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Conception de systèmes interactifs persuasifs : application au domaine de l'énergie

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Résumé

Cette thèse aborde la conception des **systèmes interactifs persuasifs (SIP)**. Ces systèmes sont conçus pour induire et accompagner un changement de comportement au travers de l'interaction homme-machine, sans coercition et avec une utilisation volontaire. Ces systèmes s'inscrivent dans la mouvance des technologies persuasives et leur conception repose sur des principes de persuasion et d'autres approches issues de la psychologie.

Dans cette thèse, nous nous concentrons sur le domaine de l'énergie et le changement de comportement pour adopter des modes de consommation plus vertueux. En effet, un des grand défis sociétaux en lien avec la question du changement climatique, la consommation énergétique domestique représente actuellement environ un tiers de l'énergie totale mondiale consommée et ne cesse d'augmenter. Outre l'amélioration technique des appareils, il est incontournable de changer nos habitudes. Cependant, changer un processus long et difficile.

Le défi est donc de concevoir une interaction homme-machine prévue pour accompagner le processus de changement et, par conséquent, pour une interaction long-terme. Pour cela, à partir d'une étude de classifications, espaces de conception et framework des systèmes persuasifs, nous proposons le **framework UP+**, notre contribution conceptuelle. Ce framework propose un cadre pour la conception des systèmes interactifs persuasifs structuré selon trois dimensions : deux relatives au processus de changement de comportement au niveau micro (cause-effet-causalité) et macro (long terme)) ; l'autre relative à la dimension psychologique de la motivation. Nous identifions quatre classes de fonctions de persuasion (comprendre, décider, agir et protéger) déclinées en douze sous-classes de fonctions de persuasion.

En nous appuyant sur UP+, l'état de l'art des systèmes persuasifs pour l'énergie montre qu'ils se concentrent principalement que sur quelques fonctions de persuasion seulement (ex. auto-surveillance). Dans cette thèse, nous nous concentrons tout particulièrement sur l'aspect décision et causalité du comportement. Une autre contribution est **l'Interface utilisateur Mondrian**, une preuve-de-concept proposant un cadre d'interface qui traite de l'implication long-terme des utilisateurs. Elle doit répondre à plusieurs objectifs : capter l'attention de l'utilisateur ; offrir plusieurs niveaux d'interaction selon le contexte s'usage ; permettre l'intégration de plusieurs briques interactionnelles support de la persuasion. En particulier, nous proposons deux briques, **Sliders4DM** et **Plan4Actions**. **Sliders4DM** est un nouveau widget d'aide à la décision conçu pour permettre à des utilisateurs novices d'explorer et trouver un compromis satisfaisant entre plusieurs critères potentiellement incompatibles. Il s'appuie sur une approche what-if. Nous avons évalué Sliders4DM par une expérimentation qualitative (16 participants) et une comparative et quantitative (177 participants). **Plan4Actions** est un nouveau concept d'interface d'aide à la décision et la compréhension des effets d'un comportement à l'aide d'explications : il permet à des utilisateurs de planifier une séquence d'actions pour à la fois réduire leur consommation énergétique tout en maintenant un niveau de confort satisfaisant. Une expérimentation qualitative menée avec 13 participants montre son utilisabilité et son utilité. Nous mettons également en évidence les limites de ce travail et la nécessité de mener une évaluation à long terme dans un environnement domestique réel pour valider entièrement leur efficacité persuasive.

Abstract

This thesis is about **persuasive interactive systems**, a subclass of interactive systems aiming at supporting sustainable behaviors. Persuasive technology is a very recent and emerging topic, which relies on persuasion to support human behavior change voluntarily without coercion and deception.

In this research, we focus the design of persuasive system for promoting behaviors change with energy as application domain. In the interest of preserving the planet, reducing domestic energy use is necessary for fighting against global warming and climate change issues. The approach to save energy by introducing more efficient appliances only tackles partially the current issues. An urgent need is to motivate sustainable behaviors in energy usage. However, changing people behaviors involves a complex and difficult process.

The challenge is to design interactive systems that take into account this process dimension and that keep users involved over time in the process of behavior change. Consequently, based on a review of classifications, design spaces and frameworks targeting the design of persuasive systems, we propose the **UP+ framework**, our first and conceptual contribution. It considers three dimensions: two related to the process aspect of behavior change, at two levels: micro (cause-effect-causality) and macro (long term)); one related to the psychological aspects of motivation.

Based on the UP+ framework, we conduct a state of the art of existing persuasive systems for energy. It reveals that most of these systems covers a few persuasive functions only (e.g., self-surveillance or eco-feedback). In this work, we particularly focus on <u>decision</u> and <u>causality</u> of behavior. A second contribution is the **Mondrian User Interface**, a proof-of-concept of UI designed to sustain daily use and to keep inhabitants motivated in the long run. We consider thrre goals: to catch user's attention; to offer multiple levels of user interaction depending on the context of use; to allow the integration of interactional bricks supporting persuasion. Particularly, we propose two bricks, **Sliders4DM** and **Plan4Actions**.

In order to assist inhabitants in preparing a change (decision), **Sliders4DM** is a novel widget allowing non-specialists to find an appropriate trade-off between (possibly) conflicting criteria in the home via *what-if* approach. Sliders4DM is evaluated with two experiments: a qualitative one (16 participants) and a quantitative comparative one (177 participants). **Plan4Actions** is a novel concept of user interface for planning daily actions. The concept is empowered by the co-decision between inhabitants and the home management system. It provides inhabitants with flexibility in planning their daily actions in order to satisfy their objectives in terms of comfort and sobriety. A twofold evaluation presented a favorable assessment from 13 participants about Plan4actions' comprehension, its usability and potential utility in the domestic context.

We also discuss the limitations related to persuasive interaction covered by current works and the needs for a long-term evaluation to mesure the behavior changes. The thesis opens new perspectives for extending current research of PIS for energy. To conclude, we define our future works, which involves short-term improvements for current prototype and its deployment in real domestic context.

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Introduction

This thesis is about **persuasive interactive systems**, a subclass of interactive systems aiming at supporting sustainable behaviors. Persuasive technologies are a very recent and emerging topic. Relying on persuasion means and other psychological approaches, they are designed to support human behavior change voluntarily without coercion and deception, to assist people in the process of change [53]. They constitute novel tools to address several societal challenges. For instance, they have shown their practical application in many critical areas such as health care, education, and potentially environment preservation.

In this research, we focus on their design from the perspective of Human-Computer Interaction (HCI). In particular, as behavior change is a long-term process, we study how user interaction could be designed to integrate this aspect in order to keep users involved over time in such process.

A societal challenge: residential energy consumption concerns

As an application domain, we specifically target energy usage in a residential context. Indeed, Residential use is currently considered as the major risk factor that results in the massive increase of energy demands. Domestic energy consumption represents approximately one-third of the worldwide total energy and keeps growing with an estimation of 40% by 2040. Energy have been used in every facet of people lives, the high demand for energy continues to growth and outperform our supply capacity. This unsustainable augmentation in energy demand laid tremendous impacts on our environment and contributes to the urgent societal challenge of global warming. The growing concerns make energy household management to become a critical topic and attracts many scientists of different domains. Reducing household energy consumption is, therefore, an extremely important tasks and requires a multi-disciplinary approach to be conducted.

How people consume domestic energy is defined by their ways of being. Pierce has indicated that energy consumption constitutes our "*normal*" ways of being [137]. Holmes considers the relationship between energy resources and people behaviors as "*inextricably"* [75]. Put it another way, people 'normal' ways of living have been defined and manipulated by the energy usage contexts which includes factors such as domestic appliances, people behaviors, habits and routines etc. Therefore, in order to effectively induce positive changes to current situation, one must interfere with these variables which together create the context. Thus, the solution would be either making change to the appliances or the current way people use their appliances.

In the residential context, we observe a potentially ongoing focus on innovating energy-efficient homes and appliances. Theoretically, a more-environmental-friendly appliance can reduce energy usage while still maintaining the occupants needs and desires. However, despite the significant improvement of energy efficient equipment, the approach to save energy by introducing more efficient appliances only tackles partially the current issue. In this line of works, many studies had confirmed that people behaviors are the direct factors that leads to the high demand of energy [84, 163]. Authors in [31, 137] indicate that not so many people aware of their monthly energy consumption. The impacts on environment are, no doubt, even harder to be acknowledged. This lack of awareness and knowledge often causes the misunderstanding or misinterpretation information relating to household consumption. For instance, people might believe that the excessive consumption is caused by the devices when it might be due to a lack of insulation. More importantly, it would result in the people *willingness* to change current behaviors.

Towards this end, an appropriate solution could be targeting the primary factor causing these issues: *people* and *their energy usage behaviors*. Understanding how and why people use energy in their residential context would provide more insightful view about the current situation, so that solutions could be developed accordingly.

A scientific challenge: designing persuasive interactive systems for long-term use

Sustainability in energy usage is a promising objective. The necessary to move towards a more sustainable lifestyle has been acknowledged and suggested by many. In order to reduce the environment impact of residential sector, an urgent need is to find ways to motivate sustainable energy behaviors. For that purpose, a variety of researchers have explored different approach to promote sustainable ways of consuming energy in household and many other contexts. However, designing interventions towards sustainability in energy represents both challenges and opportunities. One of the challenges is to motivate people to change their behaviors that are often resistant to change. Behaviors change is a complex and difficult process. Shipworth refers this process as "*a psycho-logically, socially, and culturally complex problem*" [161]. Prochaska's transtheoretical model construes change as a long procedure with six stages [144]. In addition, durability is also an important aspect when designing for sustainable behaviors. For instance, even when the targeted change is achieved, the long-term effect of the desired behaviors is being questioned by many. Overall, this societal concern has begun to capture the attention of psychologists, sociologists and especially, researchers in computer science disciplinary thank to advance in modern home appliances.

Among many fields of computer science research, Human Computer Interaction (HCI), a multidisciplinary research area empowers by interaction involving both human and computer side, have thus strong interests in investigating this problem. In this thesis, we focus on the design of persuasive interactive system to face the scientific challenge in promoting sustainable behaviors in energy.

Scientific approach and structure of the manuscript

This thesis is divided into two parts and six chapters according to our scientific approach.

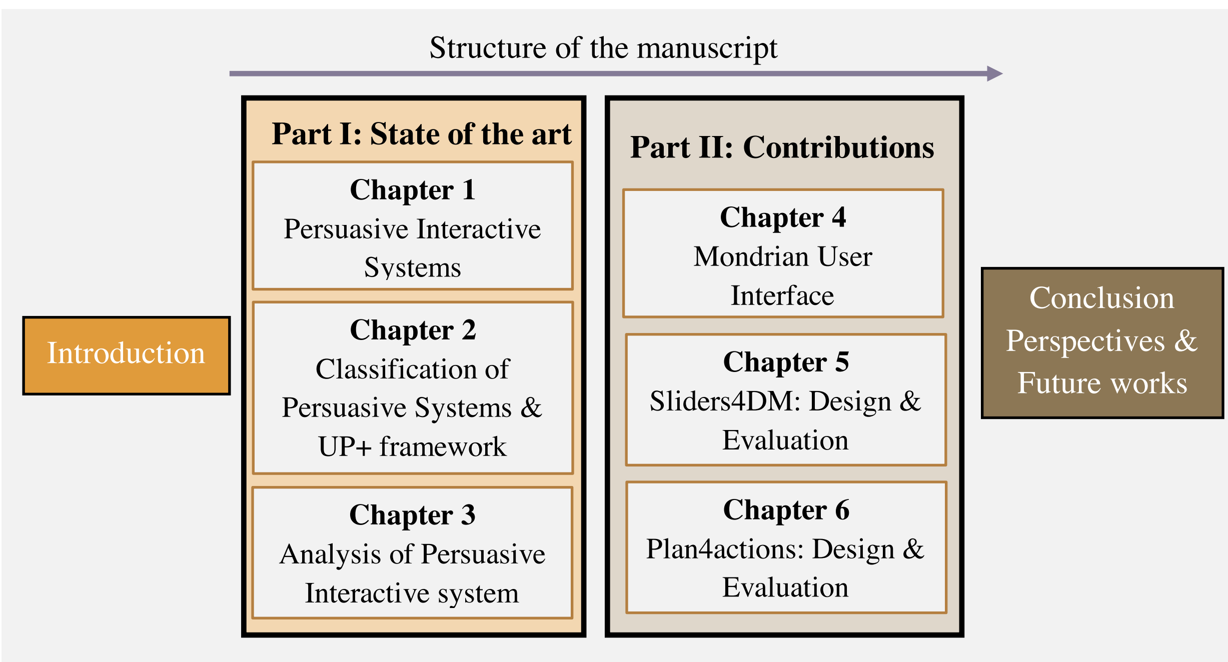


Figure 1. Structure of the manuscript

In the **first part** of this thesis, we first cover broadly the essence of persuasion and persuasive technologies (**chapter I**). Through the exploration of theories, methods, design principles and frameworks related to persuasion and behaviour change, the ultimate goal is to put into perspective the implications on designing user interaction that relies on persuasion to support behaviour change.

Despite a notable number of theories, techniques and methods have been introduced, the application of these knowledges in practice is still in its infancy. In **chapter II** of this thesis, we review surveys, classifications, design spaces and frameworks targeting the design of practical solution from the engineering point of view. The analysis of current studies creates conditions for the presentation of our framework, **UP+**, our first and conceptual contribution, a tool for exploring the design of persuasive interactive system: a conceptual tool for the designer, also used as an analysis grid to review existing persuasive interactive systems.

Chapter III provides an overview of the current state of the art on persuasive systems designed especially for dealing with energy usage concerns. Moreover, we put into question the design for sustainability. In all, the analysis offers guidelines and design principles for persuasive systems towards sustainability, and serves as foundation for to foster design solutions to drive persuasion and behaviour change.

In the **second part**, we first present our second contribution, the **Mondrian UI**, a proof-of-concept of user interface conceived to keep users involved in a long-term behavior change process (**chapter IV**). In the context of the ANR INVOLVED project, it constitutes the user interface of an e-coach, a smart energy management system integrating an explanation engine. The objective is twofold: first, to provide seamless information accessibility to all the members of the household; and second, to adapt to housing context by moving the focus to the periphery. In a word, it adopts the Mondrian painting style and contains three levels of user interaction for different use-contexts (i.e., glanceable, short-analysis, in-depth analysis).

In **chapter V**, we present **Sliders4DM**, a novel widget designed for multi-criteria decision making by non-specialists, our third contribution. It allows occupants to interactively explore a Pareto front through a “what-if” process. In our context, it entails tradeoff between *cost*, *thermal comfort* and *air quality*. In order to better accompany inhabitants in a behavior change process, we are concerned with aiding occupants, or non-expert users, to perform decision-making tasks in household context. We present two experimental evaluations of Slider4DM as well.

