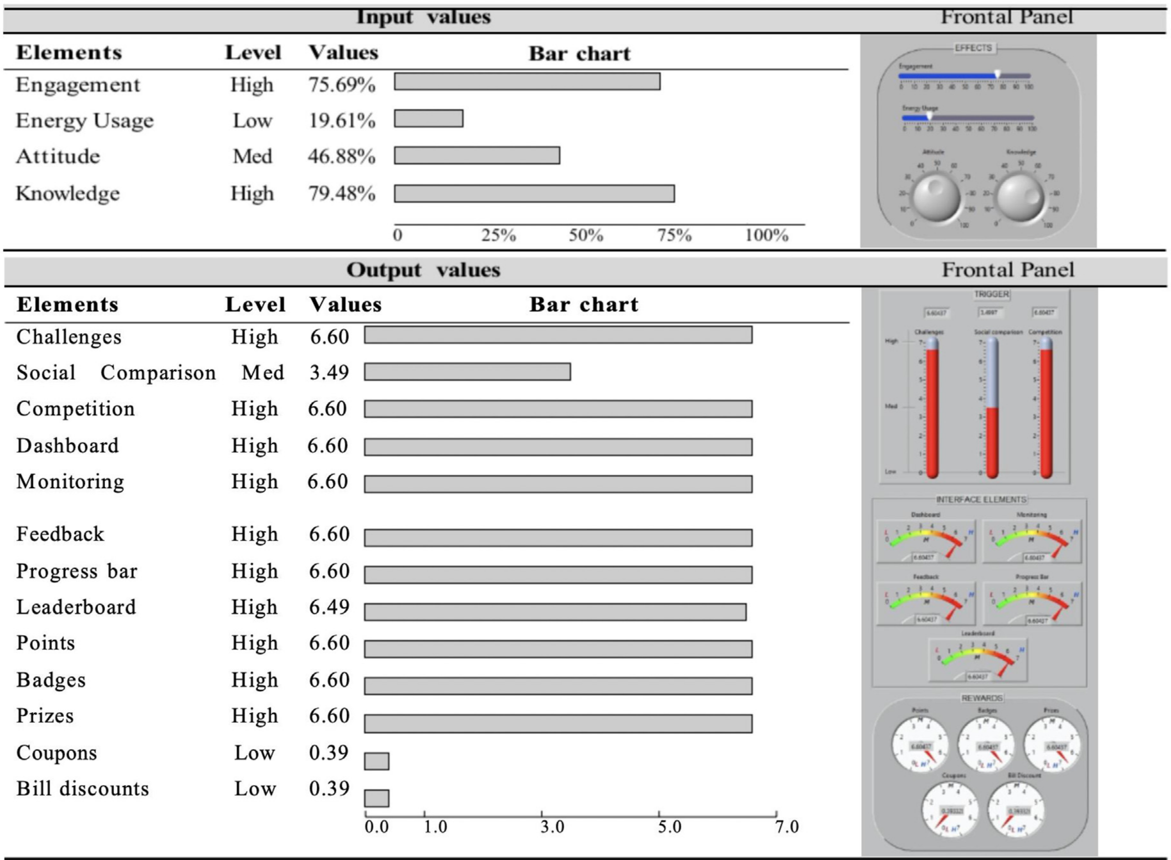


Fig. 17. Case 2a example results.

f) Interface elements: All are related to the six phases tailored for the customer.

5.1.6. Case 5 (Fig. 9)

a) Type of user: These users are motivated to save money through energy savings, believe that using new technologies does not fulfill their expectations, and are insecure because the device is internet-based. They do not know how to use a CT. The user has the following features:
b) Neuroticism, traditionalist cost-focused, and cost-oriented.
c) Usability problem: User control and freedom, skills, and privacy.
d) Behavior problem in the CT: The user's operation is different than the operation intended by the engineers. The user does not understand the functions and does not care about the advantages of the CT. The user is not aware of environmental impact, and his/her interests are not to save energy. The user also does not use the HVAC correctly.
e) Problem solution suggested: Product installation, Interface customization, Interface learned, Energy concepts learned, Interface mastered, and Gamified CT mastered.
   - This type of user is the most reluctant to undergo a conduct change. As a result, the gamification and SG for this user should be focused on economic rewards, messages, videos, and tips about the benefits of the CT, primarily emphasizing the security of the CT through several secure and encrypted elements that lead to a secure network.
   - The gamified and SG elements are primarily focused on the benefits of managing the CT with specific features without losing the comfortable temperature.
   - Because this user hardly wishes to engage in online activities or competitions with other users, the application should encourage the user to understand the interface through an SG interface in which the user is taught the characteristics and uses of every feature in the application. The control over peers element is displayed as a manner to push the user to interact with the others. However, this user is a Disruptor or Killer player that may try to impose themselves on others; therefore, for a limited time, the user can interact with the others.
f) Achievement Reward: All are related to the six phases.
g) Interface elements: All are related to the six phases.

5.1.7. Proposed energy-saving strategy

Using the six levels of the achievement structure with the gamification and SG elements proposed in Figs. 6–9 is possible to get five cases; these five cases have the purpose of providing solutions for each user regarding his/her usability and behavior problems. These cases are proposed considering the different types of users, behavior, and usability problems to exemplify the phases required to succeed in operating the CT and saving energy. This signifies that users are not required to complete the six stages of the Achievement to solve the problem they experience with the CT. However, the elements of gamification considered in each phase can be changed by other elements that meet the expectations of the users to lay the foundations of knowledge. Then, in Phase 2 of the

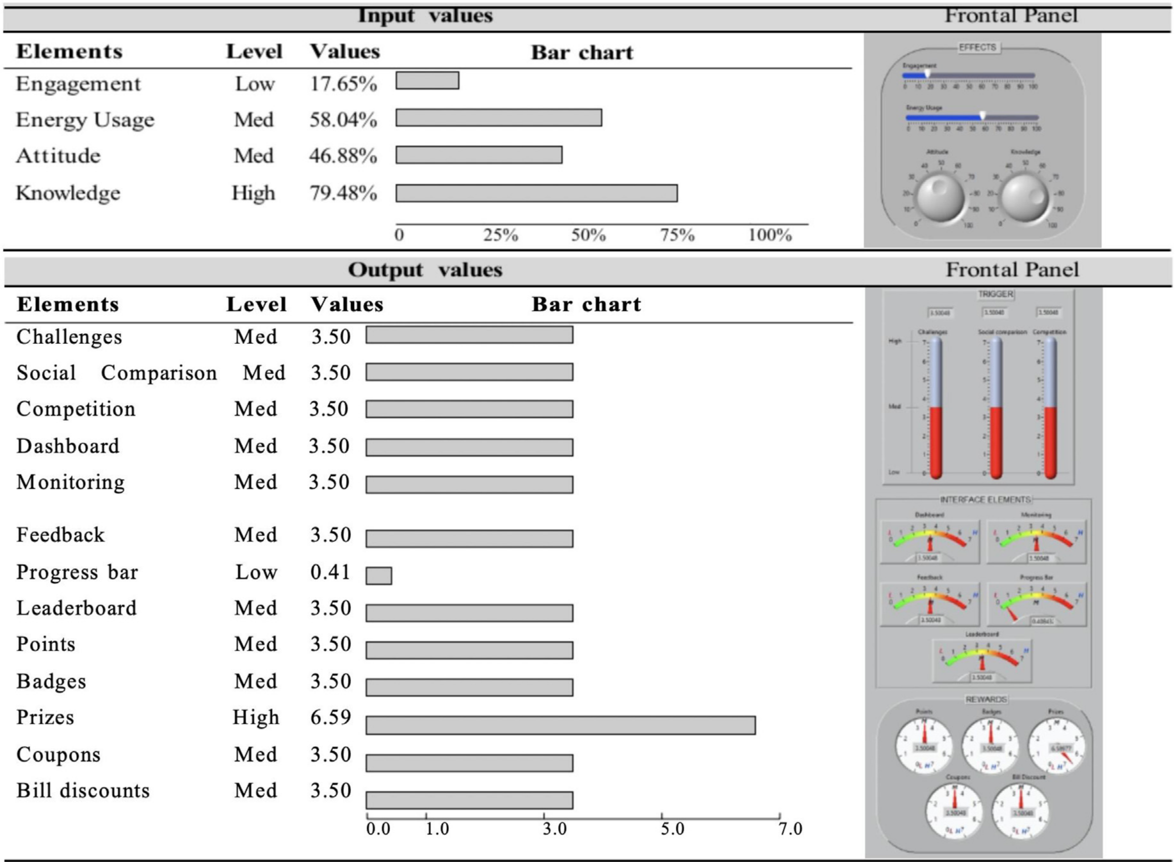


Fig. 18. Case 2b example results.

framework, fuzzy logic is used. For developing a deeper strategy, the energy-saving strategy is focused on Case 3: Energy Master Achievement. Every step related to the achievement serves to develop a Behavior problem library, in which each detected problem becomes part of the Thermostat Behavior Problem. Then, the strategy is based on attempting to solve the habits problem (Fig. 10).

Fig. 11 presents a decision tree for the energy problem solution. The elements are divided according to the method proposed in (AlSkaif et al., 2018; Beck et al., 2019; Fijnheer and Van Oostendorp, 2016) for the development of energy gamified applications. Inside the Effects element, the four reported effects of energy games (knowledge, attitude, energy usage, and engagement) are considered. The Trigger elements considered are social connection, which pertains to the comparison with peers. The Interface elements considered consist of information provision, an interactive interface, and performance status, which customers perceive as useful, easy to use, and which allow them to follow their progress. Finally, the Reward elements are proposed based on the users' energy consumption behaviors and effort.

To complete the Energy Master achievement; the decision tree considers the following two options:

1. **Completed Achievement:** The impact of each gamification element is measured to determine which elements are used the most. Based on the results, the application shows more of these elements to continue engaging the users. The principle is to not allow users to get bored and stop using the application.
2. **Not Completed Achievement:** If the users are unmotivated, then the Trigger, Interface, and/or Rewards elements must be changed, and the Achievement must be tested again until the user becomes engaged. Because the reported Effects of the energy games allow the authors to determine the success of the application, they do not change.