Our last contribution is **Plan4Actions** an interactive user interface for supporting decision-making and actions (**chapter VI**). It is an interactive action plan consisting of recommended actions generated by the e-coach. This prototype takes further our previous widget, Sliders4DM. It generates contextual actionable plans along with explanations from the user preferences specified with the Sliders4DM widget. In the same manner, Plan4Actions features the exploration of solution spaces via *what-if* method. It recommends appropriate actions to meet user desires but does not take them on behalf of the user. Using a *doing-together* approach, Plan4Actions aims at balancing user control and system autonomy in domestic context.

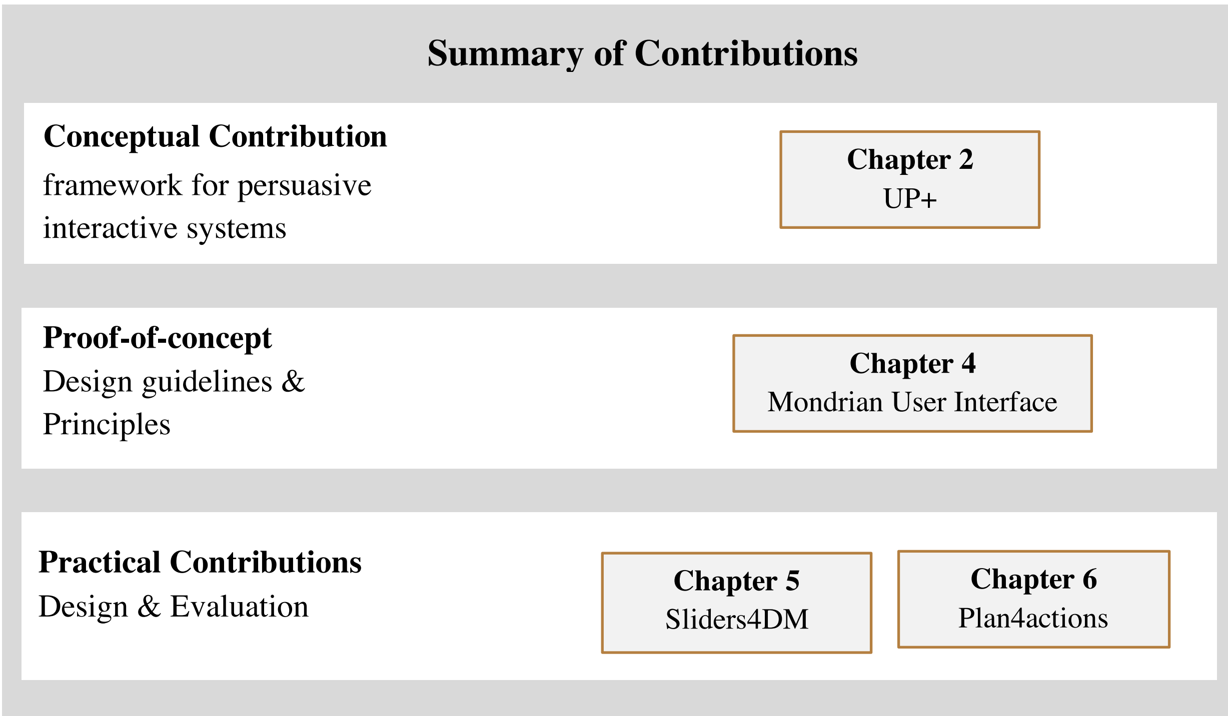


Figure 2. Summary of contributions

To conclude, the last chapter summarizes our analysis of current persuasive interactive systems, our practical design solutions and possible improvements. This section defines our directions for future works related to the installation and long-term evaluation of an e-coach for the home.

Part I. State of the art

1. Persuasive Interactive Systems

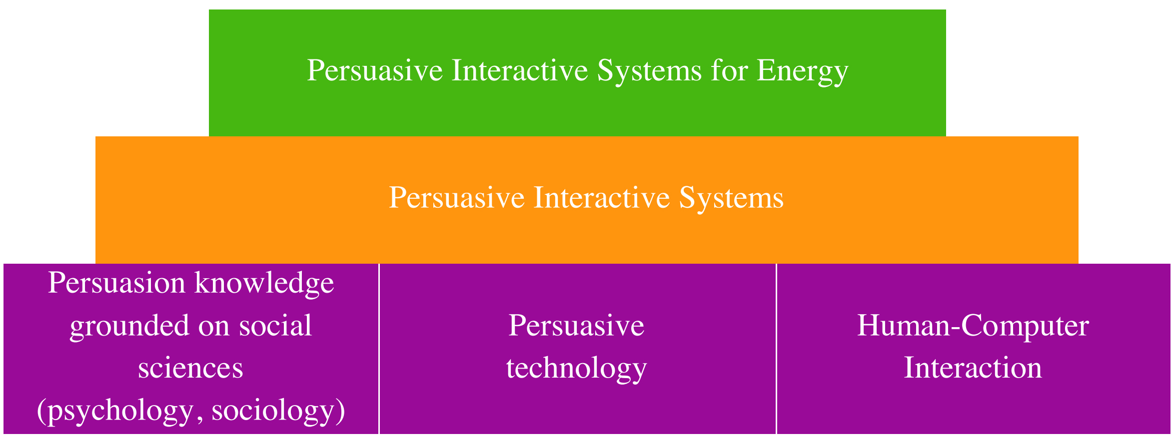


Figure 1.1. Grounds of persuasive interactive systems for energy

Designing persuasive interactive systems is a multidisciplinary activity that borrows (Figure 1.1) knowledge and methods from social sciences (i.e., psychology, sociology), persuasive technology, and, of course, human-computer interaction. This chapter is intended to capture and broadly cover the essence of persuasion and persuasive technologies. The ultimate goal is to put into perspective the implications on designing user interaction that relies on persuasion to support behaviour change.

1.1. Psychology of persuasion and influence

1.1.1. Persuasion, a mandatory first step

Persuasion is the very first step towards a behaviour change. According to Fointiat & Barbier [12], behaviour change is a process that commences thanks to **persuasion** techniques. According to the Oxford Dictionary, persuasion refers to "*the action or process of persuading someone or of being persuaded to do or believe something*". Persuasive is described as an adjective which is "*good at persuading someone to do or believe something through reasoning or the use of temptation*". Consequently, as underlined by Fointiat & Barbier, there is a gap between being persuaded and a behaviour change. Indeed, persuasion is used to change our **attitude** (or beliefs) towards a **behaviour change** (i.e., to positively accept the change). The next step is the behaviour itself and **influence** techniques will be used to help a person to start a change. The final step is to transform a desired change into a **habit** or a **routine**. Likewise, we need to stop undesired routine to be replaced with desired ones.

1.1.2. Induced compliance without pressure

Induced compliance without pressure is a theory of social psychology developed by Joule & Beauvois [23]. Persuading a person with arguments to achieve certain behaviour is not mandatory. Indeed, it relies on influence techniques to make a person acting deliberately ("*compliance without pressure*"). Such an act must have the following characteristics:

- **Cheap**, if it is the very first act (i.e., foot-in-the-door technique);
- **Public**: the commitment must be made in front of other persons (i.e., social network);
- **Explicit**: it should refer to a clear and intelligible challenge without misunderstanding;
- **Irrevocable**: no way out (i.e., no time limit)
- **With a cost**: it should require a reasonable effort. If the effort to expensive, it will demotivate;
- **Predictive**: the consequence must be observable to measure a significant progress
- **Valuable**: it must be worthy for external reasons (i.e., financial reward) or internal reasons (i.e., social recognition). Internal reasons are much more powerful than external reasons.

1.1.3. Social Influence

Social influence is an important aspect in persuasion. Research in this domain has been widely explored in Persuasive technologies. Among many principles and methods, which employs social influence as means to empower the behavior change, the 6 principles of Cialdini [24] received the most attention not only in the research field but also in real life practices.

- **Reciprocity**: People feels obliged to give back to others (i.e., a gift, a behaviour) each time they receive something first.
- **Consistency**: A person seeks for consistency when s/he takes a decision in public and act accordingly.
- **Consensus**: In public, our behaviour is often influenced by the behaviour of others in situation of uncertainty. We often think that if they act in a certain way, they should know why.
- **Liking**: A person will easily comply with a request if s/he feel like the person who is requesting an act.
- **Authority**: A person will easily comply with a request if s/he recognizes the expertise and/or knowledge of the person who is requesting an act.
- **Scarcity**: scarcity increases the perceived value of products and opportunities; a product has greater value when they are less available. A person tends to gather one of theses to possess it.

These principles are widely used in the design of technological persuasion (i.e., Fogg's principles and Oinas-Kukkonen's works).

1.2. Behaviour change: models and theories

Psychologists have proposed theories and models to model human behaviour. In order to better understand the design of persuasive technologies, we present the most well-known theories and models of the field.

1.2.1. Theories from psychology studies

Planned behaviour theory

In the theory of planned behavior, Ajzen [4] indicates that *attitude* towards the targeted behavior, *subjective norms* and *perceived behavioral control* together define the behavioral intention [4]. In other words, one’s behavior is determined by intention to perform the behavior, the stronger the intention the more likely one will perform it. Intention is influenced by the *attitude* towards this behavior change, when one evaluates this behavior change as favorable, one will likely have more intention towards this change. Besides, intention is also affected by the expectations of others people and how one reacts to it, these factors refer to the term of *subjective norms*. Finally, *perceived behavioral control*, which describes to how one evaluates the difficulty of the behavior is another determinant element.

Cognitive dissonance theory

Festinger cognitive dissonance theory [49] *considers "humans as rationalizing beings as much as rational beings"* [102]. Consequently, for Festinger, people are looking for consistency between behavior and attitude and when there exists an inconsistency, they may change either their behavior or attitude to restore the consistency. In other words, the cognitive dissonance refers to a conflict situation between "*two cognitions*". Feeling such a psychological discomfort induced by the conflict motivates a person "*to reduce the dissonance in modifying the weakest cognition*". For instance, when a person realizes that smoking cigarettes causes serious health problems, she/he experiences a cognitive dissonance situation where the attitudes (having a healthy lifestyle) and the behavior (to smoke) are not consistent. It could motivate people towards one of the three ways to reduce the dissonance [26].

- **Change the attitudes or beliefs**: In order to reduce the dissonance, one may simply change his/her attitudes/beliefs towards the behavior. For instance, a person may decide to believe that smoking is not an issue. However, it is very difficult to change our core values as they lie with us for since ever and as they reflect the self;
- **Change the behaviors**: It constitutes another way to reduce the dissonance. For instance, a person may decide to quit smoking or to smoke fewer cigarettes;
- **Change the perception of behaviors**: One common way to reduce the dissonance is to change the point of view one perceives about his/her current behavior. For instance, one may consider that there is no clear evidence that smoking can cause health problems. Consequently, one can continue to smoke (behavior) without breaking his/her beliefs (to live healthy).

Social cognitive theory

In the theory of social cognitive [11], the behavior change process is influenced and shaped by three important factors and their interactions: *internal personal factors (i.e., cognitive, affective, biological events), people surounded environmental factors (i.e., other people, social context),* and *behavior*, which together creates a "triadic relationship" [11] (Figure 1.2). Each of these factors affects the two others differently depending on the situation and contributes to explain how one could shape a behavior. The interactional connection between three elements will be summarized as follows:

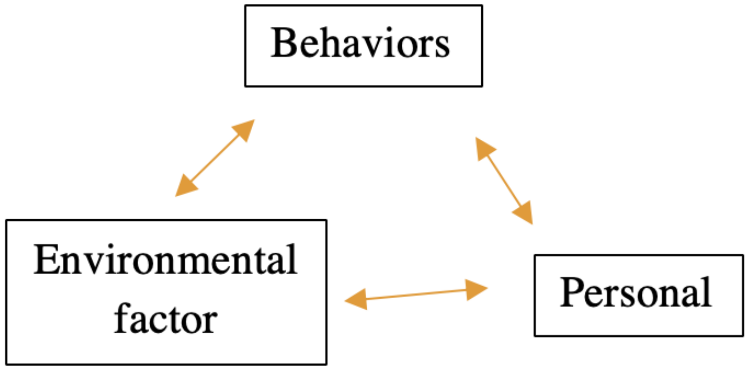


Figure 1.2. Three elements of the Triadic Relationship [11]

The *personal – behaviors* link "*reflects the interaction between (people) thought, affect and action*" [11]. People may find themselves capable of changing their behavior towards a better one if they perceive that they have the necessary skills and confidence (self-efficacy) to make the change (*personal* → *behavior*). On the other side, the outcomes of the behavior change (success or failure) may influence one in continuing the change because it can either reinforce or decrease one's motivation (*behavior* → *personal*).

The *environment* factor can also have great impacts on one's *personal* view on a behavior. For example, people may feel more confident towards a desired behavior (increasing self-efficacy) when they acknowledge that others have experienced it with ease (*environment* → *personal*). On the other side, when a particular behavior is experienced by many people without difficulty, it may change the overall assessment of people (i.e., whether it is easy to perform or not) towards such behavior on a societal level (*personal* → *environment*).

Last but not least, one's *behavior* can have an impact on *environmental* factors and vice versa. For instance, one may adopt a socially acceptable behavior (e.g., chewing gums) as way to achieve his/her goal (e.g., to quit smoking). On the other side, the results (i.e., success or failure) of a behavior (e.g., chewing gums) may affect the common approach towards this objective (i.e., most try this approach to quit smoking), hence influencing the *environment*.

Goal-Setting Theory

The Goal-Setting theory [107] suggests that goal-setting is a powerful source of motivation to adopt new behaviors. Indeed, Locke and Latham [107] believe that behavior change happens through the definition and tracking of personal goals, usually within a specific period of time. Nahrgang [32] argues that people tend to prefer specific goals rather than a vague one. In addition, Locke and Latham [107] believe that people like to pursue challenging goals rather than easy ones: the more difficult the goals are, the more effort people are willing to spend. Locke and Latham also identify five factors that affect goals-performance relationship: *commitment, importance, self-efficacy, feedback and task complexity*.

At first, making a public commitment reinforces the engagement towards the goal, because "*it makes one's actions a matter of integrity in one's own eyes and in those of others*" [74]. Secondly, Locke and Latham [107] also indicates that one's expectation towards the goal can affect his/her commitment on achieving it. Thirdly, feeling confident (self-efficacy) lays a strong impact on one's performance. Fourthly, goal-setting seems to be more effective when coupled with feedback, which allows people to track their progress and performance, and thus allowing them to adjust their efforts and/or strategies. Last but not least, the complexity of the task refers to individuals' ability to adapt the best strategies to accomplish the tasks related to each goal.