For example, Table 10 illustrates the type of user in Case 2 (conscientiousness, disengaged energy waster, and early adopter) with the following respective usability and behavior problems: the information is complicated to search because it is not focused on the user's task, and the user's interest is not to save energy. After testing the game, if the user displays these levels of commitment (i.e., has a low energy usage effect but high engagement and knowledge levels), the gamification strategy bust is changed without compromising the engagement and knowledge levels. To move the user from low to medium or high energy usage is necessary to focus on the higher elements by changing the elements appearing on the interface, potentially by sending additional recommendations or tips on how to save energy, but with a minimum number of functions so that the user feels comfortable (Ponce et al., 2017). Because bill discounts are considered medium, by providing the benefits of bill discounts, the user is likely to be more engaged. However, a test must be first be performed. In Table 11, the same case is proposed as above, including the usability and behavior problems mentioned in Table 7. However, the difference is that the user scores high on neuroticism, and is non-green selective, and cost-oriented. The strategy is such that after using the application, the user becomes more engaged through the elements of social comparison and economic rewards (AlSkaif et al., 2018; Peham et al., 2014; Ponce et al., 2019).

If the achievement is not completed, then it is necessary to

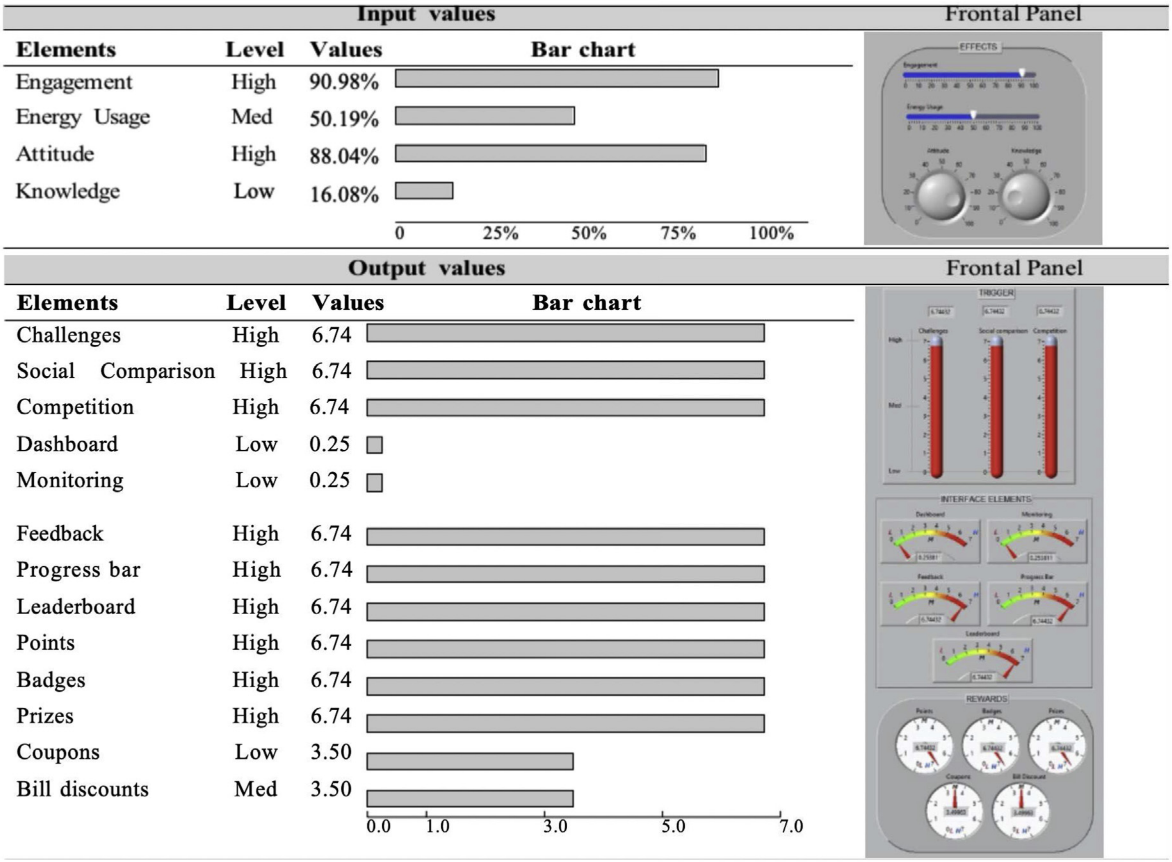


Fig. 19. First example of fuzzy logic phase.

change the features involved in the Trigger, Interface, and Reward elements according to the gamification elements, as presented in Fig. 12. Once completed, the Energy Master achievements, Effects, trigger, Interface, and Rewards values are collected and analyzed to obtain a positive value for the effects, as proposed in (Fijnheer and Van Oostendorp, 2016).

5.2. *Fuzzy logic phase*

To test the most used elements in a gamification energy application once they are defined, it is proposed to implement Type 1 fuzzy logic using LabVIEW 2018. The Effects elements are defined as Inputs in the system, while the Trigger, Interface, and Rewards elements are defined as Outputs. In addition, the Membership functions of the inputs are measured as percentages. It is proposed in (Fijnheer and Van Oostendorp, 2016) to measure the Knowledge, Attitude, and Engagement elements through questionnaires before and after the consumer uses the. Application. Furthermore, knowledge is measured with in-game tests, while engagement is determined through monitoring a player's behavior when the application is used. Energy usage is measured by tracking the energy meter of the CT; this measure must thus be observed before the user begins using the application. In contrast, the Membership functions of the output elements are measured before and after using the application through questionnaires by applying the semantic differential scale, which detects any behavior changes. This measure mainly involves using a pair of antonyms of a given concept; in this case, the concepts are the 13 elements included in the Trigger, and Interface elements, and Rewards groups using a scale ranging from 1 to 7 (where 4 is considered a neutral pole or not applicable for the specific element) (Evans, 1970).

In 1965, computer scientist Lotfi Zadeh from the University of California Berkeley, proposed fuzzy set theory as a class of sets based on membership grades from 0 to 1 and inference rules that do not require a mathematical model of the real system, but rather, rules generated by experts, polls, or consensus-building (Ponce, 2011; Ponce-Cruz et al., 2016; Zadeh, 1965). Fuzzy logic was created to model uncertainty based on linguistic words and sentences (linguistic variables) associated with human logic rather than the use of numerical values (e.g., Engagement variable = High, Low, Medium). This type of fuzzy set is known as Type-1.

Fig. 13 illustrates the algorithm structure using the Mamdani fuzzy method proposed by Ebrahim Mamdani, while Fig. 14 displays its Membership Functions proposed for the Energy Master achievement. To elicit the desired result; fuzzy logic required the following three stages: (1) The variables have a certain degree of metalinguistic uncertainty that pass through a fuzzifier process, which consists of determining which value degree belongs to a fuzz se3t between 0 and 1; (2) Inference rules are proposed from the membership functions and are defined as a conditional statement in the form of "if x is A, then y is B" (Ponce-Cruz et al., 2016). These rules serve as a guide for the system to behave in a desired way according to a reference model, and they assign a degree of membership to the fuzzy set that characterizes the outputs; (3) It is determined through a defuzzification method, the center of are to be converted into a crisp number (Ponce, 2011; Ponce-Cruz et al., 2016).

As proposed in (Ponce et al., 2018a), signal detection theory

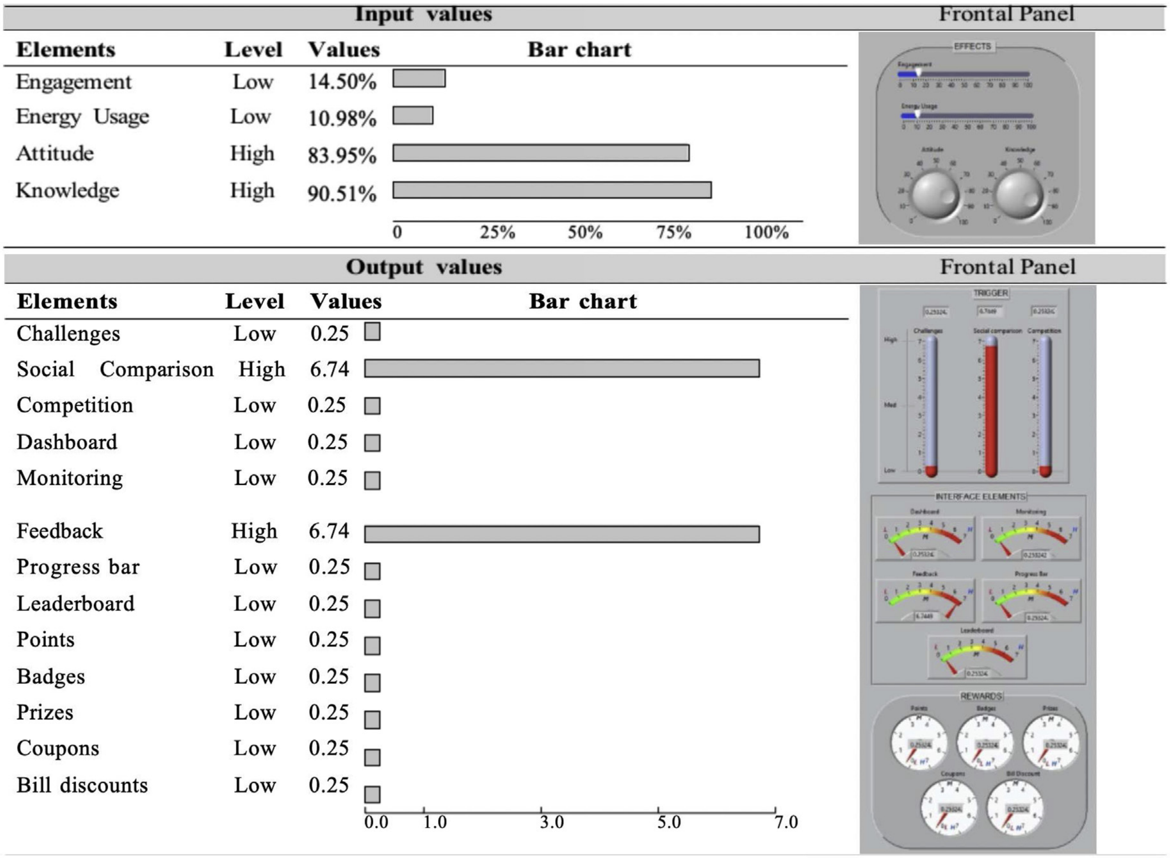


Fig. 20. Second example of the fuzzy logic phase.