Sharing similar points of view on how goal setting can affect one's motivation and performance, Consolvo et al. [27] indicate that "*the encouragement only towards achieving the goal might result in reducing the performance, and the encouragement should be presented in a wider, more general manner*". Furthermore, Consolvo et al. [27] consider feedback as an essential element in achieving a specific goal. However, negative feedback might introduce side effects and should be avoided. Within this study, it is supposed that self-set goals are easier to achieve than preset goals or goals set by others.

Summary: In psychology, different approaches exist to characterize behavior change. **Cognitive dissonance** and **goal-setting theory** are among the most popular.

1.2.2. Process of behaviour change

Behaviour change is not instantaneous: it takes time. Research in psychology of behaviour change considers that behaviour change can be modelled as a process made of steps, each step requiring motivational techniques and persuasive strategies to go through the process. This section presents three models of behaviour change processes: the Transtheoretical Model of Behaviour change (TTM) [143, 144], Fogg's behaviour model (FBM) [52], and the very recent Habit Alteration Model (HAM) [140].

Transtheoretical Model of Behaviour change (TTM)

The Transtheoretical Model of Change (TTM) [143, 144] proposed by Prochaska and DiClemente considers behavior change as a process made of five stages (Figure 1.3). They consider that a person needs to experience each step in a specific order to achieve the targeted behavior change. According to Prochaska, "*it is important to know in which stage of change individuals are in rather than looking at strategies to improve task motivation*". The five stages are:

- **Pre-Contemplation (Not Ready):** This stage involves persons who are not ready to change their behavior in the next 6 months, either because they are unaware of their current behavior and its consequences, or they are aware but unable to make the change;
- **Contemplation (Getting Ready):** This stage involves persons who are willing to change in the next 6 months. Although they are aware of their current behavior and its consequences, these persons are not decided to engage into a change;
- **Preparation (Ready):** This stage involves persons who are planning to take serious action in a near future. These persons have understood the pros and cons of the behavior change and are developing their plan towards it;
- **Action:** This stage involves persons who have taken actions to change their behavior for the upcoming 6 months. These persons have accomplished their action plan and started to adopt their new behavior into their routines;
- **Maintenance:** This stage involves persons who have obtained the behavior change and prevent their new behavior from relapsing to earlier stage.

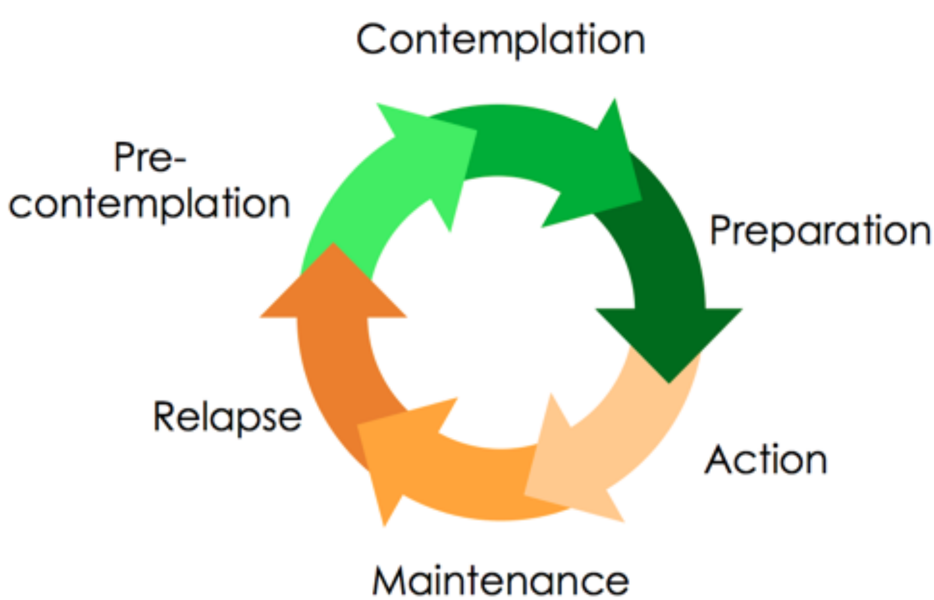


Figure 1.3. The Transtheoretical Model [143, 144]

Processes of change. In order to move from one stage to another, one must apply appropriate "*covert and overt activities*", identified as the processes of change [143]. These processes support people by providing guidance and intervention means to progress through the cycle. Ten processes appear to be key:

- Consciousness Raising (Increasing awareness about the causes, consequences);
- Dramatic Relief (Focusing on emotional feelings);
- Environmental Reevaluation (Noticing the effect on others);
- Self-Reevaluation (Focusing on evaluating self-Image);
- Social Liberation (Increasing social opportunities);
- Self-Liberation (Making commitment and act on it);
- Counter Conditioning (Using substitutes);
- Helping Relationships (Getting support);
- Reinforcement Management (Using Rewards);
- Stimulus Control (Taking advantage of the environment).

Fogg's behaviour model

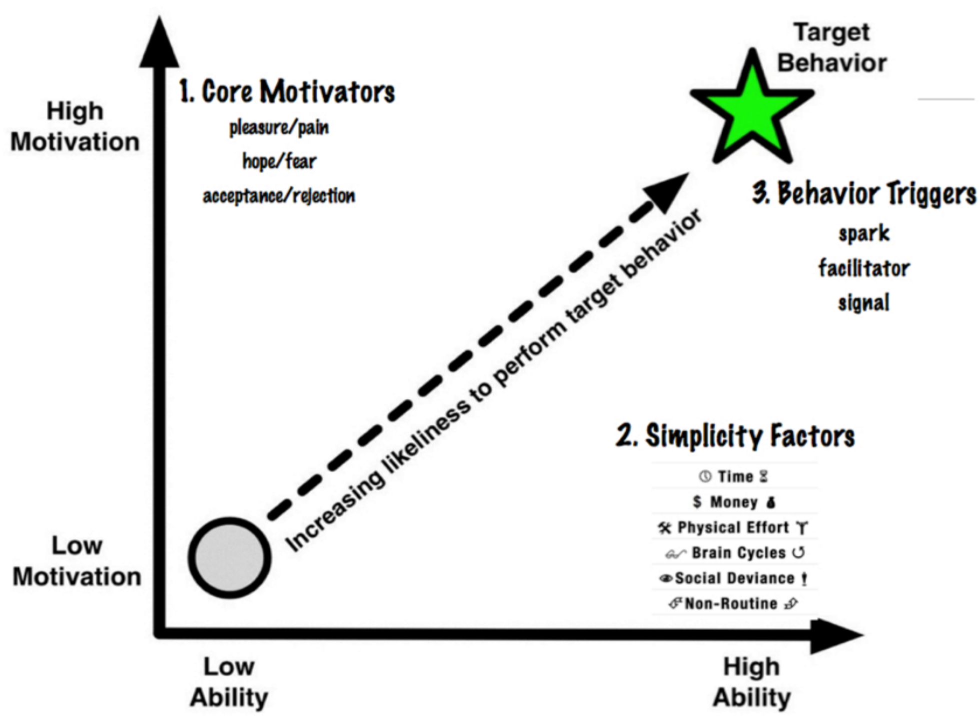


Figure 1.4. The Fogg behavior model (extracted from [52])

In *A Behaviour Model for Persuasive Design, J.B.* Fogg [52] introduces a framework called Fogg's Behaviour Model (FBM), targeting the design of persuasive systems. The FBM identifies three factors required to obtain an effective behaviour change: *motivation, ability,* and *trigger* (Figure 1.4). The change is likely to happen if the targeted behavior is triggered when there is a high motivation and a high ability to achieve the behavior. According to the author, motivation can evolve depending on three couples and complementary factors: Pleasure/Pain, Hope/Fear, Social acceptance/Rejection. As learning new skills may be difficult, ability can be increased if the behaviour is simple to achieve. Respectively, Fogg distinguishes six possible factors that can impact ability:

- Time (if the behaviour requires more time than one can afford);
- Money (if the behaviour costs more money than one can afford);
- Physical effort (if the behaviour requires doing exhausting physical activities);
- Brain cycles (if the behaviour requires one to think harder);
- Social deviance (if the behaviour requires one to break the rules of society);
- Non-routine (if the behaviour involves non-routine tasks).

FBM suggests that motivation and ability factors are trade-offs. For instance, if the motivation is low but the ability is high, one may likely be able to accomplish the task. Conversely, if a person has a low ability but with a high motivation, s/he will likely be able to perform the task. However, it depends on how high is the activation threshold in terms of motivation and ability. Furthermore, it must be achieved at the right moment. Consequently, the third factor in FBM is the trigger. According to Fogg, triggers are crucial elements in designing persuasive products. Fogg states that for people who are already above an activation threshold – meaning they have sufficient motivation and ability – a trigger is required. Fogg identifies three types of triggers:

- *Spark as trigger* that motivates one towards performing a behaviour;
- *Facilitator as trigger* aims at making a behaviour easier to be accomplished;
- *Signal as trigger* serves as a reminder for achieving a behaviour.

Habit Alteration Model (HAM)

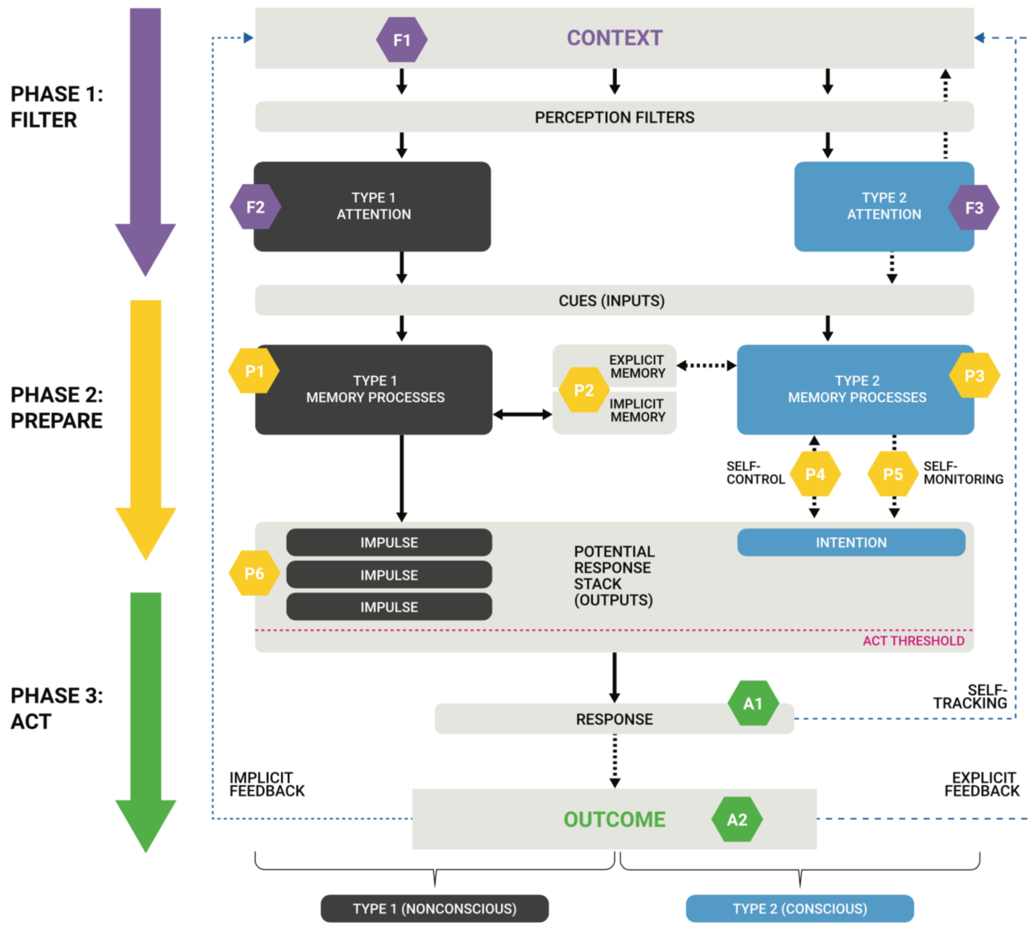


Figure 1.5. Habit Alteration Model (extracted from [140])

Through an extensive review of the literature in the fields of social psychology and persuasive technologies, Pinder et al. [140] introduced the Habit Alteration Model (HAM) as a unifying model targeting habit/behaviour change, aiming at bridging the gaps between theories and models. It aims at being a practical model to be used as a guide for the design of Digital Behaviour Change Intervention (DBCI) systems, including persuasive interactive systems.

According to Pinder et al., the formation of *desired* habits and the breaking of *undesired* habits are important elements for the purpose of achieving a long-term behaviour change [140]. The formation of habits can also enable the maintenance of desired behaviours since routine is the most common behaviour in any situation [140]. The model articulates different theories that address habit formation and habit breaking. These theories are Dual Process Theory, Modern Habit Theory and Goal Setting Theory. HAM prescribes the transfer of non-conscious undesired habits into conscious ones first, then the transformation of undesired conscious habits into desired ones, and desired behaviours into unconscious habits.

As shown in Figure 1.5, the HAM consists of three stages: *filter*, *prepare* and *act*. The *filter* stage consists in filtering perceived signals (i.e., the context). The filtered signals constitute the input cues. There are two classes of signals: the external signals (e.g., physical location, people nearby) and the internal signals (e.g., mood, emotions). Perception processes filter and generate two classes of input cues: Type 1 cues related to non-conscious habits (implicit attention processes), and Type 2 cues related to conscious habits (explicit attention processes). These cues serve as an input for the following stage: *prepare*.

In the *prepare* stage, behavioural plans for action are generated based on the input cues and memory processes. Two types of actions are presented, *impulses* for implicit memory (Type 1) and *intentions* for explicit memory (Type 2). These two types will compete to become the enacted behaviour, which will be transferred into the *potential response stack*. The latter constitutes the outputs of this stage. The stack, therefore, might consist of impulse(s) and intention(s).

In the last stage, *act,* any *impulse* or *intention* that surpasses the *act threshold* will be considered as *response(s)*. In case of multiple responses, an *arbitration process* will occur, based on the characteristics of the responses, only one *response* will be followed by an *outcome*, which could generate implicit or explicit feedback injected in the process loop.

In order to form a habit, the desired behaviour must go through these three stages and be repeated sufficiently in stable contexts. Besides, if the default behaviour is also the desired one, the purpose is to transfer this behaviour from Type 2 (Conscious) to Type 1 (Non-conscious). On the contrary, when the default habit is the unwanted behaviour, the objective is to break this habit.

In order to form or to break habits, Pinder et al. [140] highlight a variety of strategies that could be served to intervene in different stages. For instance, the tactic is to strengthen or to alter the targeted behaviour at specific point(s) of intervention such as the ones presented in the model (Figure 1.5 F1-F3, P1-P6, A1-A2). Moreover, Pinder et al. have identified several design principles in order to facilitate the design of habit-targeting systems. These principles will be explained in detail in a following section.

Summary Behavior change is a long and complex process. We have presented three models: TTM, FBM and HAM. TTM construes the behaviors change as a process of six stages (Precontemplation, Contemplation, Preparation, Action, Maintenance and Relapse). FBM relies on Ability, Motivation and Trigger dimensions. HAM considers the break/formation of undesired/desired habits as key and considers 3 phases: filter, prepare and act.

1.3. Persuasive Interactive Systems

Persuasive technologies take advantage of social and cognitive psychology to ground on models and theories related to behaviour change and persuasion. Fogg [54] defines persuasive technologies as "*an interactive technology that attempts to change an attitude, behaviour or both at the same time, without the use of coercion or deception*". Oinas-Kukkonen and Harjumaa [73] consider a persuasive system as "*a computerized software or information system designed to reinforce, change or shape attitudes or behaviours or both without using coercion or deception*". To date, these two definitions are currently the most referenced for characterizing persuasive technology.

1.3.1. Persuasive Technology as research field

The works of Fogg and Oinas-Kukkonen are considered to be the milestones in this highly interdisciplinary field of research. Fogg is the pioneer in the study of computers as persuasive technologies. Introduced at ACM CHI 97 conference, persuasive technologies have been denoted as a research field called CAPTOLOGY (for Computer As Persuasive TechnoLOGY). Fogg considers Captology as a research domain focusing on the design of technological solutions that uses computers to deliver persuasion means.

The purpose of Captology is to study persuasive technologies with some restrictions [159]:

1. "*To attempt to change attitudes or behaviour or both without coercion or deception*",
2. "*To focus on human computer interaction*",
3. "*To focus on planned persuasive effects*",
4. "*To focus on endogenous or 'built-in' persuasive intent, which means that a system is intentionally designed to persuade*",
5. "*To consider persuasion at either the macro or the micro level*".[159]

On the other hand, Oinas-Kukkonen prefers to call persuasive technologies as Behaviour Change Support Systems or BCSSs [123]. BCSSs had been presented in the 5th international conference dedicated for persuasive technology studies, PERSUASIVE'10. Defined by Oinas-kukkonen as a "*key construct for research in persuasive technology*" [123], BCSSs marked an important step towards the design, development, evaluation of persuasive interactive systems. The characteristics of persuasive technology according to these definitions are presented below.

1.3.2. Scope of persuasion and of persuasive technologies

According to Fogg, persuasive technologies aim at voluntarily changing people behaviors or attitudes. Thus, the persuasion, in order to be effective, should be based on the voluntary participation of the user(s) and their own ability and motivation to change. Indeed, "*machine have* *no intentions*": persuasion comes from people and from their use of such technology. Persuasive technologies are designed to simply convey persuasion, to facilitate behavior change through the support of the behavior change process.

Fogg identifies three types of intent that technology can support, depending on designer's intent:

- **Endogenous intent**: A technology is considered to inherit endogenous intent when it is designed with the purpose of persuading people;
- **Exogenous intent**: A technology is considered to inherit exogenous intent when one person uses such technology with the purpose of changing another person's behaviors or attitudes;
- **Autogenous intent**: A technology is considered to inherit autogenous intent when one voluntarily adopts it in order to change his/her own behaviors or attitudes.

Although many of the existing persuasive technologies systems target the individual, it may target groups such as families. Indeed, Fogg identifies six levels of analysis depending on the entity targeted by persuasion: *the intra-individual level (one person only), the inter-individual level (friends), the family level, the group level, the organization level, the community level* and *the society level*. Hence, a persuasive application can target one or multiple levels. For example, a system that encourages users to reduce water consumption can be considered both at the family level and at the societal level as a tool to limit water usage.

By contrast, Oinas-Kukkonen [22] believes that persuasive technology can play the role of mediator between two human beings. Oinas-Kukkonen identifies three actors in persuasive interaction, *persuadee*, *persuader* and *technology,* and the categories of persuasion that link these actors [73] (Figure 1.6).

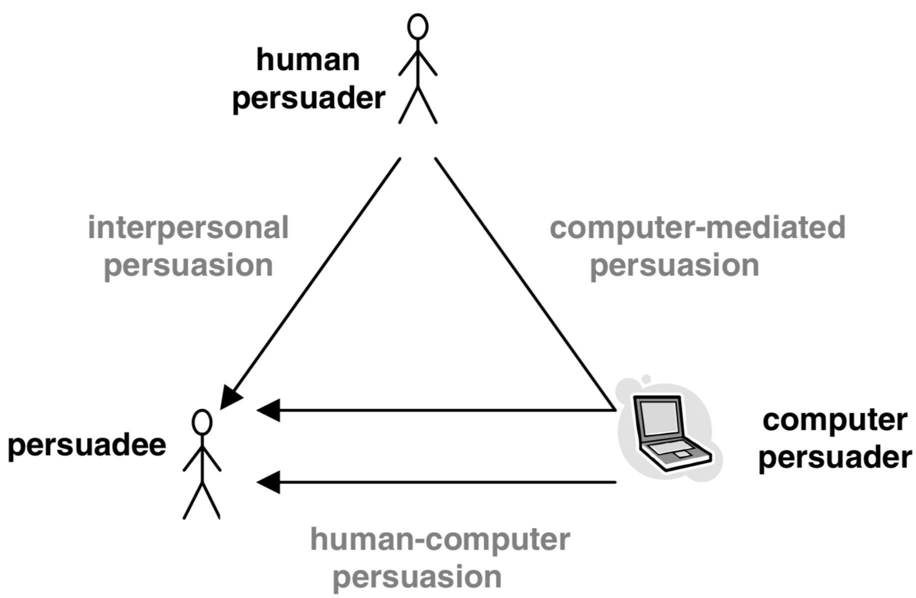


Figure 1.6. Taxonomy of Harris-Oinas-Kukkonen (extracted from [73])

- **Interpersonal persuasion**: This type of persuasion occurs when two people or more communicate with each other. The communication lies with the purpose of changing one's behaviors or attitudes. In other words, it implies a communication between persuader and persuadee, which could be in a verbal or non-verbal form of behavior;

- **Computer-mediated persuasion:** This type of persuasion occurs when people communicate with others using technological means such as computer, messages or e-mails. It implies an indirect communication between the persuader and the persuadee with technology serving as a communication link;

- **Human-computer persuasion:** This type of persuasion occurs when the technology communicates with people in a way that affects people's attitudes or behaviors. However, it is not clear who plays the persuader role in this exchange because "*machines have no intentions*" [54]. It refers to the three type of intents introduced by Fogg [54] when computers inherit human intentions.

1.3.3. Approaches for the design of persuasive technologies.

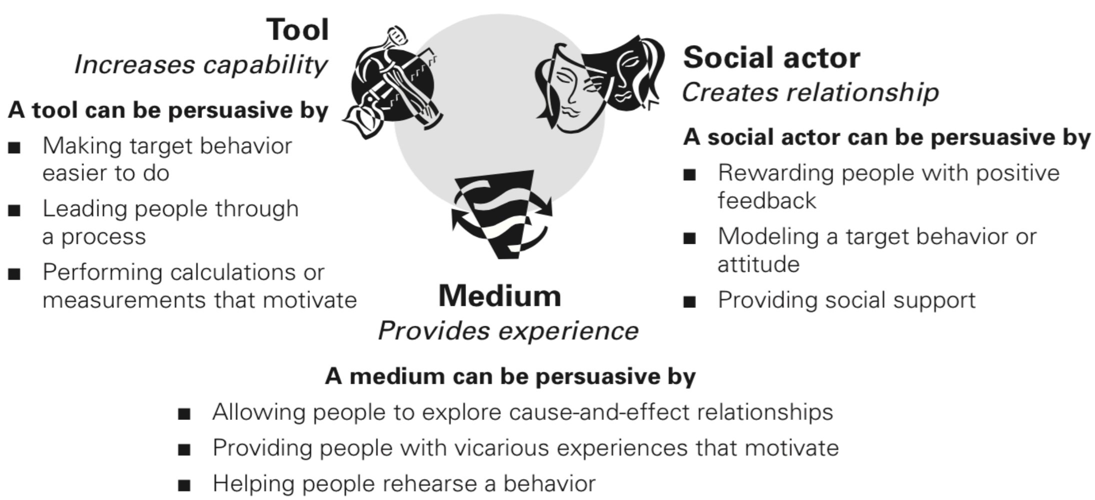


Figure 1.7. The functional triad (extracted from [56])

To design a persuasive technology, Fogg [56] identifies three roles it can play. These roles are explained in [102]:

- **As tool** where "*technology can make activities easier or more capable to do*";
- **As media** where "*technology can shape attitudes and behaviour by providing compelling simulated experiences*";
- **As social actor** where "*technology persuades by giving a variety of social cues that elicit social responses from their human users*".

These roles constitute the *functional triad* (Figure 1.7) that serves as a framework to design or to study computers as persuasive technologies. In addition, for each role, Fogg identifies a set of design principles that can drive the implementation of a persuasive system. These principles will be explained in more details in the next section.

A persuasive system can be integrated at two scales:

- **Macrosuasion**: It represents systems entirely designed for the purpose of persuasion. For instance, it could be an application designed to encourage people to walk more;
- **Microsuasion**: It represents a system that is not specifically designed to convey persuasion but that contains elements of persuasion. For instance, a notification mechanism in a calendar application can remind users to take today's challenge or a compliment message when a user accomplishes his/her walking schedule.

Oinas-Kukkonen prefers the concept of Behavior Change Support System (BCSS) [73] rather than persuasive system. Although in the essence BCSS are using persuasion to empower the human's change, BCSS studies are different from persuasive systems by considering not only designer's intentions but also the psychological and behavioral outcomes targeted by persuasion. Thus, the design approaches of BCSS seem to be more complex as multiple objectives/goals are presented. Indeed, based on the intended outcomes (formation, alteration, reinforcement) of three categories of the change (complying, behavior and attitude), Oinas-Kukkonen defined in total 9 different goals which a system could target.

Moreover, based on the *functional-triad* and principles of Fogg [56], Oinas-Kukkonen extends this work by targeting more specific requirements for and implementation features of BCSS. These approaches lead to the Persuasive System Design (PSD) model, so-called "*the state-of-the-art vehicle for designing and evaluating BCSSs*" [122]. More on this method are presented comprehensively in the next part.

Summary: we are interested in approaches for designing persuasive interactive systems. Fogg identifies a functional triad, which consists of three possible roles for a PIS: as tool, as media and as social actor. Oinas-Kukkonen prefers the concept of BCSS, which relies on the formation, alteration and reinforcement of the change.

1.4. Persuasive Design Principles

A fundamental question is the design of effective persuasive technologies. In order to help the designer, numerous works introduce a significant number of persuasive design principles covering several aspects of persuasion. This chapter presents these principles in general way.

1.4.1. Principles of Fogg

Jointly to its functional triad of persuasive systems (see previous section), Fogg listed more than 60 persuasion strategies [56]. This section summarizes the main design principles organized into three categories: as a tool, as a media, and as a social actor.

As a tool, "*technology is designed to make activities easier or more efficient to do"[102]*. The corresponding design principles are described in Table 1.1 below.

Reduction	Reduction principle makes the target behaviour easier to be achieved by reducing a complex activity into simple ones
Tunnelling	Tunnelling uses technology to guide users through a pre-determined multi-step set of actions, thus increasing opportunities to persuade them.
Tailoring	Tailoring provides tailored information specifically to the individual in order to be more persuasive.
Suggestion	People seem more likely to be persuaded an engaged in an activity if they can receive intervention/suggestion at the right time.
Surveillance	Surveillance allows people to monitor the behaviour of others in order to adapt to their own.
Self-monitoring	Self-monitoring allows people to supervise themselves, thus modify their behaviour to meet the pre-defined objectives.
Conditioning	Conditioning employs positive reinforcement to change behaviour towards desired one or to convert existing behaviours into habits.

Table 1.1. Persuasive design principles organized as tool

As media, "*technology can shape attitudes and behaviour by providing compelling simulated experiences" [102]*. Table 1.2 summarizes the principles of this category.

Cause and effect	Computer systems can obtain persuasion by allowing people to immediately observe the relationship between their behaviors and its consequences.
Virtual rehearsal	Virtual rehearsal provides a simulation environment to practice the targeted behaviour.
Virtual rewards	Through rewarding users in virtual simulated environment, this principle aims to influence people to adopt more of the same behaviours in the real world.
Simulation in a real-world context	This principle employs everyday objects to reflect the behaviour's impacts, thus provoke a change in people current behaviours.

Table 1.2. Persuasive design principles organized as media

As social actor. "*Technology persuades by giving a variety of social cues that elicit social responses from their human user*" [26]. Some of these are similar to the social influence principles introduced by Cialdini (Reciprocity and Authority). The others design principles are attractiveness, similarity, and praise (Table 1.3).

Attractiveness	A visually attractive technology is likely to be more persuasive.
Similarity	Computing technology can increase persuasion by offering users similar functionalities, concepts etc.
Praise	By offering praise via words, images or sounds, people can be more open for the technology, thus increasing chance to persuade them.
Reciprocity	People feels obliged to give back to others (i.e., a gift, a behavior) each time they receive something first, even when the favors are from computers.
Authority	Technology with more authoritative role will have greater persuasive power as people will easily comply with its request.

Table 1.3. Persuasive design principles organized as social actors

Other principles. Credibility is an important perspective when designing any technological products including persuasion. However, Fogg notices that the research on computer credibility is quite limited [57]. Within his research, Fogg outlines some key terms and concepts about credibility in which the below seven important design principles appeared to be the key elements (Table 1.4).

Trustworthiness	The reliability of a technology has great impact on its persuasion power.
Expertise	The expertise aspect of a technology will have also an impact on its persuasion power.
Presumed Credibility	General assumptions of the perceiver minds (people) towards a technology.
Surface Credibility	Assumptions of individual towards a technology after some first simple inspections (e.g., via visual appearance).
Reputed Credibility	The credibility of technology can be affected by its reputation and how third parties have reported the technology.
Earned Credibility	The credibility of a technology in perceivers after having been experienced for a period of time.
Perfection	A technology will be considered as credible if it works properly and if it has been designed to meet all the user requirements.