(SDT) and fuzzy detection theory (FDT) are used to determine whether the output values are related to the input values introduced to the system. Therefore, it is proposed to develop an experimental study by surveying 50 participants to understand which elements of gamification and SG lead them to get engaged and improve their energy usage, attitude, and knowledge. In addition, the study intends to solve participants' behavior and usability problems to determine the best energy strategy for each user. The study is designed to help users understand how the CT operates.

In Fig. 15, a fuzzy system design is proposed to test whether the proposed rules are in accordance with the users' answers or whether the output values must be changed. Fig. 16 illustrates the relationship between the input values and the output values.

- **Engagement:** Challenges, Competition, Progress bar, Leaderboard, Points, Badges, and Prizes. In (Fijnheer and Van Oostendorp, 2016), it is proposed to monitor users' behavior while they use applications; thus, these elements are used to determine how engaged a user is.
- **Energy Usage:** Challenges, Competition, Dashboard, Monitoring, Coupons, and Bill Discounts. In (Fijnheer and Van Oostendorp, 2016), monitoring an energy meter is suggested for measuring energy usage; thus, in this case, the CT energy usage is monitored using these elements.
- **Attitude:** Social Comparison, Leaderboard, and Badges. This measures whether the user has a change in attitude toward saving energy (Fijnheer and Van Oostendorp, 2016).
- **Knowledge:** Challenges, Dashboard, Monitoring, Feedback, Points, Prizes. Knowledge is measured by in-game quizzes (Fijnheer and Van Oostendorp, 2016). In this case, gamification elements are proposed to determine whether the user is learning how to save energy and how to operate a thermostat.

Similar gamification elements in the input effect values may be repeated because it complements between each other; for instance, Energy Usage and Knowledge have common gamification elements that determine whether the users, through the challenges, dashboard, and monitoring, understand how the CT operates and whether they are saving energy.

5.3. Evaluation phase

As a result of the fuzzy logic phase, during this phase, the system displays the values of the gamification elements. Fig. 17 presents the results for a user who scores high on conscientiousness and is a disengaged energy waster, and early adopter. In this example, the behavior problem is that the user's interests are different from those of saving energy, and the usability problem is that the information is complicated to search because it is not focused on the user's task.

The input value effects for this type of user are as follows.

- Engagement and Knowledge Effects: High.
- Attitude Effect: Medium.
- Energy Usage: Low.

The output values are:

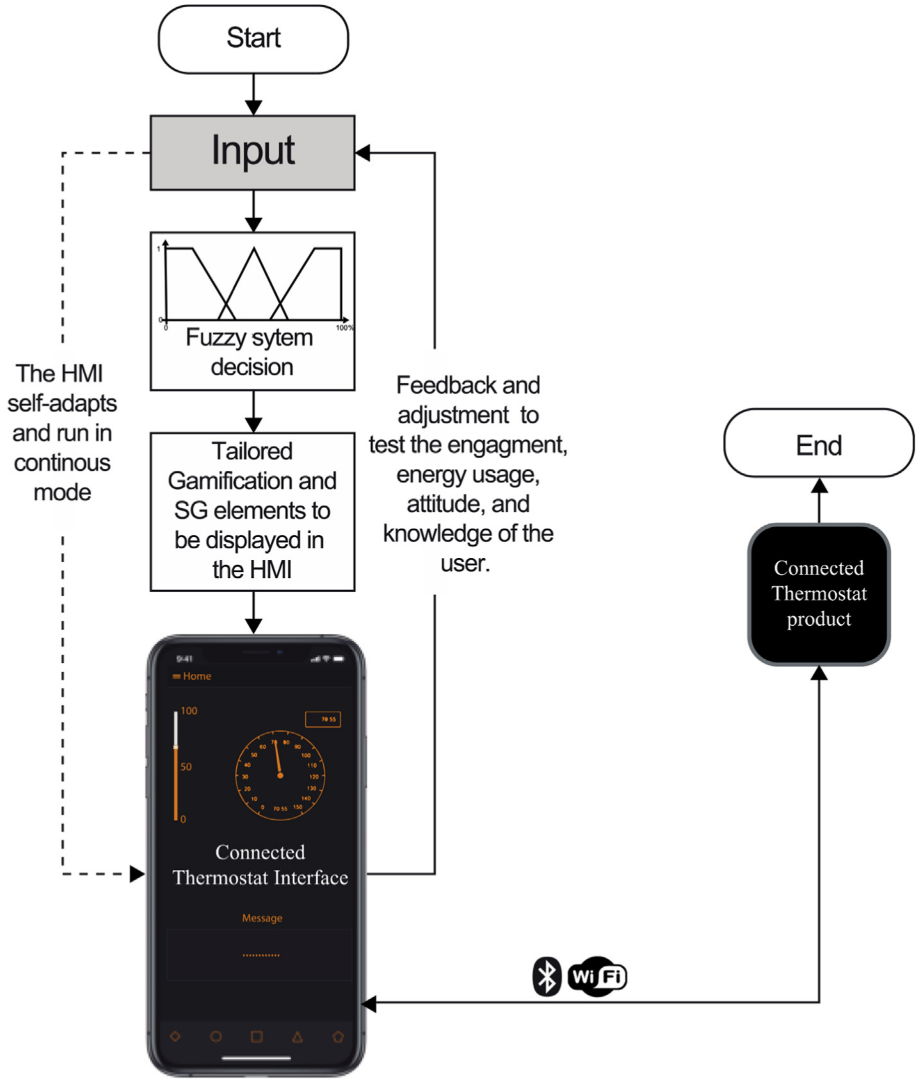


Fig. 21. HMI using the fuzzy system.

- **Trigger:** High in Challenges and Competition; Medium in Social Comparison.
- **Interface Elements:** High in all elements.
- **Rewards:** High in Points, Badges, and Prizes; Low in Coupons and Bill Discounts.

Based on the High and Medium levels, the proposal to motivate these users to become energy-aware involves providing them with more of these gamification elements corresponding to their amount of electricity reduction. Fig. 18 displays the results for a user with high neuroticism, who is non-green selective and cost-oriented with the same behavior and usability problems presented in Fig. 17.

The input values for this user are:

- Knowledge Effect: High.
- Energy Usage and Attitude effects: Medium.
- Engagement: Low.

Giving as a result:

- **Trigger:** Medium in all elements.
- **Interface Elements:** Medium in Dashboard, Monitoring, Feedback, and Leaderboard; Low in Progress Bar.
- **Rewards:** High in Prizes; Medium in Points, Badges, Coupons, and Bill Discounts.

Because this user is cost-oriented and has low Engagement, the application focuses on the high and medium output values; that is, the application aims to provide the user with greater Rewards based on how much the user knows about the CT and its economic benefits.

Two examples are provided to detail how the evaluation phase works.

a) Fig. 19 refers to the type of user with high levels of openness, who is home-focused and cost-oriented. The behavior problem is that these users do not know how to use the HVAC system, and the usability problem is that the interface tries to replace the users' skills, background knowledge, and expertise. The fuzzy system displays the following values:
   - Input values:
     - o Engagement and Attitude: High
     - o Energy Usage: Medium

Table 12
Knowledge base used in gamification and the serious game interface.

Knowledge base	
Type	Characteristics
Personality	Conscientiousness
Energy end-user	Disengaged energy waster
Energy target group	Early Adopter
Usability problem	Aesthetic and minimal design
Thermostat behavior problem	User's interests are different from energy saving

Table 13
Fuzzy logic used in gamification and the serious game interface.

Fuzzy logic elements			
Effects	Trigger	Interface	Rewards
Engagement	Challenges	Dashboard	Points
Energy usage	Social comparison	Monitoring	Badges
Attitude	Competition	Feedback	Prizes
Knowledge		Progress bar	Coupons
		Leaderboard	Bill discounts

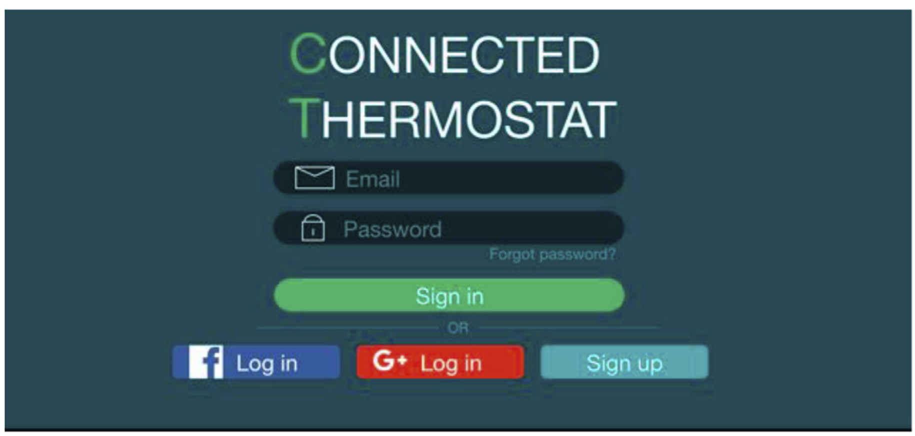


Fig. 22. Achievement 1.

  o Knowledge: Low
- Output values:
  o **Trigger:** High in all elements.
  o **Interface Elements:** High in Feedback, Progress bar, and Leaderboard; Low in Dashboard and Monitoring.
  o **Rewards:** High in Points, Badges, and Prizes; Medium in Coupons and Bill Discounts.
- Solution proposed:
  o Although this user has high engagement and attitude elements and an average value for energy usage, the knowledge is low. As this user must understand how the HVAC system works and has an open personality, the way to teach the user should be through the trigger elements. Feedback has a high value; thus, the application pays special attention by displaying tips to the user on how to improve knowledge of air conditioning. In terms of design, the thermostat designer should change the interface in such a way that the users do not feel that the application aims to replace them.

b) Fig. 20 refers to a type of user with high extraversion, who is disengaged and an early adopter. The behavior problem is that these users' interests are not to save energy, while the usability problem is that messages are displayed in code, and users cannot recognize, diagnose, or recover from errors. The fuzzy system shows the following values:
- Input values:
  o Attitude and Knowledge: High
  o Engagement and Energy usage: Low
- Output values:
  o **Trigger:** High in Social Comparison; Low in Challenges and Competition.
  o **Interface Elements:** High in Feedback; Low in Dashboard, Monitoring, Progress bar, and Leaderboard.
  o **Rewards:** Low in all elements.
- Solution proposed:
  o Because these users are not interested in saving energy but are interested in being part of social media communities, the application displays a blog where the users can post comments on any doubts or questions they have. This serves to encourage users to compare themselves with other users in terms of energy reduction. The thermostat designer should change the information so that the users can understand the benefits of becoming energy-aware.