Table 1.4. Persuasive design principles to enhance credibility of a product

Fogg highly appreciates the potential of persuasion thanks to modern means such as web, tangible and mobile devices. Fogg, therefore, proposes new design principles for these devices. In the context of web applications, the design principles for enhancing the credibility of a website are summarized in the table below (Table 1.5).

Real-world feel	A website will obtain more credibility if it provides user the feeling of not interacting with a virtual system.
Easy Verifiability	A website credibility will be enhanced if it facilitates users to verify the authenticity of its content.
Fulfilment	A website that works properly and meets all the user requirements will be perceived as more credible.
Easy-of-use	An easy-to-use website will earn more credibility from users.
Personalisation	A website which offers personalisation functionalities will achieve more credibility from its users.
Responsiveness	A more responsive website will achieve more credibility from its users.

Table 1.5.Persuasive design principles to enhance credibility of a website

In the context of mobile and tangible systems, the specific design principles are:

Timing	A mobile application is likely to be more persuasive if it is able to give users suggestions at opportune moment.
Convenience	A mobile application provides readily accessible user experiences will have potential to be more persuasive.
Mobile simplicity	An easy-to-use application is likely to have wider opportunities for persuasion.
Mobile loyalty	A mobile application that aims to fulfil its owner requirements rather than others parties will have more persuasion power.
Mobile marriage	A mobile application facilitates intensive, positive relationship with users through interactions in the long-term will have greater potential to persuade.
Information Quality	Mobile applications or tangible devices that provide users with relevant, correlated information are likely to be more persuasive.
Social Facilitation	People performance of a desired behaviour can be improved by the presence of other facilitative factors such as an application which keeps track of their performance or device which allows them to observe other people who perform similar behaviour.
Social Comparison	A mobile application or tangible device which allow people to compare their performance with others, especially those with similar objectives, have greater potential of persuasion.
Normative Influence	Social norms can be employed by computing technology to influence people about adopting/avoiding particular behaviour.
Social Learning	By demonstrating the desired behaviour in detail to people or allowing them to observe and learn from others, computing technology can motivate people to perform this behaviour more frequent.
Competition	To make users to compete with their peers or others people is one approach to increase their motivation of doing the desired behaviour.
Cooperation	To make users to cooperate with others people is also an approach to increase their motivation of doing the desired behaviour.
Recognition	Mobile application and tangible device can employ the public recognition whether individually or by group to increase the persuasion means.

Table 1.6. Persuasive design principles to enhance persuasion power of mobile applications or tangible devices

According to Fogg, each of these principles "*applies a different strategy to change attitudes or behaviours"* and they are *"directly applicable by designers"*. These principles are often used in conjunction with another one as part of a persuasive system. However, due to the complexity of user's context, designers must understand the appropriate use of these tools in order to be effective in persuasion. Consequently, a method, named the behaviour wizard (presented later on) is mandatory to select the suitable design principles.

1.4.2. Principles of Oinas-Kukkonen

In Persuasive Systems Design (PSD) model, Oinas-Kukkonen [125] defines a range of categories of software features which BCSS could implement: *primary task support, dialogue support, system credibility support,* and *social support*. Each of these categories addresses a specific aspect of technology-mediated persuasion, hence are accompanied with a set of related design principles. Most of these principles are based on Fogg's principles. However, Oinas-Kukkonen rejects the use of conditioning and surveillance principles because of ethical reasons. In all, 28 principles are presented, divided into four groups:

- **Primary task support.** This dimension addresses directly the user and supports his/her primary activities. For instance, for an application which supports users to walk more, the function that provides real-time tracking of user's walking behaviors could be placed in this category. This dimension consists of seven design principles: reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal.

- **Dialog support.** This dimension involves the computer-human dialog in which the system interacts with the users, and guides them towards the desired behavior. Taking the above example, a function that reminds users to walk could be situated in this group. This category considers seven design principles: praise, rewards, reminders, suggestion, similarity, liking, and social role.

- **System credibility support.** This dimension addresses the credibility of a persuasive system. For instance, a regular update with new functionalities would help increasing credibility of the application. The PSD model considers seven design principles, which are: trustworthiness, expertise, surface credibility, real world feels, authority, third party endorsements, and verifiability

- **Social support.** This dimension supports social features in persuasive system. For example, our application could provide options to compare the user performance with a social standard or with their friends. Seven design principles provide social support: social learning, social comparison, normative influence, social facilitation, cooperation, compensation, and recognition.

1.4.3. Principles of ambient persuasion

In the study of *Ambient Persuasive Technologies,* Kaptein et al. [86] have identified several persuasive principles from the literature in social psychology, which Kaptein et al. prefer to call "*mental shortcuts*". These mental shortcuts are not meant to sustainably change someone's attitude or behaviours. However, it can effectively serve during the formation of new behaviours or for temporarily changing of one's attitudes. Eight principles are reported. The two first, scarcity and consistency, correspond to the two related Cialdini's influence principles. The six other principles are described in the below table.

Loss aversion	People tend to avoid losses instead of obtaining gains.
Sunk cost	People tend to ignore alternatives in a choice in favour of a prior choice, especially if they already put an irrecoverable effort on it.
Framing	People tend to react differently in a choice depending on the way the choice is presented. Shaping such a presentation may influence the decision.
Foot in the door	People tend to comply with a greater request if they already accepted an effortless request first.
Contrast principle	People tend to value something or someone to another. Altering the comparison in increasing the contrast may influence one's decision.
Disrupt-then-reframe	People tend to reinforce their choice after a reframing phase following a disrupting phase making them going beyond the rational way of thinking. With such an approach, a choice seems to be more acceptable.

Table 1.7. Principles of ambient persuasion [86].

1.4.4. Principles to alter habits (Habit Alteration Model (HAM))

As highlighted in section 1.2.2, the Habit Alteration Model [140] models how users form and break habits in order to drive effective habitual change intervention. With the application of HAM, Pinder et al. identify a set of design principles to serve as a starting point to design intervention on habits. Seven principles are introduced in the table below:

Understand and Simplify Target Behaviour and Context	It recommends to clearly identify the target response and to reduce complex behaviours to simpler ones. Besides, understanding and simplifying the context into a stable one is crucial.
Tailoring	Intervention should be adapted to individuals. Users require different interventions depending on their stage in the process of habit forming.
Design for Type 1 and	In order to effectively empower the behaviour change, interventions

Type 2 Congruence	must be focused in both Type 1 and 2 processes congruently.
Design for Persistence	Persistency in designing intervention is required for maintaining the habit over a long-term period.
Design for multiple points of intervention	DCBIs can be designed in a way that includes multiple interventions, which support each other in different aspects of the targeted process, thus improve the system efficiency.
Design for reactance	Reactance is triggered when intervention threatens user's autonomy or freedom. Designers should avoid the appearance of reactance in user's experience by limiting inappropriate suggestions, reminders etc. Instead, low-reactance method should be chosen.
Design ethically	Designers must ensure that the interventions are ethical.

Table 1.8. Principles to alter habits [140].

Some of the principles proposed by HAM, such as tailoring, present similarities with Fogg's [56] and Oinas-Kukkonen's [125] principles. However, some interesting aspects could be mentioned such as the persistency in designing persuasive system in order to foster the long-term habit and such as the reactance of individual that must be avoided in user experience.

Summary Current works introduce a significant number of persuasive design principles covering several aspects of persuasion. We presented more than 60 the principles from Fogg. Based on this work, Oinas-Kukkonen introduced 28 principles ranged into 4 categories. Some other notable works are covered by Kaptein (8 principles for ambient persuasion) and HAM (7 principles).

1.5. Methods for the design of persuasive technologies

The principles of persuasion are numerous. However, it is difficult for a designer to easily identify the suitable principles to be used for a given problem. To help him/her for such task, methods have been created to select the appropriate persuasion principles. Sometime, they provide guidelines for their implementation and more generally for the implementation of persuasive technologies. Persuasive Systems Design [125] and Behaviour Wizard [55] are two of these methods.

1.5.1. Persuasive Systems Design

As mentioned in a previous section, Oinas-Kukkonen developed a three-steps method for designing BCSS, named Persuasive System Design or PSD [125] model. According to Oinas-Kukkonen, it is essential that designers should fully acknowledge the seven common postulates of BCSSs, the fundamental that could be applied for any Persuasive System.

1) "*Information technology is never neutral*",
2) "*People like their views about the world to be organized and consistent*",
3) "*Persuasion is often incremental*",
4) "*Direct and indirect routes are key persuasion strategies*",
5) "*Persuasive systems should be both useful and easy to use*",
6) "*Persuasion through persuasive systems should be unobtrusive to user's primary tasks*",
7) "*Persuasive systems should always be transparent*".

To illustrate these postulates, let us consider a persuasive system which aims at encouraging people to do physical activities. If this system provides plenty of fancy functionalities, however too difficult to navigates between screens (P5), it does not seem to be persuasive. On the other hand, if the primarily focus of such system is to sell sport shoes or other purposes different from its original aim (P7), it does not seem to be persuasive either.

The second step is the analysis of the context of persuasion. This step requires from designers to identify and map the important elements of the PSD model into their BCSS. The context itself consists of the *intent, event* and *strategy*. To be more specific, this step implies:

- Identifying the intent of the persuasion: this sub step concerns the identification of the persuader and the change target. According to Oinas-Kukkonen, the persuader could be the one who produces (endogenous), distributes (exogenous) or adopts (autogenous) the technology. The targeted change can be either behaviors or attitudes.
- Understanding the persuasion event which consists of three sub-contexts: the context of user (e.g., energy consumption, health care etc.), the user context (e.g., culture, personality, habits etc.), and the technology context.
- Analyzing the persuasive strategies, the system messages and the routes (direct, indirect or both) that the system would use to deliver the persuasion means to the user.

Taking the above example, to analyze the context of persuasion, if the system provides users with specific exercises to follow, the persuader is, therefore, the designers. However, if the system is designed to help users keeping track of their physical activities, raising awareness about their current behavior and indirectly motivating users, the persuader would be the users themselves. The designers could choose to deliver the persuasive message directly (e.g., a pop-up that suggests users to do some activities) or indirectly (e.g., by revealing current situation through feedback information).

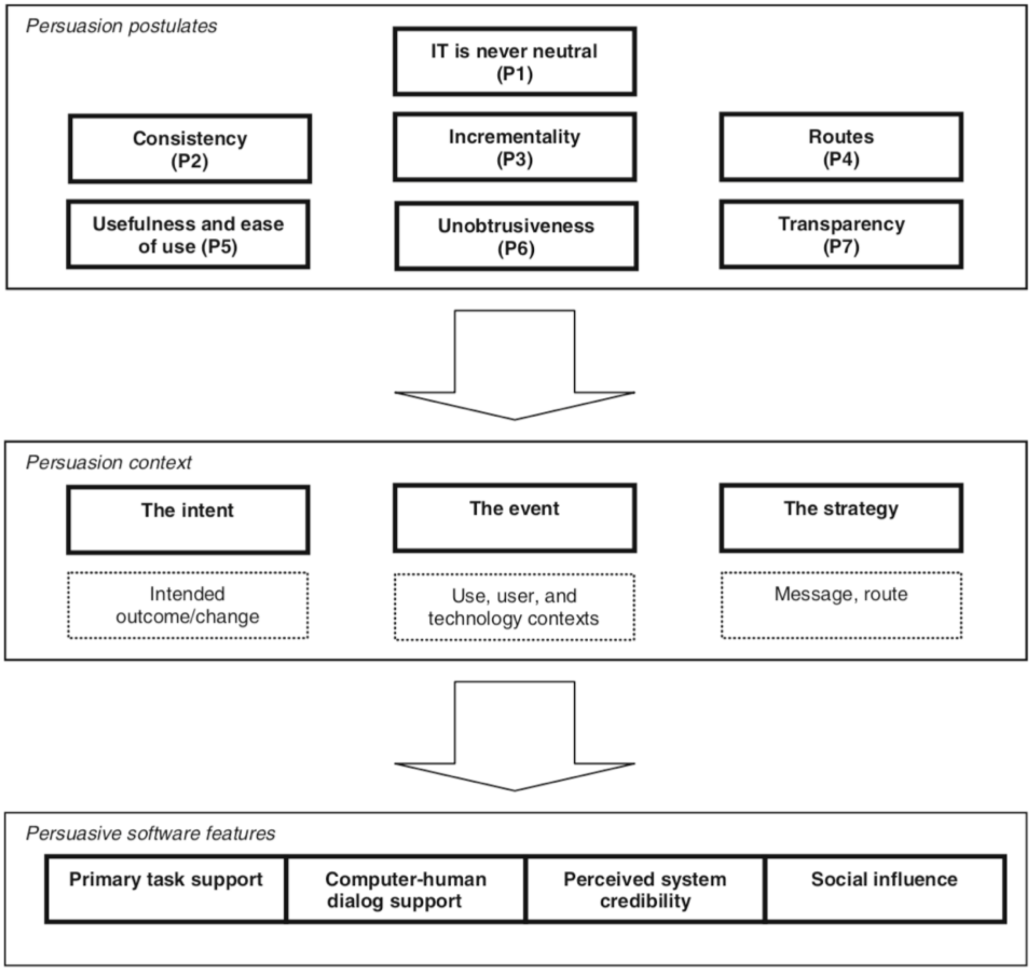


Figure 1.8. The components of PSD Model (extracted from [125])

The last step concerns the persuasive software features. PSD divides these features into four categories: primary task support, computer–human dialog support, perceived system credibility, and social influence. Each category consists of a list of design principles which we have been summarized in the previous section. Once the second step is completed, designers are able to define which categories should be the central point. The following figure (Figure 1.8) illustrates the core components of PSD model.

For instance, for the primary task, our sport application could motivate people thanks to real-time tracking, offering weekly challenges and goal-settings etc. This system can also alert users of undesired results, and reward for desired ones (Computer-Human Dialog Support). Moreover, such system should be updated frequently (credibility), and may rely on famous athletes (advertisement) to involve more users (social influence).

About the evaluation of persuasive systems using the PSD model [125], Oinas-Kukkonen reports that many works employ multiple techniques to support the persuasion [170]. In the primary task, tailoring, tunnelling, and reduction seem to be the most used principles. In addition, designers regularly consider the suggestion method to support the user-system dialogue. Social comparison and normative influence are considered as important means to provide social support. Last but not least, surface credibility has been approved to be one of the most efficient principles in the credibility research.

In addition, Oinas-Kukkonen notes that the PSD model does not suggest the combination of all these features when designing BCSS. Besides, he believes that the model can be utilized in various settings including the design of software in early stage.

1.5.2. Behaviour Wizard

To help designers to efficiently select the right persuasive principles and strategies, Fogg developed a framework called *The Behavior Grid* [55] which outlines 15 ways to change behaviors. Each of these 15 ways is associated with different persuasive techniques according to its behavior type and duration. More specifically, these 15 types of behavior are grouped into a table of 5 columns of different behavior types and 3 rows of different degree of behavior duration illustrated in figure 1.9. For visual aids, the types are marked with colors and durations are illustrated as visual marks.

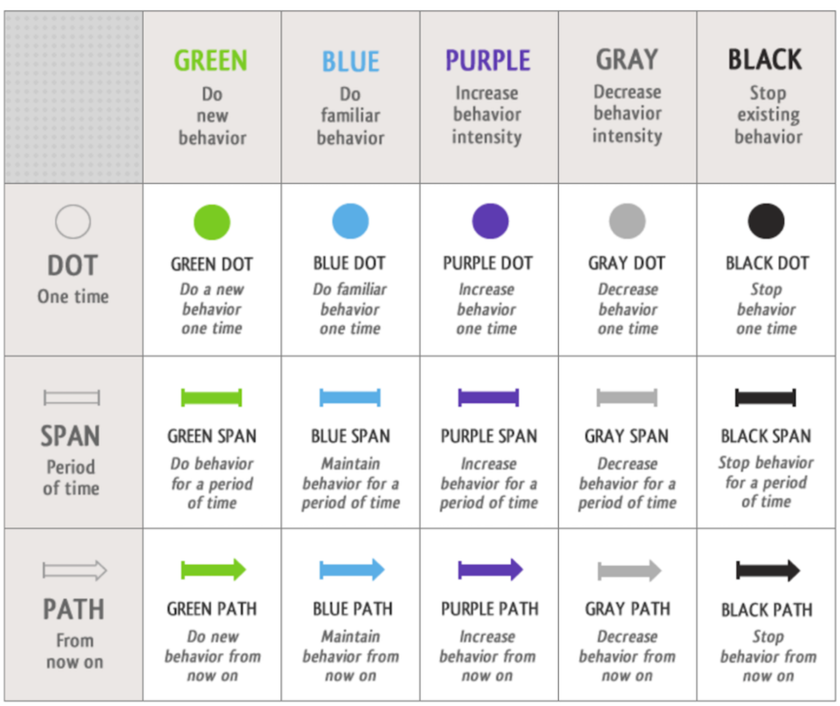


Figure 1.9. Fogg's Behavior Grid [55]

The Behavior Wizard [55] is available as an interactive tool to provide appropriate suggestions and strategies for each selected category of the grid. For instance, to engage in a long-term implication (e.g., start going to the gym regularly), the Wizard will help users to select the "Green-Path" (i.e., do new behavior from now on) type of change. For that purpose, several suggestions are provided by the interactive tool. Firstly, it proposes to make the new behavior more familiar in order to eliminate any demotivation factor. Secondly, for increasing user self-efficacy, it suggests to make the task easier to perform: appropriate tools such as tracking application, devices to support user may be needed. Finally, it recommends to associate the new behavior with existing habits to trigger users to perform the behavior frequently.

Summary: Design methods are presented to better identify the principles to be used for a given problem. We presented Persuasive Systems Design [125] and Behaviour Wizard [55], two among the most popular methods. PSD model consists of three steps: Acknowledgement of seven postulates; Analysis of persuasion context; and Definition of design principles. Meanwhile, Behaviour Wizard is an interactive tool, allowing user to choose among 15 types of behaviour change, each associated to its corresponding design principles.

1.6. Ethics

Technological persuasion has been received notable attention from researchers and is becoming a new paradigm to change people's behavior in many aspects of everyday life. In addition, rapid development of mobile and ubiquitous technology allows persuasive technology to reach and influence people in a broader and closer context. However, while the advantage of persuasive technology is quite obvious, a big issue is the ethical concerns, which are not well covered in current persuasive studies.

Fogg considers the adoption of ethical values in persuasive technologies as an essential consideration. Indeed, the two domains, persuasion and technology, on which it relies on present themselves ethical issues [54]. Indeed, in the chapter dedicated to ethics in CAPTOLOGY [56], Fogg notes a number of ethical issues should be considered by designers. Six appears to be key:

- "*The novelty of a computer system can blind users to designer's persuasive intent*";
- "*Designers can exploit computers reputation as intelligent and fair*";
- "*Computers can be far more ubiquitous and persistent than a human persuader*";
- "*Computers cannot be negotiated with; they do only what they are programmed to do*";
- "*Computers can affect emotions but do not have emotions themselves*";
- "*Computers do not share in moral responsibility for harmful outcomes*".

For analyzing the ethics of persuasive technologies, Fogg proposes a method which relies on the gains and losses of stakeholders when using persuasion. The seven steps analysis [54] helps to explain why persuasive technologies could be ethically questionable. These steps are:

1) "*List all the people in concerns (designer, distributor, user etc.)*";
2) "*List what each stakeholder gains with the use of technology*";
3) "*List what each stakeholder loses to the use of technology*";
4) "*Assess which stakeholder gains the most with the use of technology*";
5) "*Assess which stakeholder loses the most to the use of technology*";
6) "*Evaluate relative gains and losses between stakeholders to identify inequality. Deduct the gains and losses in terms of moral value, considering of cultural and personal subjectivities*";
7) "*Identify the values on which the assumptions and remarks are based previous steps*".

However, in a critical review of Fogg's work about ethics in persuasive technology, Atkinson [10] argues that "*not enough attention is paid to ethical principles that encapsulate society's collective understanding of ethical problems"*. For instance, Atkinson emphasizes one important principle in designing persuasive system: "*the audience must be informed of the persuader intent in order to make the persuasion to be ethical"*.

Berdichevsky [15] on the other hand, proposes a different perspective of ethics in persuasive technologies. The work of Berdichevsky differentiates with other by focusing more on the consequences and the allocation of responsibilities rather than the causes. For this purpose, Berdichevsky separates the outcomes into intended and unintended consequences. The unintended groups are divided into smaller subgroup depending on the predictability of the consequence, hence it has unintended predictable outcome and unintended unpredictable outcome. After that, based on the ethical or unethical characteristic of these outcomes, Berdichevsky identifies the responsibility of designers. For instance, if an ethical intended outcome is detected, designers would be judged as praiseworthy. However, in case the results are unintended unethical but predictable, designers are found to be faulty responsible. The framework also defines several principles for designing ethical persuasive system in which one is considered to be the golden rule: "*The creators of a persuasive technology should never seek to persuade a person or persons of something they themselves would not consent to be persuaded to do*".

1.7. Persuasive Interactive Systems

Originally stated by Oinas-Kukkonen [125], *Persuasive technology is not about computer-mediated communication, but rather about human-computer interaction*. Fogg [56] defines the main function of persuasive technology as the study of how people are persuaded when interacting with computer technology. Human Computer Interaction (HCI), therefore, plays an important role in the development of research in persuasive technology. More importantly, the interaction between human and technology in a persuasion context seems to be the key element in this domain of research.

In the HCI community, there is an increasing interest for research being at the crossroad with the research on persuasive technology. The application domains vary from promoting healthy activities (exergame), fostering green energy consumption (eco-feedback) to educating people. Among many different fields of research within HCI, persuasive design for sustainable behaviour is becoming a popular topic (e.g., sustainable HCI).

Indeed, Reitberger et al. [142] argue that persuasive technology can be a key component of sustainable HCI by giving users information about the impact of their actions on the environment, and by heightening the desirability of pro-environmental behaviour. An analysis from DiSalvo [37] reports a prominent number of studies about "*designing systems that attempt to convince users to behave in a more sustainable way*". It represents nearly 45% of all the publications about sustainable HCI. Furthermore, "*one of the broadest and comprehensive goals of the persuasive system is convincing users to behave more sustainably*".

Eco feedback systems, a related research domain often referred as an extension persuasive technology, aims to reduce environmental impact of user's actions by providing feedback on individual or group behaviours [64]. This field of research shows a significant increase: 56 of 139 the sustainable HCI papers are related to eco-feedback. Moreover, Pierce et al. [138] reviewed 51 papers related to energy sustainability from HCI literature: while 70% of these works address *electricity consumption feedback,* more than half of these studies focuses on design recommendations or strategies for eco-feedback design.

Persuasive interactive systems appear to be a promising approach for helping resolving certain problems. It presents an opportunity to design solutions to adopt new and sustainable behaviours but is also challenging, especially for energy domain.

1.8. Positioning: Persuasive interactive systems for energy

Social psychology shows that persuasion and influence are powerful tools to help people to change an unwanted behaviour towards a more desired one. In this scope, persuasive interactive systems are promising technological tools aiming at facilitating and at accompanying a person during a process of change. Indeed, Hamari [71] highlights that these systems have a positive effect on users' behaviour generally. As a consequence, since a decade, we observe a growing interest in the HCI community for persuasive interactive systems. However, although this field of research grounds on theories, models and principles borrowed from human sciences such as social psychology, the research on **persuasive interactive systems** (PIS) is still in its infancy and needs more robust foundations. For instance, designing a persuasive interactive system able to adapt user interaction depending on stages of the process of change, and conducting long run evaluations to assess the effectiveness of the system constitute hard issues.

Another hard challenge is related to the application domain tackled by persuasion. Based on 95 research studies, Hamari et al. [71] identify many application areas ranging from health/exercise, green consumption, education/learning, and economic/commercial/marketing to entertainment and security. However, it appears that persuasion techniques to be applied are domain-dependent. Indeed, Mogles [114] remarks (1) that the application domain may have strong impact on the efficiency of persuasive approach and (2) that it depends on, based on social sciences, how designers effectively identify and incorporate relevant influencing strategies. For instance, PIS targeting health through sport mostly rely on motivation to encourage users *do more* activities sportive. By contrast, PIS targeting sustainability mostly rely on raising awareness to help users to *do it right* in a pro-environmental way. In the scope of this thesis, we target the exploration persuasive interactive systems particularly for energy. Towards that end, next chapter targets the state-of-the-art of PISs for energy.

In this context, this thesis addresses
the design of **persuasive interactive systems** for **energy**.

As discussed in the previous section, this topic is a major research area in the field of sustainable HCI and is particularly challenging. Indeed, there is no guarantee that one strategy that promotes sustainable energy consumption can effectively guide users to a sustainable lifestyle. Moreover, although the frameworks presented in Oinas-Kukkonen [125] and Fogg [52] appear to be the most influential in support of systematic behaviour change interventions strategies, Mogles [114] states that they are too general and it is not clear how each of these principles or strategies can be implemented for a specific context of use. Furthermore, a major risk is to design an ineffective interactive system in terms of persuasion. Indeed, adopting a critical design approach while questioning the efficiency of current research in persuasive technology towards sustainable behaviour, Brynjarsdottir [21] claims that persuasive sustainability narrows the focus to a limited framing of sustainability. According to Brynjarsdottir, the major problem is that designers attempt to prescriptively persuade users to take actions consistent with their definition of how to be sustainable, which is often out of context. Similarly, Strengers raises concerns about the long-term effects of behaviour change [95].

Consequently, in order to identify appropriate key aspects of design for PIS in the energy domain, the focus is put on designing PIS that considers (1) the **process of change** dimension and (2) involves users in a **constructivist approach** (i.e., "what-if" approach) instead of a prescriptive one.

All things considered that a call for expanding the scope of persuasion towards sustainability is therefore evident. In chapter 3, we explore in depth many solutions of persuasion in sustainable HCI and on energy specifically. Our objective is to address suggestions to overcome these issues of sustainable persuasion. Combining with results obtained in Chapter 2, we present our approach for designing a persuasive interactive system towards sustainable energy usage.

2. Classification of persuasive systems and the UP+ framework

The content of section 2.3 about UP+ has been partially published
in the ACM conference EICS 2018 titled **UP!, Engineering Persuasive Interactive Systems**

Before establishing a state-of-the-art on existing persuasive systems for energy, this chapter first reviews surveys, design spaces, and frameworks related to the design of persuasive interactive systems, particularly for energy. Indeed, we need for an analysis grid in order to systematically and rigorously review each system in order to identify their intrinsic properties in terms of persuasion. As highlighted in chapter 1, most of the works focus on persuasion principles but are difficult to employ when coming to the software design and engineering of persuasive interactive systems. In this chapter, we propose UP+, a new framework that synthetizes and revisits existing surveys, design spaces, and frameworks useful for engineering persuasive interactive systems.

This chapter is organized around three major parts. The first part reviews eight surveys, design spaces and frameworks from the literature. The second part presents a synthesis that highlights their similarities and differences. Based on this synthesis, the last part presents UP+.

2.1. Design spaces for Persuasive Interactive System (PIS)

This section reviews eight surveys, design spaces and frameworks from the literature: Pierce et al's dimensions for Eco-Visualizations, Froehlich's and Fang's design spaces on feedback technologies, Froehlich's comparative survey of eco-feedback systems, Hamari et al's review of persuasive technologies, Cano's design space and the SEPIA framework.

2.1.1. Dimensions for Eco-Visualizations: feedback, use-context, and strategies

Eco-Visualizations (EVs) are a subset of persuasive interactive systems, dedicated to the visualization of consumptions, aiming at revealing energy usage and hence promoting sustainable behaviors. In a critical survey of ten noteworthy EVs, Pierce et al. [136] identify three dimensions to characterize EVs in terms of scale and contexts of use: feedback type, use-context and strategies.

Feedback type. As EVs mostly focus on revealing energy consumption as a means to induce behavior change, the design of the feedback plays a crucial role. Pierce et al. focus on: the *data* to be represented and the *visualization* it employs.

- **Data**. Consuming energy has an impact at many scales: locally (i.e., at home level) or globally (e.g., at a city level). The data feedback is then characterized in terms of small-scale context of effects (e.g., a home appliance) and of large-scale context of effects (e.g., residential area).
- **Visualization.** Two styles of visual feedback are considered: *pragmatic* or *artistic*. Pragmatic design refers to approaches where the information is illustrated through traditional visual elements such as lines, charts or graphs etc. This visualization style aims at providing clear and intelligible information or patterns. In the other hand, *artistic* style provides different kinds of user experience where the same information is presented to the user in artful and abstract manners.

Use-Context refers to "*the environmental and cultural conditions of the space in which the EVs are implemented*" [136]. Pierce et al. consider the amount of control to characterize EVs into different use-contexts. Two axes of control are considered:

- **Dweller control**: depending on the context, a dweller may have a high level of control over energy consumption (e.g., at home) or a low level of control (e.g., public area).
- **Third-Party control**: depending on the context, a third-party may have a high level of control over the dweller (e.g., business offices in a building) or a low level.