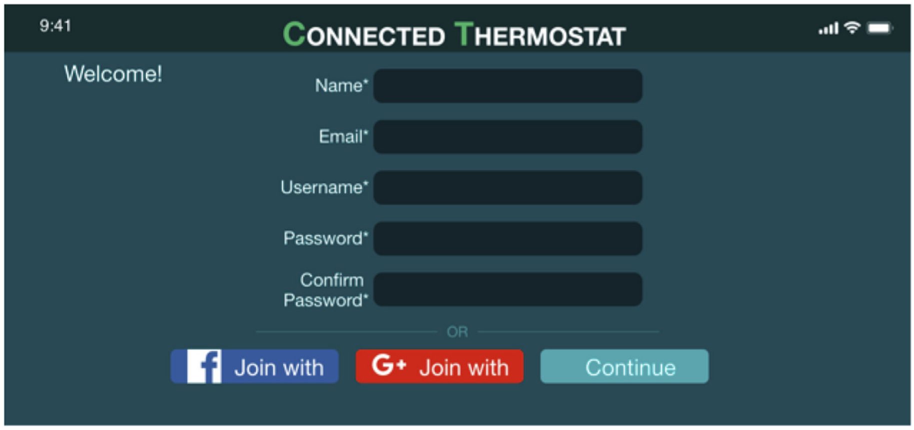


Fig. 23. Achievement 1.

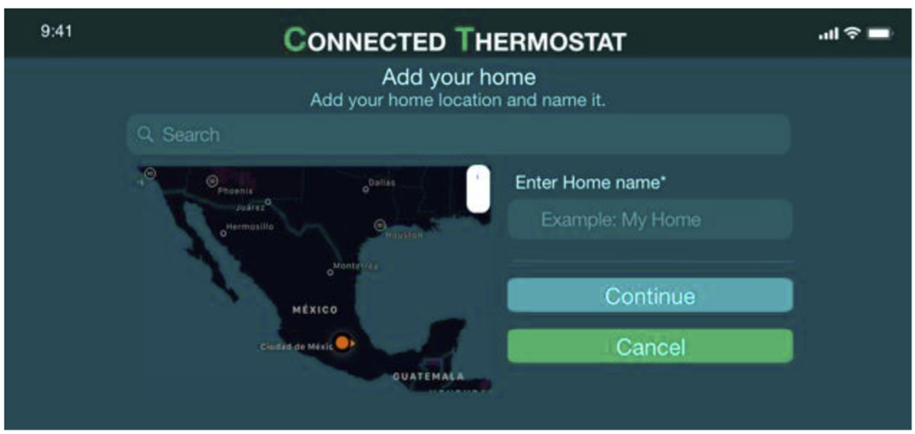


Fig. 24. Achievement 1.

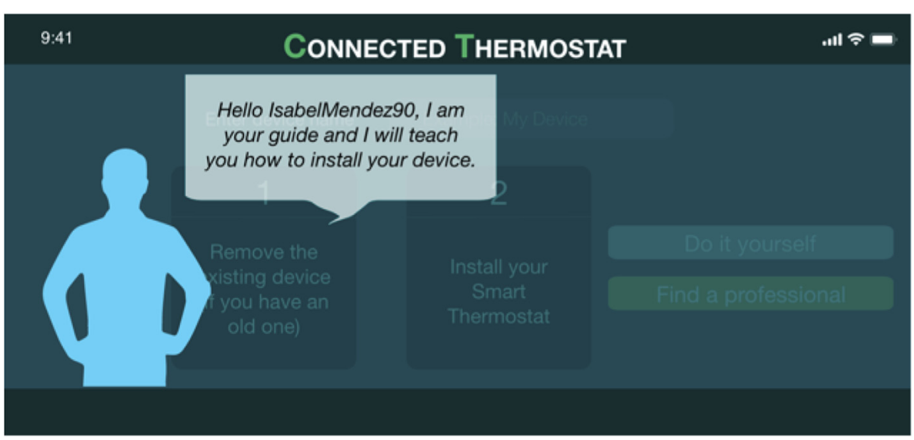


Fig. 25. Achievement 1.

6. Results

Fig. 21 presents a diagram for the operation of the fuzzy system. The fuzzy system displays the most important gamification and SG elements required in the CT interface for a specific user. Then, the application and CT communicate with each other, and the application provides feedback to the input system to continue self-adapting to the interface. The main goal of the application is to change the user's behavior to save energy; thus, the input values are intended as the highest values.

Tables 12 and 13 present a summary of the elements considered in the Energy Master achievement illustrated in Fig. 10, as well as the methodology proposed (Fig. 3) for the knowledge base and fuzzy logic elements. The HMI required for the specific type of user,

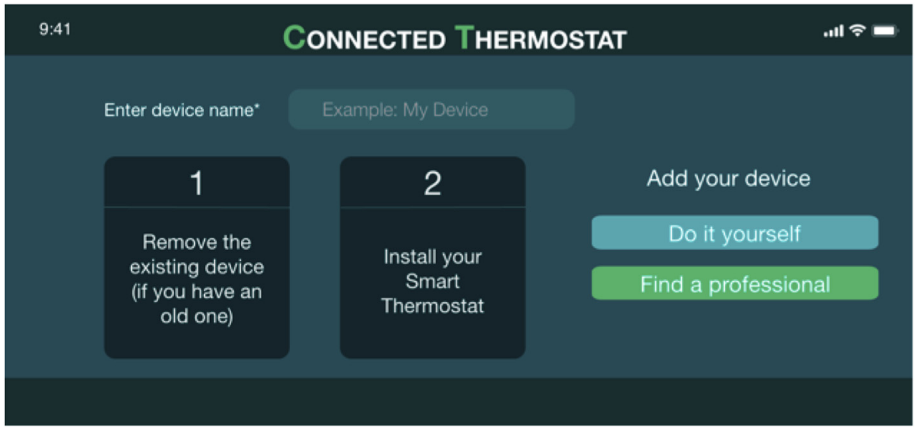


Fig. 26. Achievement 1.

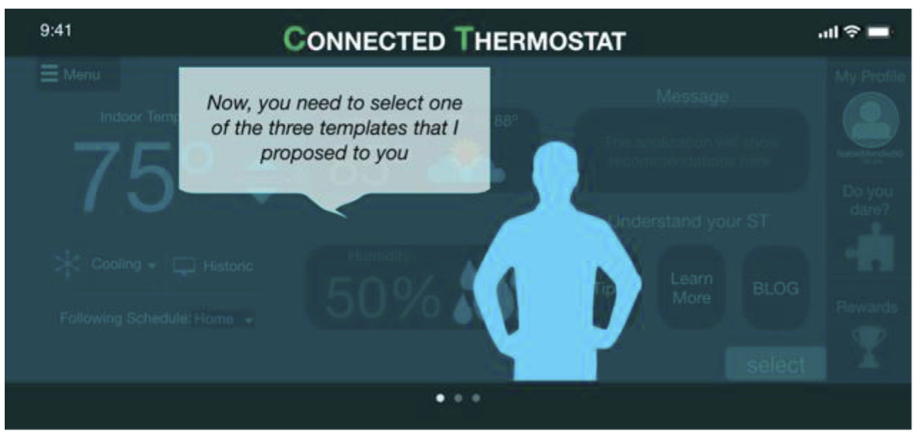


Fig. 27. Achievement 2.

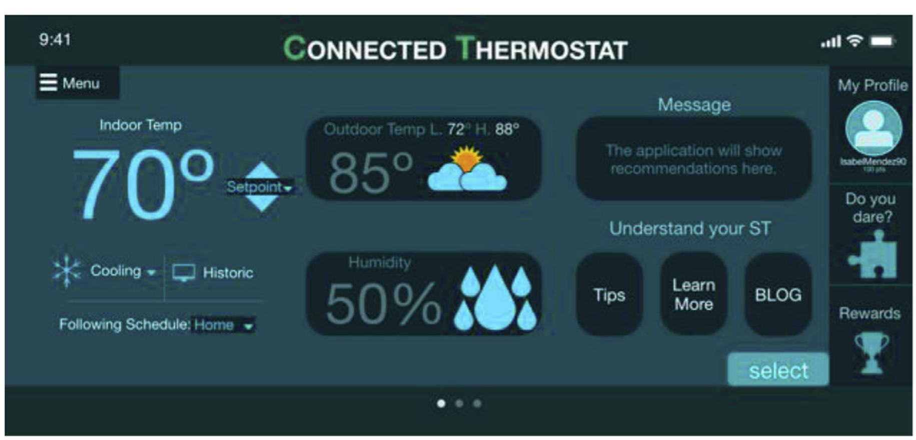


Fig. 28. Achievement 2.

usability, and thermostat behavior problem requires the use of gamification and SG elements to shape the users' conduct and make them energy-aware.

It is important to understand which elements of gamification and the SG improve engagement, energy usage, attitude, and knowledge, and solve users' behavior and usability problems. These results guide us to propose the gamification and SG elements required by the customer and the fuzzy logic and determine the output values needed in the HMI.

For the development of the HMI, every new user must first

Fig. 29. Achievement 2.