Consequently, a use-context is a two-dimensional level of control. At home, a dweller has often a high level of control but the third-party control should be low in a house but high in a flat part of a housing building. Such a two-dimensional plotting facilitates the identification of the essential elements in the design of an EV.

Strategies. Complementary to use-contexts, Pierce et al. identify 8 persuasive strategies [136] that an EV system may rely on:
Scope: to conserve goals (clear and useful feedback)

1. *Offering behavioral cues and indicators*
2. *Providing tools for analysis*

Scope: to create incentives

3. *Creating social incentive to conserve,*
4. *Connecting behavior to material impacts of consumption*

Scope: to create or support goals

5. *Encouraging playful engagement and exploration with energy*
6. *Projecting and cultivating sustainable lifestyles and values*
7. *Raising public awareness and facilitating discussion*
8. *Stimulating critical reflection*

We consider a number of takeaways from this work. Firstly, related to how EV systems visualize data in a more informative and engaging way in residential context, we appreciate the "artistic route", which provokes user's reflection towards other aspects such as motivation, interest, emotion, rather than just presenting the data. This approach could allow an interactive system to blend into the housing environment and become a valuable part of everyday life. Secondly, the suggestion of cooperative inhabitants towards a common goal is related to social support (i.e., Fogg, Oinas-Kukkonen) in persuasion.

The authors uncover two issues we also consider in this work: (1) how to effectively incorporate and apply strategies to different use-contexts; (2) how to ensure a long-term change. They recommend designing interactive systems able to evolve overtime to better adapt to user's commitment and understanding.

Summary: The design space identifies three dimensions for characterizing EVs: feedback type, use-context and strategies, it proposes 8 persuasive strategies for designing an EV. Overall, we appreciate the author's idea of "artistic route" and the importance of long-term implication of EV system.

2.1.2. Feedback technologies: Froehlich's Design Space

Observing the growing interest for feedback technologies, especially the ones targeting energy consumption, Froehlich identified a ten-dimensional design space to characterize such technologies [62]. Feedback technologies are designed to provide feedback that raises awareness about behavior in order to help changing behavior. The dimensions are:

1) **Frequency**. This dimension concerns how frequently a system updates its feedbacks. According to the author, it improves people's perception of the link between their actions and the consequences [62].
2) **Measurement Unit**: some units are too technical to be easily understood by normal people (i.e., the ppm unit for suspended particle concentration in the air). Froehlich recommends using alternative units (e.g., number of trees) that enhances the comprehension while providing subtle information that raises people's different interests and motivations.
3) **Data Granularity**: A system could present data at different granularities such as a whole building consumption or room's consumption (space dimension), devices consumption (source dimension), for a day or one hour (time dimension), etc.
4) **Push/Pull**: Pushed/pulled feedbacks are employed to inform about anomalies or unusual events on the environment where the system takes place.
5) **Presentation Medium**: Feedback can be presented using traditional (paper) or modern (electronic displays) medium.
6) **Location**: Location of the feedback system is key as it could provide information in an effective manner. It could be embodied with the device (e.g., highly localized) or independent (e.g., bill).
7) **Visual Design**: The visual presentation of feedback may be, according to Pierce et al. [136], either "pragmatic" (using numerical values and comprehensible representations through graphs or else) or "artistic" (or both).
8) **Recommending Action**: A feedback system may offer personalized recommendations based on user's context.
9) **Comparisons:** Providing means to compare one's behavior with past ones or with a social norm is a powerful approach to support behavior change.
10) **Social Sharing**: This dimension concerns whether a feedback system employs social sharing feature as motivational incentive.

Despite the overlap between certain dimensions (e.g., a feedback system can provide comparison supports through its visual design or it can recommend actions through push/pull feedback notifications), this work offers a clear overview about the design of feedback systems. Dimensions such as *Push/Pull, Recommending Action, Comparisons, Social Sharing* fully fall in the scope of persuasion as they are intended to induce a change in users' behaviors.

2.1.3. Feedback technologies: Fang's Design Space

In the same vein as [64] and [136], Fang [45] considers that the research on the design of feedback technologies is still insufficiently fostered. Fang identifies four significant dimensions related to the visual design of feedback systems: *ambient, aesthetic, emotionally-engaged* and *metaphorical*.

1) **Ambient***:* This dimension concerns the way a persuasive system presents feedback that does not interrupt users' daily life. He considers that an "*ambient information consumes little or no awareness*" [45]. Power-Aware-Cord [69] and the Mona Lisa bookshelf [117] are typical examples. Besides, *Informative Art* is one technique often utilized in this type of persuasive system.
2) **Aesthetic**: As people tend to pay more attention to the attractive appearance, aesthetic is becoming an important factor in the design of feedback systems. As example, Fish'n Steps [106] and Mondrian weather tiles [76] are the studies placed in this dimension.
3) **Emotionally-engaged***:* Emotions should be considered to engage users with the system to increase motivation. Using emotions has been proven efficient for a successful behavior change [140]. [35] and [106] are two studies that employed emotional incentives as ways to encourage people.
4) **Metaphorical***:* Metaphors have been employed in many studies to enhance user's comprehension and to raise user's interest and curiosity. Some example of metaphor interfaces are the virtual tree [96], the aquarium [116], the virtual garden [26], the virtual apple tree in Ubigreen [65], virtual island [162] and polar bear [35].

Although specific, strictly centered on feedback and its visual design, this design space considers multiple sources of motivation, in particular emotions and aesthetics. Such an approach is strongly related to informative art, another research field [48, 76, 150].

2.1.4. Froehlich's Comparative survey of eco-feedback systems

Froehlich [64] conducted a comparative survey of 133 scientific publications from environmental psychology and Human-Computer Interaction (HCI) research fields. Within this study, Froehlich classified eco-feedback systems in terms of persuasive techniques that promote pro-environmental behaviors. Feedback is one of the techniques proposed in this study:

- **Information**: information is essential and is the very first vector to inform and to promote pro-environmental behavior. In addition, although well-informed people are mandatory to give rise to such behaviors, the presentation and the location of such information play a significant role to be successful.
- **Goal-Setting***:* considered as an effective source of motivation, goal-setting constitutes a means to engage a person (or a group) in a particular direction but also to compare a performance towards a past or towards other's goals. Such a means is efficient when combined with feedback.

- **Comparison**: this dimension is the same as in Froehlich's Design Space [62]. Social networks constitute a good approach to support social comparison.
- **Incentive/Discentives and Rewards/Penalties***:* according to the author, "*Incentives/Disincentives are antecedent motivation techniques and Rewards/Penalties are consequence motivation techniques*" [64]. Incentives may be financial or else. Rewarding mechanisms are taken from games (e.g., points, medals, etc.) to elicit positive behaviors.
- **Commitment**: making a commitment to a specified goal enhances engagement towards the goal. A person who previously expressed his/her interest about a specific behavior will likely pursue the targeted behavior. Commitment has, thus, potential and could be considered to enhance the persuasion of a PIS.
- **Feedback** considered as a vital factor, feedback can be used in conjunction with other motivation techniques in order to convey information in the most persuasive way.

This study provides a notable number of motivational techniques targeting environment impact reduction. It is indicated that feedback is the most important feature for conveying persuasion messages. In addition, combinations of these dimensions are mandatory. However, it is not clear when and how these combinations can take place (e.g., in the process of change).

Summary: Froehlich classifies eco-feedback systems according to 6 techniques in which feedback seems the most important feature. In order to effectively convey persuasion means, the combinations of these techniques are mandatory.

2.1.5. Motivation affordances and psychological outcomes

Hamari [71] reviewed 95 studies related to persuasion, with the purpose of providing an overview about how motivational affordances, psychological mediators/outcomes and behavioral outcomes are considered. Figure 2.1 illustrates how the three aforementioned aspects together create Hamari's process of behavior change. These aspects are:

- **Motivational Affordance:** Zhang describes the term motivational affordance for Information and Communication Technology (ICT) as "*the properties of an object that determine whether and how it can support one motivational need*" [185]. The higher the motivational affordance an ICT system has to offer, the more user's motivation, engagement and interest will be achieved. Among ICT systems, a PIS aim at increasing user's motivation towards a successful behavior change. For Hamari [71], the motivational affordances are design elements embedded in a PIS inducing motivation. For instance, motivation needs can be achieved through visual feedbacks, ranking or rewards etc.

- **Psychological outcomes:** When PIS's motivational affordances meet individual's motivational needs, it induces psychological effects. For instance, for a PIS aiming at promoting energy conservation, giving feedback about resource consumption can promote user's awareness towards the goal. Hamari categorized the psychological outcomes of reviewed studies into eleven group including awareness, engagement, enjoyment etc.

- **Behavioral outcomes.** The psychological impacts in one's mind may shape his/her own ways of behaving towards a specific behavior. Hamari's classification investigates various types of behavioral outcomes including health/exercise, ecological consumption, education/learning etc.

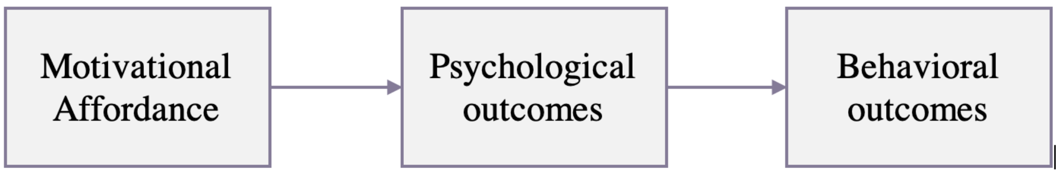


Figure 2.1 The conceptual framing of Hamari [71]

As reported by Hamari [71], virtuous consumption is the second most studied area for PIS. Of the 95 studies reviewed, 20 (21.1%) considered virtuous consumption as behavior outcome. We present the main motivational affordances and psychological outcomes reported by the study (Tables 2.1 and 2.2).

Motivational Affordance	**Frequency**
Visual or audio feedback	Frequently
Ambient or public displays	Frequently
Social support, comparisons, feedback, interaction, sharing	Frequently
Rewards, credits, points, achievements	Frequently
Objectives and goals	Frequently
Competitions, leaderboards, ranking	Frequently
Social agents	Rarely
Emoticons and expressions	Rarely
Persuasive messages and reminders	Rarely
Suggestions, advice	Rarely
Tracking	Rarely
Subliminal persuasion	Rarely
Progress	Not used
Video-based persuasion	Not used
Positive reinforcement	Not used

Table 2.1. List of motivational affordances [71]

According to Hamari, for ecological related systems, the most often implemented affordances are visual and audio feedback, social features, ambient/public representations and rewards. Many of the studies featured objectives and goals. Besides, competition is also found to be among the popular implementations. This review shares similar results with other mentioned design spaces [45, 62, 64, 136].

Psychological outcomes	Frequency
Awareness	Usually
Motivation	Frequently
Engagement, encouragement	Frequently
Enjoyment, "fun"	Rarely
Negative attributes	Rarely
Attitude	Not used
Self-efficacy	Not used
Trust, credibility	Not used
Commitment	Not used
Sense of community	Not used
Adherence	Not used

Table 2.2. List of psychological outcomes [71]

In terms of psychological impacts, raising awareness about current consumption seems to be the dominant outcome. This is relevant to what have been concluded by [102]. Motivation and engagement were found to be employed quite frequently. Furthermore, some studies were also concerned (i.e., emotions) with the enjoyment and the negative attributes of persuasive systems. We consider the psychological impact as well as motivational elements as important factors to be deeper analyzed.

Summary: Hamari reviewed 95 PIS and provided an overview about how motivational affordances, psychological mediators/outcomes and behavioral outcomes are shaped in current studies. Of these studies, 20/95 targets energy-related behaviors. Visual and audio feedback, social features and goal-settings are among the most popular affordances. For psychological outcomes, most of the studies aimed at raising awareness and motivation.

2.1.6. Cano's Design Space

Cano et al. [22] present a critical analysis of 10 persuasive systems dedicated to energy. In this survey, the authors propose a design space composed of 6 dimensions. These dimensions (see Table 2.3) include the domain(s) (i.e., application domains covered by the persuasive interactive systems), persuasion functions, data representations, user interaction, scales and devices. For some of the dimensions, sub-dimensions are identified. They are detailed below (Table 2.3).

1. Domain(s)	
2. Persuasion functions	Mirror (details of appliances, feedback, history, comparison) What-if (future projection, simulation payment) Explain What-for Recommend Suggest-and-Adjust
3. Representation	Textual, Realistic, Symbolic, Artistic, Quantitative
4. Interaction	Multi-Device Management History navigation Annotations Gamification elements Objectives, Goals Personalization
5. Scales	Time (past, present, future) Space (room, house, neighborhood) Human (individual, family, community)
6. Devices	Smartphone, tablet, PC, web application, ambient

Table 2.3. Six dimensions of Cano's design space.

The domain under study can be any domain but it has been applied to energy consumption. The second dimension identifies persuasive functions to be implemented in a persuasive system. Cano has identified and defined 6 classes of persuasion functions:

- **Mirror.** Such a function is designed to make observable the current users' behaviors in terms of energy consumption. For instance, an implementation could be a visualization of energy consumption per appliance;

- **What-if.** Such a function is designed to allow users to simulate a future behavior and to observe its possible consequences. The goal is to provide users with a means to explore and experiment various possible behaviors in order to find a feasible and appropriate behavior to be achieved;

- **Explain.** This class of functions aims at explaining, enlightening users, making them understand not only the effects but also the causes of their current behaviors;
- **What-for.** This class of functions aims at guiding users towards the achievement of their objectives. Such an interactive simulation tool would allow the selection of desired effect and to explore the possible actions to be achieved (i.e., goals) in order to obtain this effect.
- **Recommend.** This class of functions aims at providing appropriate recommendations and suggestions based on user-context to promote and support behavior change;
- **Suggest-and-Adjust.** This class of functions aims at facilitating the decision-making process through a user/system negotiation approach. For instance, the system could suggest situations then adjust them based on user's responses.

The third dimension deals with the types of representations of information: *Textual, Realistic, Symbolic, Artistic, Quantitative*. It echoes the design spaces discussed previously (e.g., Fang's design space [45]). The fourth dimension targets aspects of the user interaction considered to convey persuasion. This dimension is original compared to the design spaces discussed above. For instance, providing a user interaction that allows the exploration of past consumptions is a means to implement Mirror and Explain persuasive functions. The fifth dimension considers information scale. It echoes the data granularity in the techniques identified by Froehlich [64]. Finally, the sixth dimension is related to the devices used to interact with the persuasive user interactive system and thus to convey persuasion.