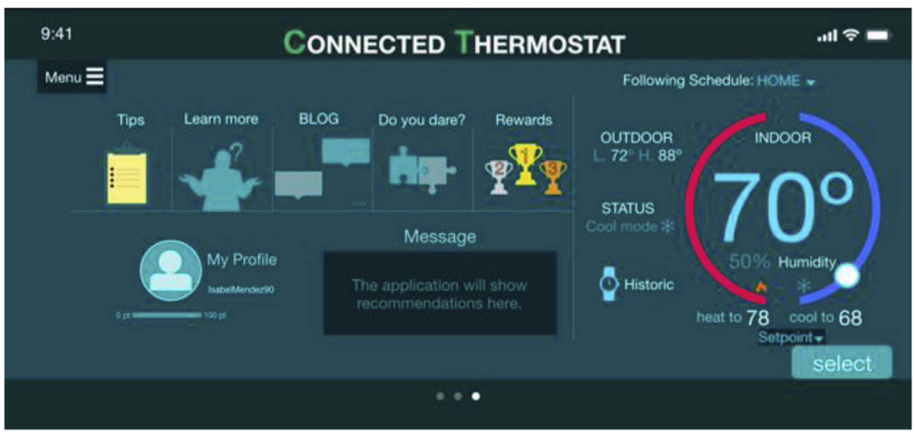


Fig. 30. Achievement 2.

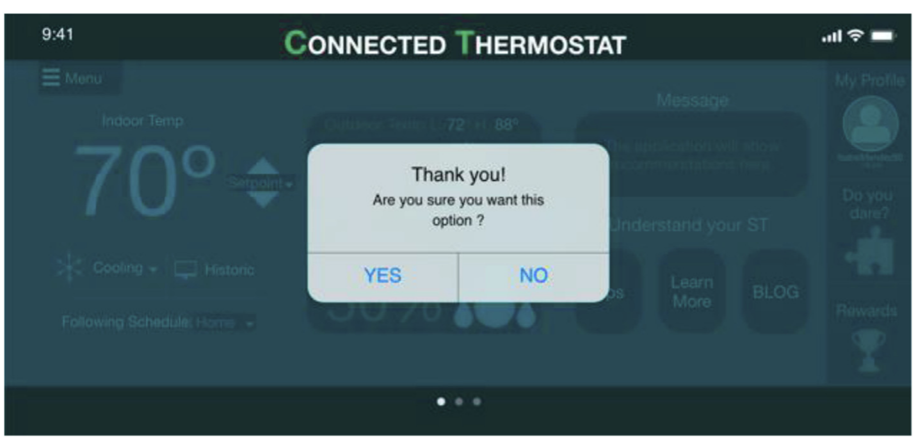


Fig. 31. Achievement 2.

complete Achievement 1: Installed and Read, and Achievement 2: Build to Suit, which is related to product installation and interface customization, respectively. In Figs. 22 and 23, the users must log in to the CT application either by using Google or Facebook or by creating a new account. Once the users have logged in, the application instructs them to locate and assign a name to their home and device so that the interface search for climate data and electricity rates. In addition, users can develop a sense of belonging as suggested by core drive 4 Ownership and Possession (Chou, 2015) (Figs. 24–26). Furthermore, in Fig. 26, the application asks the users if they wish to install the thermostat using a tutorial (i.e., using the core drive 2 Development and Accomplishment (Chou, 2015)) or to call an expert to help them perform the installation. Even if the users request the option of a professional, later, when they gain confidence, if they decide to install another CT, they will have another chance to install it on their own in the menu option of Add/

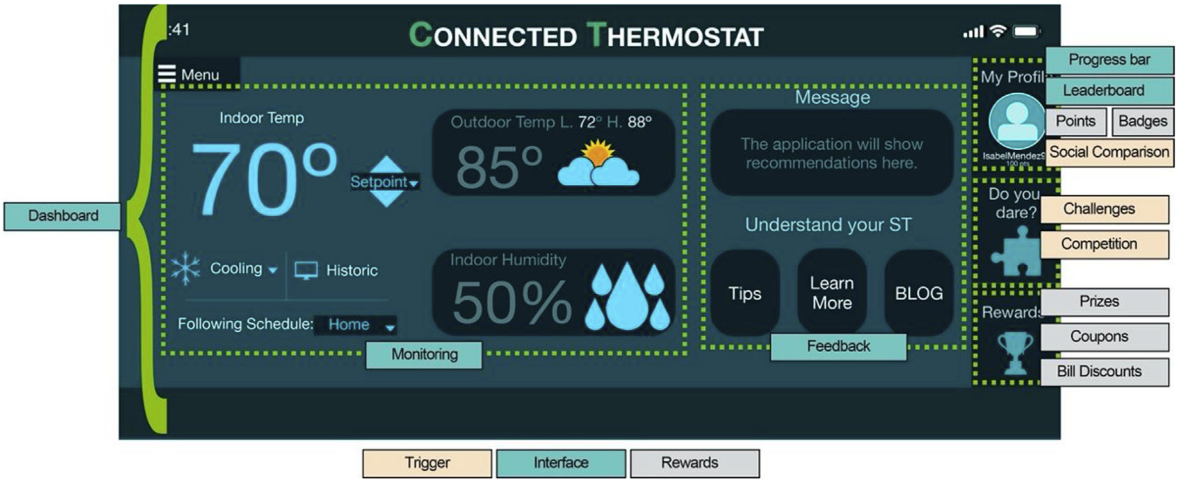


Fig. 32. Dashboard elements.

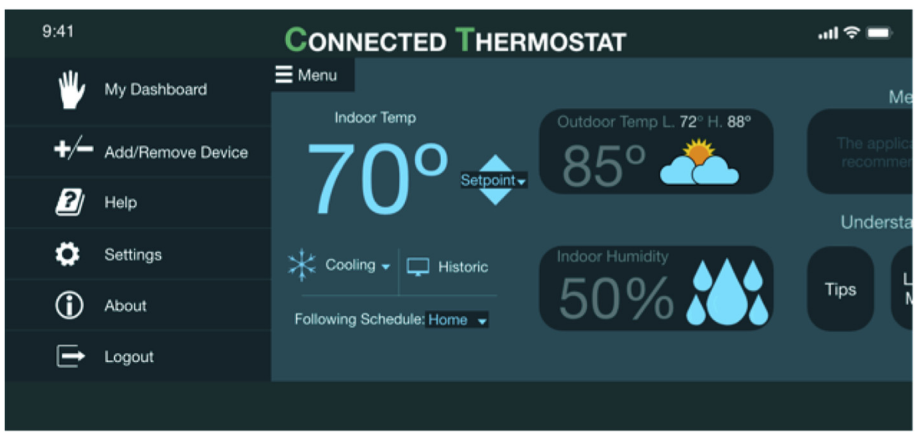


Fig. 33. Menu option.

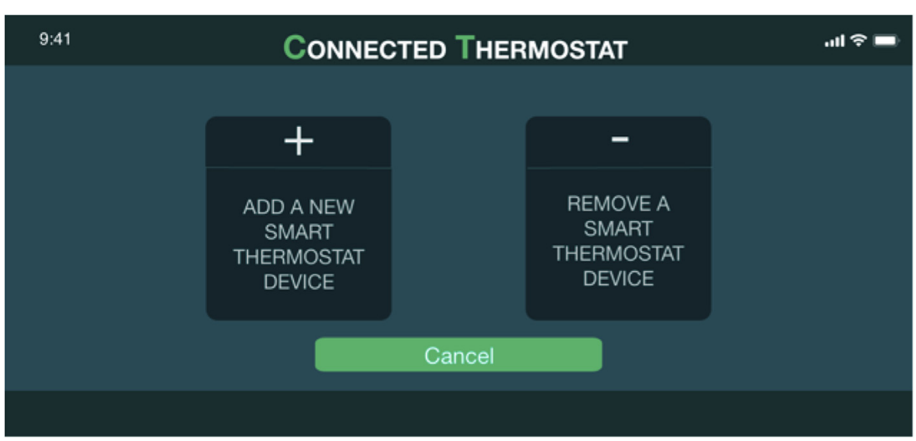


Fig. 34. Add/remove device.

Remove Device (Figs. 34 and 35). From Figs. 27–31, the application uses core drive four by instructing the users to select one of the three available templates in accordance with the type of user previously defined in Table 9. To develop this idea is supposed that the user selects the first template (Figs. 28 and 31); thus, hereinafter, the menus displayed are designed for this type of user.

Appearing next is the description of the options with the core drive, which are related to the descriptions in Fig. 5. The dashboard is the home page of the application; thus, because the main goal is to engage the user, the most representative elements are illustrated in Fig. 32. On the right side of the image, the menu bar considers options related to the system, (Figs. 33–39); meanwhile, on the

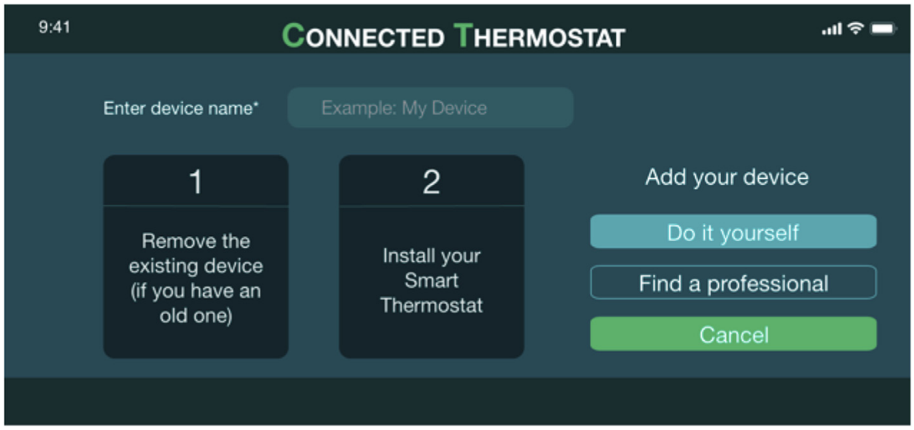


Fig. 35. Add/remove device (2).

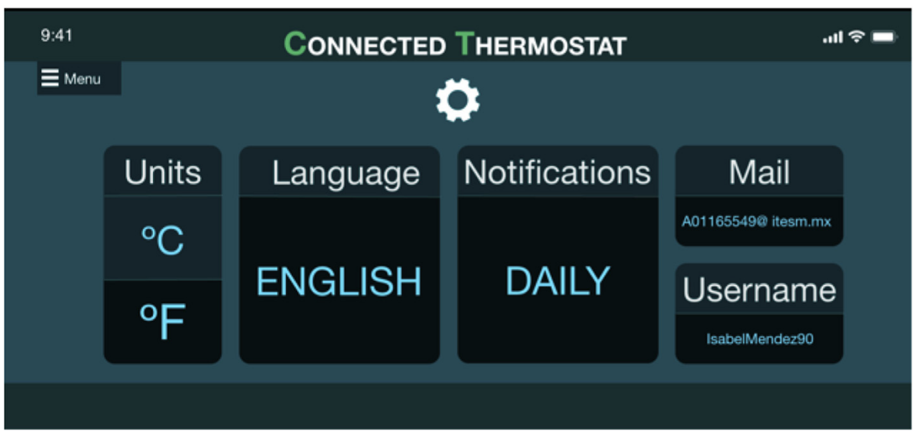


Fig. 36. Settings in °F.

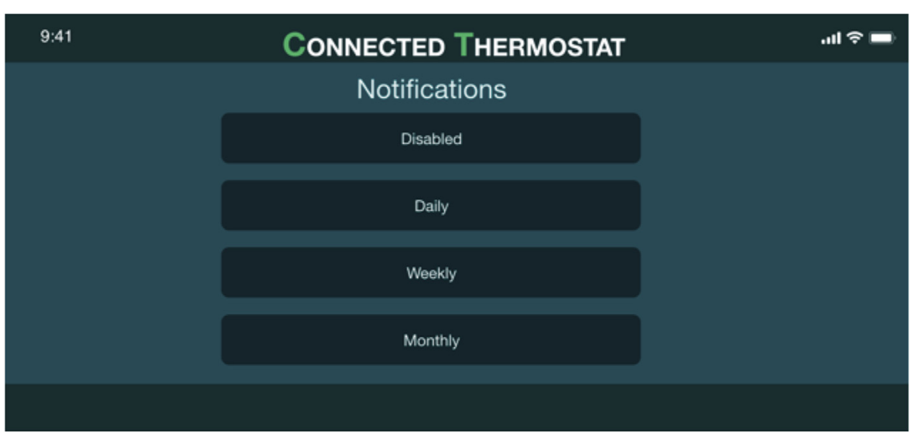


Fig. 37. Notification settings.

right side, three-button bars are displayed: (1) inside the "My Profile" button (Fig. 40), the users are able to change their profile images with a photo or avatar; to monitor their progress bar punctuation, rank in the leaderboards, badges they have won; and, if desired, post on Facebook. These actions belong to core drives 1, 2, 4, 5, and 8 (Chou, 2015); (2) In the button "Do you dare?" (Fig. 41) The challenges assign the users daily, weekly, and monthly goals to push them to save energy; for instance, Table 14 displays an example of those energy challenges. In order to prevent possible monotony due to repeating similar goals, the challenges are designed to change when they are achieved. Thus, if the user performs a month of kWh reduction, the application will ask the user to achieve six periods of monthly kWh reduction to continue the engagement. If the achievement is not completed and/or the user is not interested, the application is designed to receive that feedback and change the type of challenges.

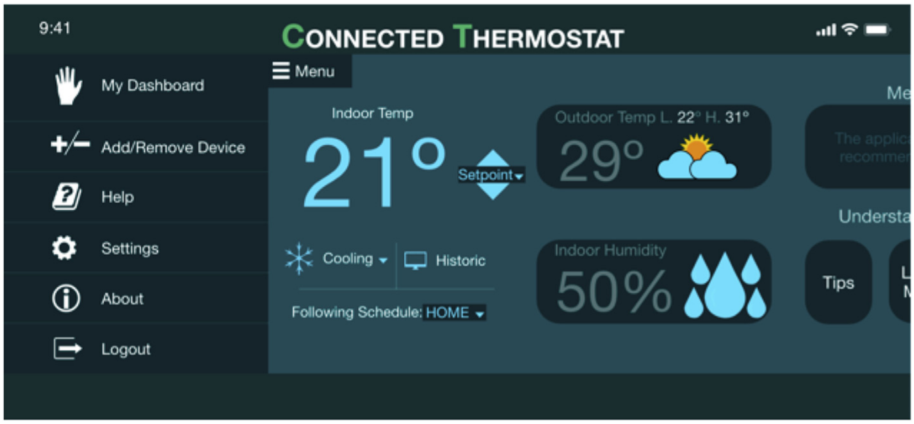


Fig. 38. Dashboard in °C.

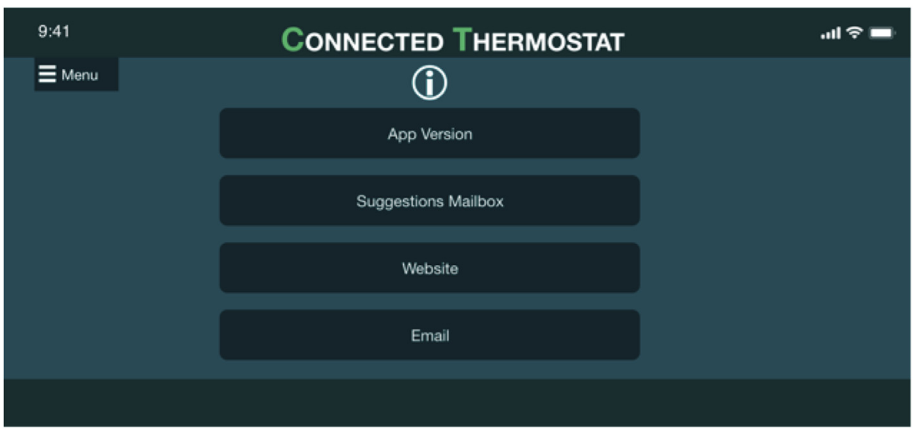


Fig. 39. About Menu option.

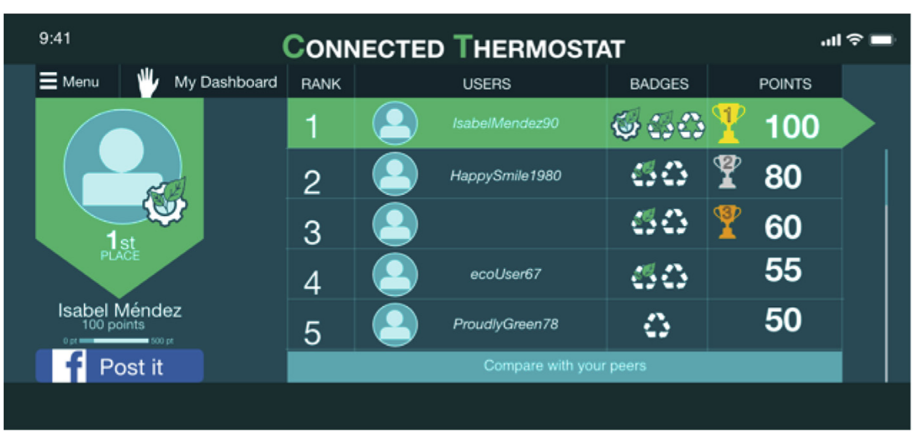


Fig. 40. Profile.

In the competition section, users can compete with other users to determine who is the thriftiest of all. The 6th and 8th core drive (Chou, 2015) belong to this general button; (3) The Rewards button (Fig. 42) contains the prizes, coupons, and bill discounts elements; these elements are related to core drives 4, 5, 6, and 7 (Chou, 2015). On the central layout, the feedback rectangle (right side) is composed of three options: (1) inside the Tips button (Fig. 43), the HVAC and Dwelling sections provide advice on how to improve the use of air conditioning and learn tips to improve energy usage for the housing; core drive 3 and 4 belong here (Chou, 2015); (2) By using SG techniques such as virtual scenarios, the Learn More button (Fig. 44) has the purpose of making users understand how the dashboard works; thus, the use of the CT can be improved; (3) The BLOG button (Fig. 36) redirects users to a webpage where they can post every doubt, complaint, or comment that they have regarding the application; this section is composed of core drives 3

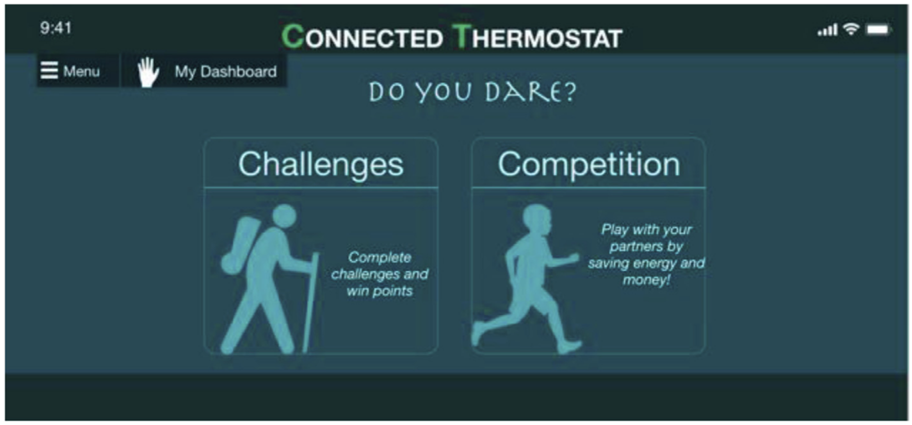


Fig. 41. Do you dare?.

Table 14
Daily, weekly, and monthly challenges examples.

Daily	Weekly	Monthly
Save 100 kWh per day: Turn off the HVAC when you are not at home. Reward: 10 points	Save 700 kWh per week by achieving a daily challenge. Reward: 70 points	Save 2800 kWh to 3100 kWh per month by achieving the weekly challenge. Reward: 350 points
If your HVAC is on, check if the windows are closed. Reward: Access to the energy quiz.	Complete the energy quiz. Reward: two badges.	Compete with your friends in the local tournament. Reward: win the pass to the regional tournament.
		Save 10% of your electric bill. Reward: a coupon to exchange it for real products in the market.
	Play in the Dashboard Serious Game section and master its operation. Reward: Random	Master the monthly Dashboard operation to understand the Connected Thermostat operation. Reward: Rand, simulated discounts in the electric bill, and coupons.
		Achieve six periods of kWh reduction. Reward: 10,000 points and bill discounts

Fig. 42. Rewards.

and 4. Finally, on the Monitoring block (left side), the elements displayed are the Setpoint degree temperature (Fig. 45), HVAC mode (cool, fan, heat, auto; see Fig. 46), schedule (home, vacations, or custom; see Fig. 47), and the Historic button. In the Historic button, on the left side, four blocks are displayed, where the users are able to see how much energy and money they are using and saving. The central part presents a graphic in a day, week, month, and year mode, so that the users can monitor their energy usage (Figs. 48–52). For instance, for the day option, Fig. 49 displays the graph at 10.00 h. To demonstrate to the users how much they use at that specific hour. Fig. 53 shows an example of a reduction in energy usage on a common day. The image is just for illustrative purposes because a real scenario needs to be done.

7. Discussion

In this paper, based on the literature review, it is proposed a framework composed of three phases: the knowledge base phase, the fuzzy logic phase, and the evaluation phase. For the development of this framework, in the first phase, it is used the analysis of the gamification and SG achievement diagram to develop a solution according to a single behavior problem and single usability problem. To this end, it is used the Energy Master achievement to develop a decision tree that leads to the Membership Functions of

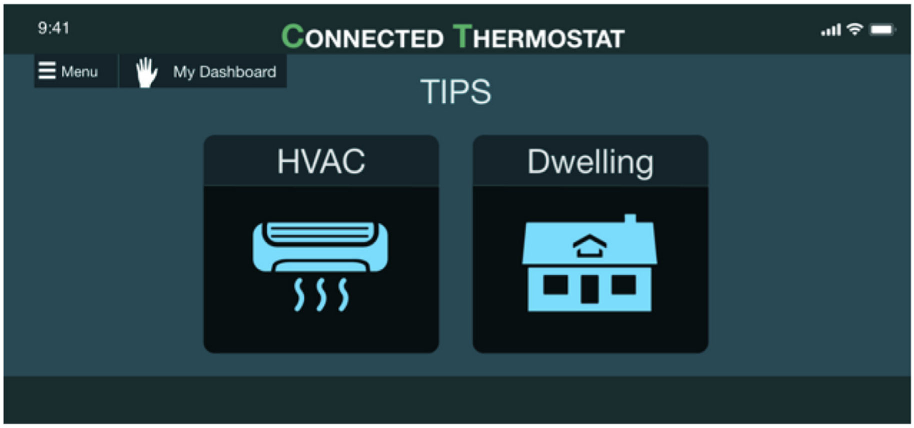


Fig. 43. Tips.

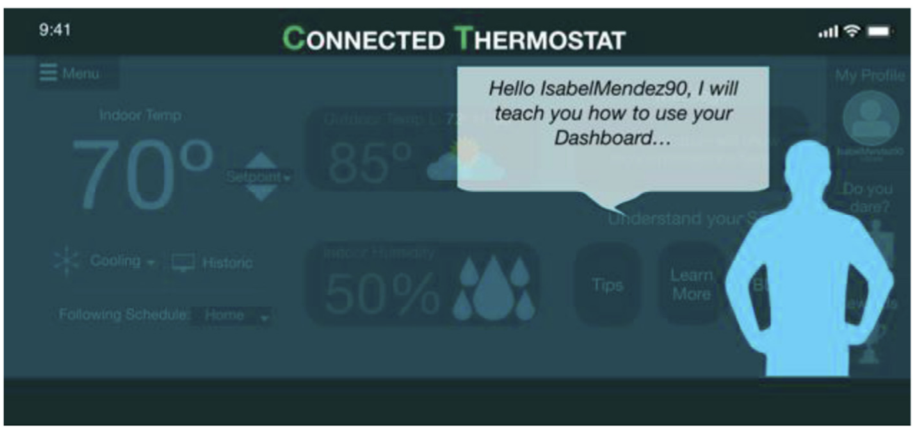


Fig. 44. Learn more.

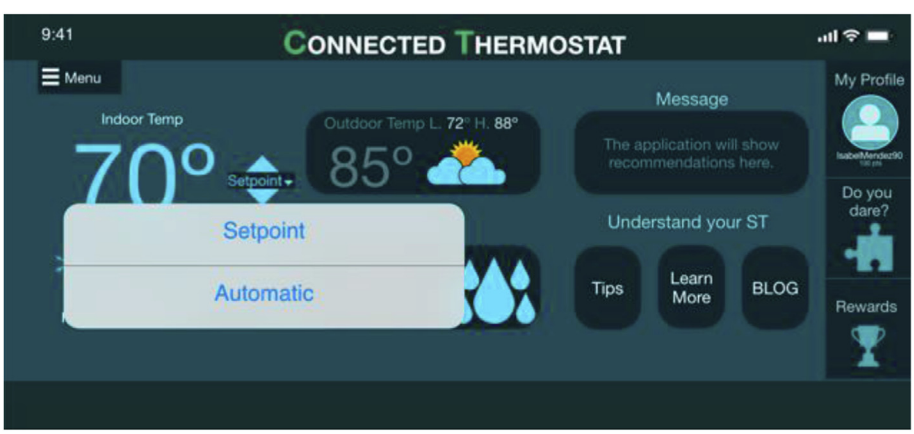


Fig. 45. Setpoint.

the fuzzy logic phase. The fuzzy logic uses the knowledge base to determine how the input and output values are related by proposing a tailored HMI for every customer. Finally, in the evaluation phase, the interaction between the CT and the interface, known as natural and non-natural behavior communication proposed in (Ponce et al., 2019) for S^3 products, tests the levels of engagement, energy usage, change of attitude, and knowledge in terms of how much energy savings the user achieves. Based on the tested values obtained from the system, it is reviewed which gamification and SG elements require reinforcement, to change them.

This framework can be improved by automating the process of the knowledge base with an artificial neural network. This network can gather information to be fed back to the knowledge base to identify which gamification and SG elements are required by the customer. Thereby, the knowledge base can be strengthened to propose more than one solution to usability and behavior

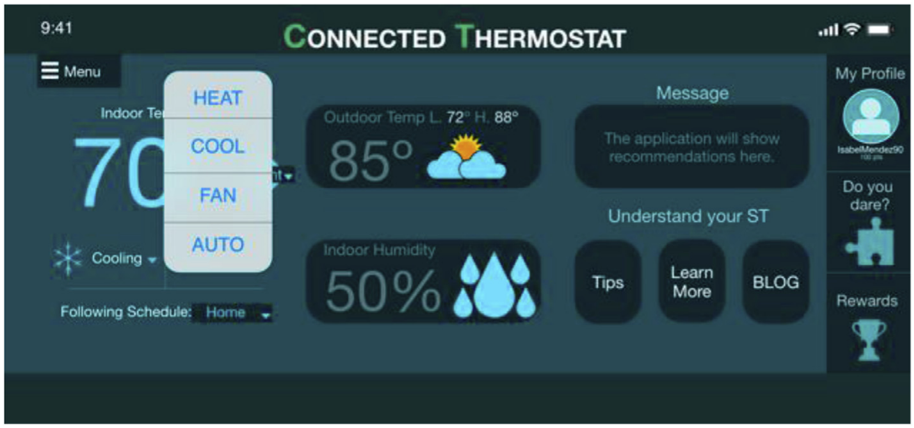


Fig. 46. HVAC mode.

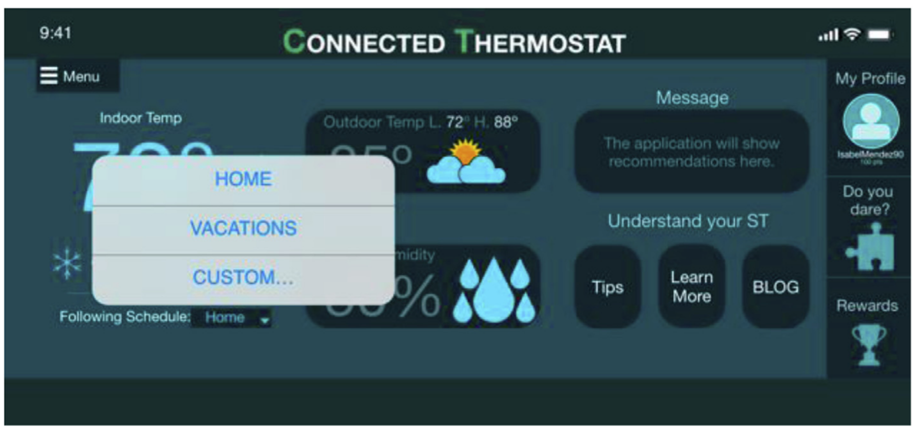


Fig. 47. Schedule options.

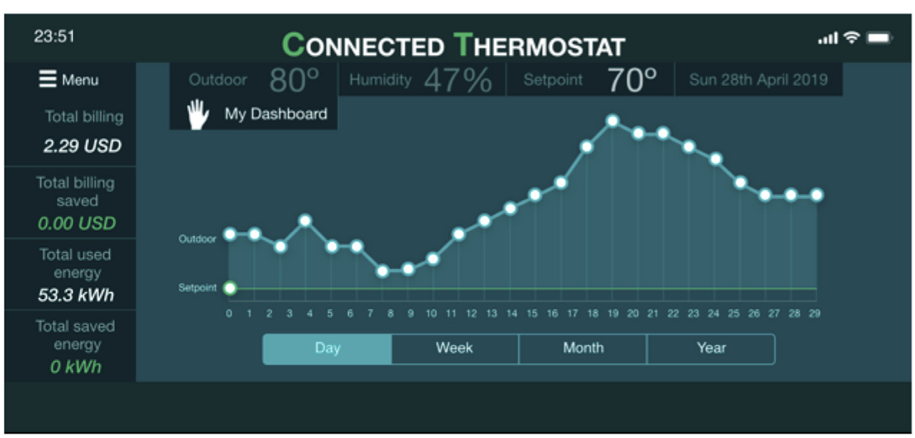


Fig. 48. Historical graph – Day.

problems. This framework does not consider its interaction with other smart devices; however, this will be feasible with further research that allows the knowledge base to know the usability and behavior problems of the smart devices. With the proposed interface, the behavior problems presented in (Ponce et al., 2018b, 2017) can be solved by providing users with gamification and SG elements that are designed to teach them to take advantage of their product. In addition, to solve the physical usability problems, the thermostat designer can propose a design based on the suggestions of the knowledge base. Thus, once the knowledge base and fuzzy logic are completed, the usability problems can be solved as well, and the designer can propose a design for the interface and its variants.

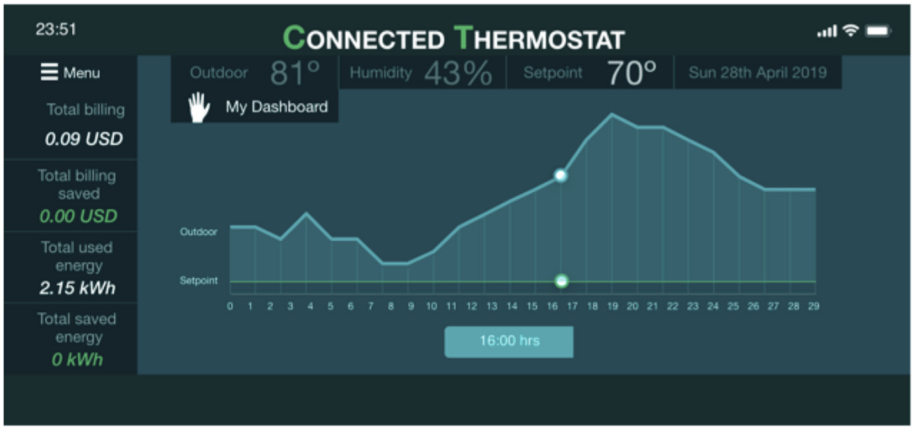


Fig. 49. 10:00 h. Example day.

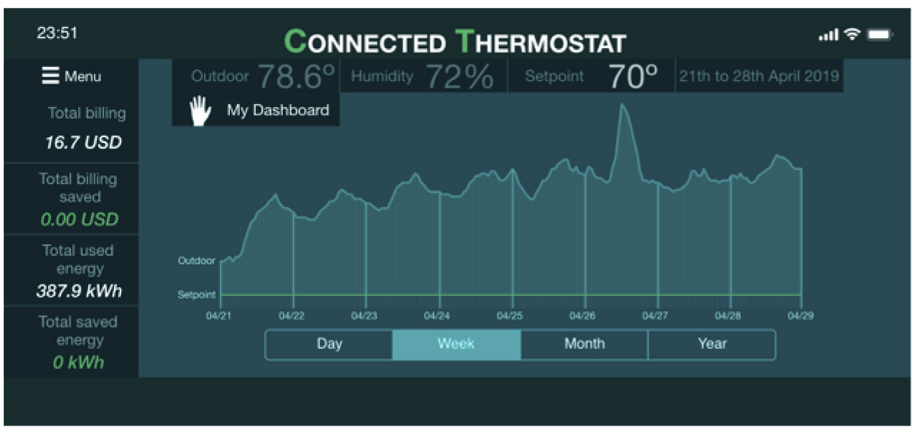


Fig. 50. Historical chart – Week.

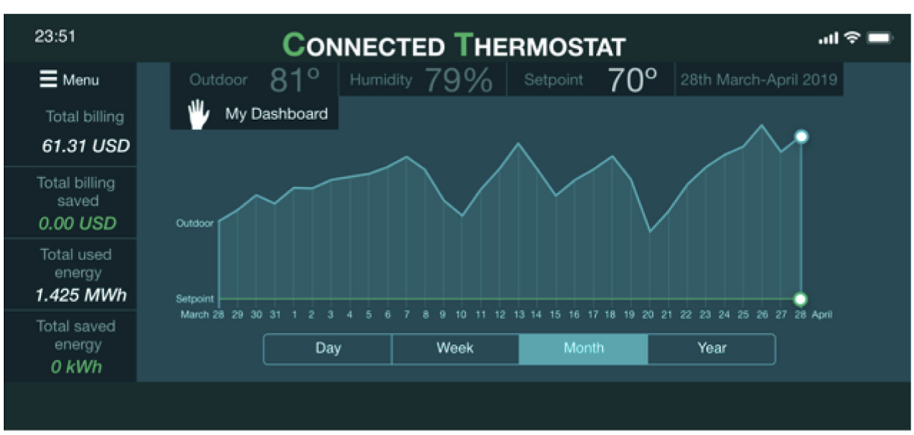


Fig. 51. Historical chart – Month.

8. Conclusion and directions for future work

State of the art shows that there does not yet exist a dynamic interface that uses gamification and SGs using the fuzzy logic analysis to save energy using smart devices by considering behavior and usability problems when a connected product is deployed, such as a CT. However, the combination of those techniques allows designers to achieve a dynamic interface that engages end-users to adopt cleaner production technologies. Moreover, the dynamic interface improves the sustainability of connected devices at smart homes or buildings. Thus, the main goal of this paper is to propose a comprehensive framework that enables the customer to save energy in the CT by teaching, engaging, and motivating end-consumers through this novel dynamic interface. Besides, the proposed framework has only three friendly phases for designing a smart, sensing, and sustainable product, so it contributes to

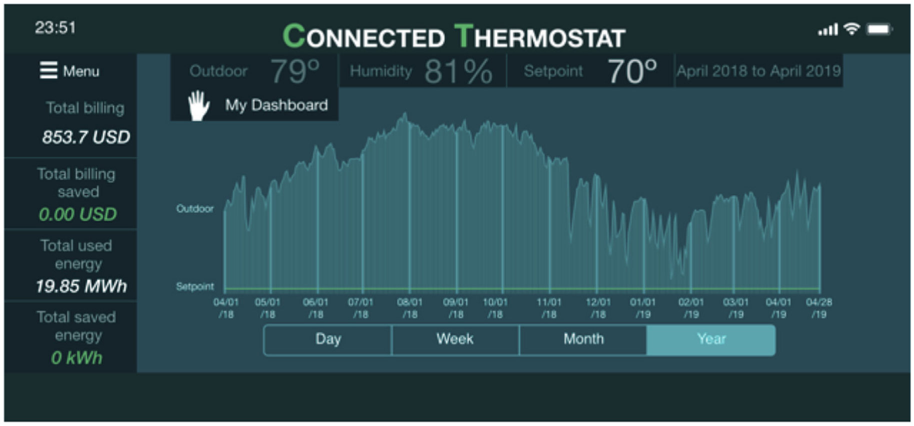


Fig. 52. Historical chart – Year.

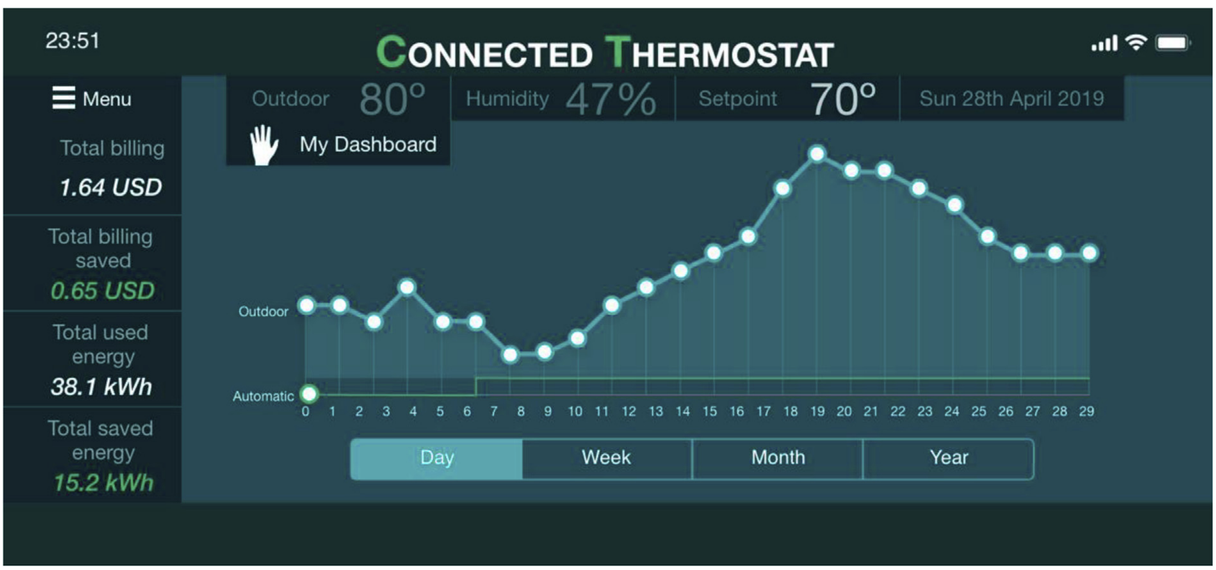


Fig. 53. Example of electrical energy reduction.

improving the performance of connected devices at smart homes when those phases are implemented on a clenear product design. Besides, this framework is created to bridge the gap between users' expectations and their usability and behavior problems about achieving fundamental goals, such as saving energy in the HVAC system through the correct operation of thermostats.

The ultimate goal of this proposal is to shape the users' behavior by proposing a customized interface and therefore achieve energy consumption reduction in the household, so they can become energy aware even if they are not interested in it. This proposal covers all types of users (non-typical and typical users); however, to validate this proposal meticulously in the real end-user market, it is required to (1) develop more questionnaires that confirm the classification of each user by its personality traits for gameful experiences; (2) evaluate and improve the proposed application according to the external evaluation of end-users under different real scenarios. Not only does run the proposed application into controlled environments such as university laboratories but also it has to be evaluated in several countries in which cultural factors could be a factor to consider in the framework; (3) update the application as required according to an acceptable sample of end-users that represents more than a few end-users' behaviors.

Moreover, the implications of this work on the development and adoption of cleaner production technologies are through the promotion of eco-efficient products at the household that helps the customer achieve sustainable attitudes and lifestyle allowing a reduction in pollution and carbon footprint; the framework is also designed to allow an energy auditing through the electric bills reviews and provide a sustainability analysis by the charts and the on-line monitoring system available at the dashboard. Hence, automatic self-evaluation and feedback regarding energy consumption can be provided, so the end-user could change his energy consumption behavior in a short period of time. Thus, it could be possible to construct sustainable energy communities based on this proposal.

Declaration of competing interest

No conflicts of interest.

CRediT authorship contribution statement

Pedro Ponce: Conceptualization, Methodology, Investigation, Writing - original draft, Formal analysis, Validation, Supervision.

Alan Meier: Conceptualization, Methodology, Writing - original draft, Formal analysis, Investigation. **Juana Isabel Méndez:** Conceptualization, Methodology, Writing - original draft, Formal analysis, Data curation, Visualization. **Therese Peffer:** Conceptualization, Methodology, Investigation. **Arturo Molina:** Conceptualization, Methodology, Investigation. **Omar Mata:** Software, Formal analysis, Validation.

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