This analysis reveals some interesting insights about persuasive interactive systems for energy. First, the **Mirror** function is employed in most of the existing persuasive systems. This finding is consistent with other findings in the literature [64, 71, 102]. By contrast, the **what-for** function is reported to be totally absent from the analysis. Second, despite being widely used, the quantitative/numerical/symbolic representations are not always considered as appropriate ways to induce behavior change. Finally, the analysis reveals a particular attention on user interaction aspects. We believe that besides traditional interaction/navigation techniques, other ways of interacting with users would be worth considering to support persuasion. This aspect is worth to be deeper investigated.

Summary: Cano's work involves the analysis of 10 persuasive systems for energy. It introduced a design space composed of 6 dimensions (domain(s), persuasion functions, data representation, interaction, scales and devices). The analysis revealed that most of the studies aim at making observable current users' behaviors. In addition, it suggests to forster user interaction aspects of persuasive systems.

2.1.7. SEPIA framework

Focusing on user interaction aspects of persuasive interactive systems, Laurillau et al. [102] address the design of persuasive interactive system by introducing SEPIA, a support for engineering persuasive interactive applications. SEPIA targets two aspects of the design space: the *phenomenon* under study and the *properties of persuasion* of a persuasive interactive system. Figure 2.2 illustrates the design space.

Properties / Phenomenon		Effect	Cause	Causality
Doing-related properties	**Maintainability**	Benefit	Sustain	Reward
	Accountability	Target	Engage	Control
	Protectability	Alert	Prevent	Anticipate
Understanding-related properties	**Learnability**	Induce	Deduce	Experiment
	Intelligibility	Situate	Recommend	Explain
	Observability	Reveal	Reflect	Discover

Figure 2.2. SEPIA Design space

Inspired by classical properties of user interfaces (i.e., observability), six properties of persuasions are identified, organized into two groups of three properties: functions to understand the phenomenon or behavior under study (understanding); functions to be achieved by the system and support for new behaviors (doing). The six properties are: Observability, Intelligibility, Learnability, Protectability, Accountability and Maintainability. Each property is considered through the prism of the phenomenon in terms of cause, effect and causality. Consequently, it leads to 18 classes of interactive functions of persuasion. Table 2.4 to 2.9 detail the 18 classes.

Observability. This set of UI properties aims at making users aware of their behaviors.

Reveal	**Reflect**	**Discover**
Making visible the effects of user's current behavior related to the phenomenon under study.	Making visible the human activity.	Making visible the relationship between the causes of a behavior and its effects.

Table 2.4. Observability properties

Intelligibility. This set of UI properties aims at better understanding the reasons of current behaviors.

Situate. Making sense of the current behavior effects by providing means to compare with others, and putting the current situation into context.	**Recommend**. Suggesting appropriate situations to reach a desired behavior.	**Explain**. Explaining the relationship between the causes and its consequences (effects)

Table 2.5. Intelligibility properties

Learnability. This set of UI properties aims at allowing users to discover and learn new behaviors.

Induce. Based on simulation engine, this function aims at helping user to identify the suitable behaviors that could lead to the defined goals.	**Deduce**. Based on simulation engine, this function aims at helping user to identify the possible effects of a defined behavior.	**Experiment**. Facilitating the induce/deduce iteration. This function allow user to find the compromise between their desired goals and behaviors.

Table 2.6. Learnability properties

Protectability this set of UI properties aims at protecting users from undesired behaviors and/or contexts.

Alert. This function alerts users of an actual undesired situation (effects).	**Prevent**. This function prevent user from undesired behaviors (causes).	**Anticipate**. This function anticipates the potential causes that could produce undesired situation and to help users to avoid such situations.

Table 2.7. Protectability properties

Accountability. This set of properties aims at engaging users in the achievement of new behaviors.

Target. This function helps users to identify and set goals in order to achieve new behaviors.	**Engage**. This function engages the user in an action loop to achieve a new behavior (i.e., notification mechanism).	**Control**. This function controls the causes and effects in a way that balance user's actual behaviors and desired outcomes.

Table 2.8. Accountability properties

Maintainability. This set of properties aims at maintaining behavior change over time.

Benefit. Making users aware of the effects either desired or undesired in the future.	**Sustain** Making users aware of the behaviors that could lead to undesired/desired outcomes in the future	**Reward**. This function rewards users of either obtaining a desired outcomes (effects) or avoiding unwanted behaviors (causes).

Table 2.9. Maintainability properties

In this work, Laurillau et al. [102] conducted an analysis of ten energy-related studies to analyze the evaluation power of SEPIA. Figure 2.3 characterizes these works.

Properties / Phenomenon		Effect	Cause	Causality
Doing-related properties (3)	Maintainability (1)	Benefit	Sustain	Reward
	Accountability (3)	Target	Engage	Control
	Protectability (0)	Alert	Prevent	Anticipate
Understanding-related properties (10)	Learnability (3)	Induce	Deduce	Experiment
	Intelligibility (5)	Situate	Recommend	Explain
	Observability (10)	Reveal	Reflect	Discover

Figure 2.3. Characterization of 10 studies with framework SEPIA

The study shows that most of the systems under study target the understanding-related properties. In other words, existing systems aim at making users aware of their current behavior and to understand the consequences of these behaviors. A few of these systems provides means to learn new behaviors. However, existing systems does not engage users to achieve new behaviors. This analysis is consistent with the observations made by the works considered in this chapter. Indeed, referring to the TTM model [143, 144], in terms of behavior change process, current works are mostly targeting *precontemplators* and *contemplators*. In addition, designers mostly explore the effects of user's behaviors and less the causes nor the causality. This framework provides a worthy foundation to be further explored in future works.

Summary: SEPIA targets two aspects of the design space: the *phenomenon* under study and the PIS's *properties of persuasion*. Within the design space, six properties of persuasions are identified, divided into two groups (understanding, doing) of three properties (cause, effect, causality), giving rise to 18 classes of persuasive functions. The evaluation of SEPIA shows most of the systems under study targets the understanding-related properties. Besides, it targets more the effects of user's behaviors and less the causes nor the causality.

2.1.8. Persuasive Interactive Systems: Corpus of Classification

Daniel et al. [33] achieved the classification of 44 existing persuasive systems dedicated to energy based on 15 criteria organized into four classes: the system, the user interface, the user and the context. Interestingly, some of these criteria explicitly target the process aspects of behavior change. Indeed, Daniel's *target change* criteria is based on the five stages of the TTM [143, 144]. In addition, nine persuasion and eight gamification functions are examined. The persuasion functions are: *Prediction, Suggestion, Evaluation, Simulation, Immediate Feedback, Cumulative Feedback, Temporal Comparison, Spatial Comparison* and *Social Comparison*. In terms of gamification functions, *Challenge*, *Competition, Collaboration, Progression, Social Interaction, Personalization, Reward* and *Achievement* appeared to be keys.

As a result, this study highlights that none of these systems has covered all the stages of change. Surprisingly, all these systems are providing functions to maintain the individual's motivation. However, only half of them covers the *precontemplation* stage and a quarter covers the *preparation* stage. Expectedly, most of the existing studies offer feedback as a persuasive function. The comparison functions are worth considered by being implemented by half of the systems. However, little seems to support prediction, suggestion or simulation functions. Moreover, the study reveals that the implemented interfaces are primarily in the form of mobile devices or ambient representations. The author suggests to make "*graphical and ambient interfaces coexist and complement each other*" [33] by combining their different functions, to cover all the stages of the TTM model.

This work provides a significant overview about current research in persuasive interactive systems especially in energy. However, we observed some inconsistencies between the results of this classification and others classifications. For instance, the studies of Laurillau [102] and Cano [22] have shown the lack of support for the TTM's maintenance stage. However, according to Daniel et al., all the systems claimed to support the maintenance stage.

Summary: Daniel et al classified 44 persuasive systems for energy based on 15 criteria of four classes: the system, the user interface, the user and the context. Some of these criteria target the process aspects of behavior change (based on the TTM). The evaluation reveals that feedback, comparison functions are widely used while other techniques (simulation, suggestion) seem to be insufficiently exploited. Besides, it provokes some inconsistency with other design space and framework within this section.

2.2. Discussion

The review of the eight classifications reveals differences between them in terms of focus: some classifications have a strong focus on feedback (i.e., eco-feedback) while others focus on the perception of motivation (i.e., Hamari's classification [71]). Furthermore, this review also reveals that the HCI aspects of persuasion are often secondary or implicit. However, in order to conduct a rigorous state-of-the-art of persuasive interactive systems for energy, we need to identify relevant criterion related to the persuasive aspects of user interfaces and user interaction. Thus, this part analyses these classifications in order to highlight their complementarities as well as their differences: the ultimate goal is to build an analysis grid of the persuasive aspects of HCI based on criteria that cover, and that are consistent with these existing classifications.

2.2.1. Method and graphical meta-classification

We considered three aspects to build a meta-classification: the psychological dimension of persuasion and behavior change, the motivational and/or behavioral change support strategies/principles identified by these classifications, and the HCI aspects related to persuasion. Then, we filled each category with each criterion considered by a classification. As some classifications may share the same criteria, we annotated this with a number (last digit of the section number of the sections constituting part 2.1). As much as possible, we reuse the same terminology used by classifications to group criteria. Otherwise, we choose a category's name that is semantically close to the group of criteria. In addition, we annotated the criteria with a generic aspect of persuasion: (1) motivation and related psychological factors; (2) behavior change support; (3) attention stimulation (i.e., triggers).

The resulting graphical mapping of the classifications is represented in Figure 2.4. We used a hierarchical structure with the three main branches, the three aspects mentioned above. Icons are used to tag the nodes (see legend on Figure 2.4): a smiley indicates that a node is related to motivation (i.e., a psychological outcome or a motivational affordance); a rocket indicates that a node is related to behavior support; a warning sign indicates that a node is related to attention stimulation; a light bulb indicates that a node is related to comprehension (one of the sub-nodes of the branch related to the strategies of persuasion).

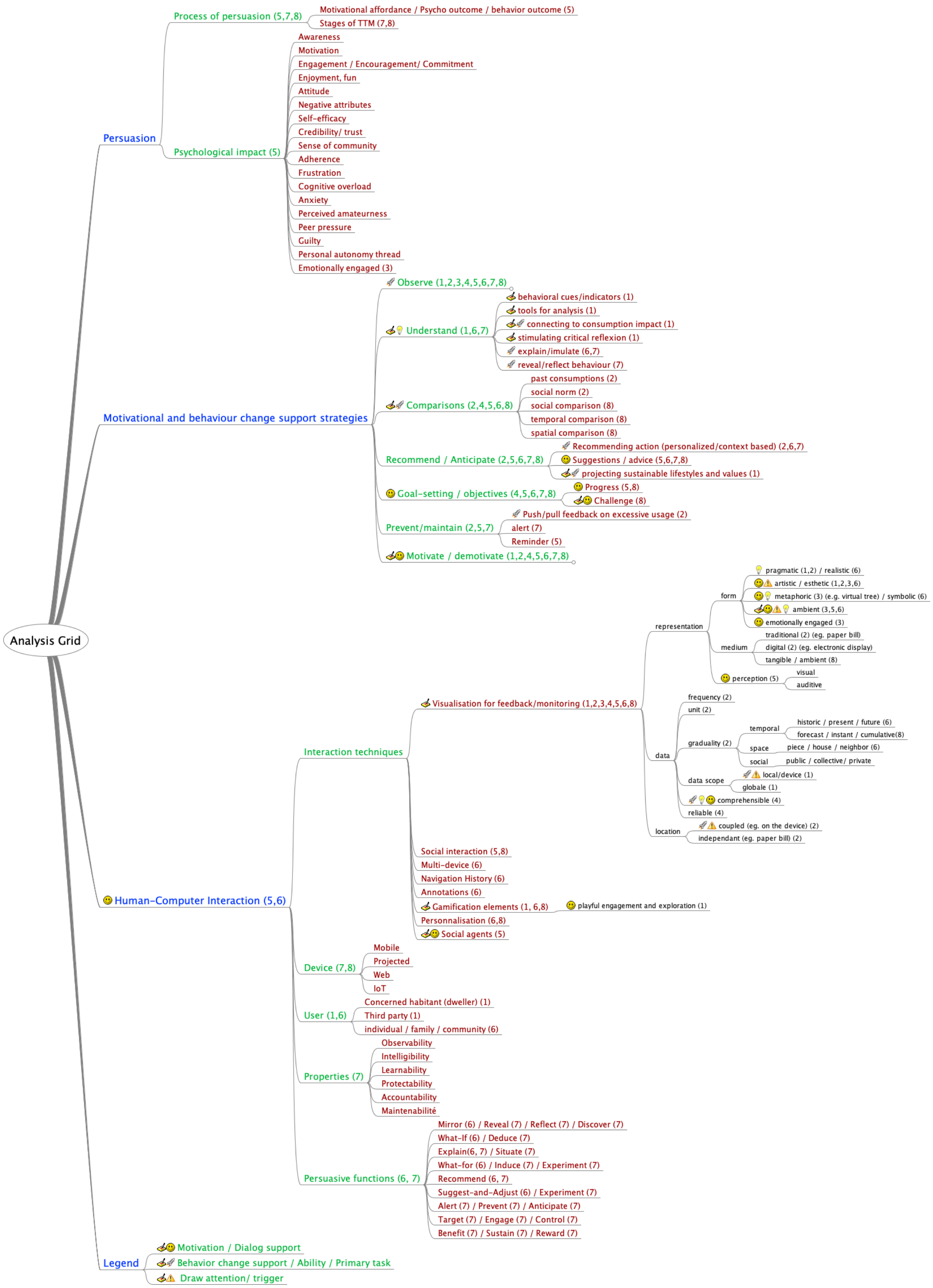


*Figure 2.4. Analysis grid of eight studies, the number in the brackets refers to the subsection index in this section (i.e., number 2 for section 2.2.**2**). Icon represents the effect in terms of motivation, ability, etc.*

2.2.2. Analysis

In this part we discuss how these classifications cover each of the three aspects.

Persuasion. This branch covers the psychological aspects of persuasion and behavior change. The classification of Hamari et al. [71] is the only one that explicitly addresses the psychological aspects of persuasion through a conceptual process of persuasion made of three steps related to: motivational affordance, psychological outcome and behavior outcome. Based on the literature, they identified several psychological outcomes (awareness, enjoyment, engagement, commitment etc.). Conversely, based on the Transtheoretical Model of behavior change, two classifications (the study of Daniel [33] and SEPIA [102]) explicitly consider the process dimension of behavior change. As highlighted by Pinder et al. [140], "*behavior change is a long-term process*" and they advocate for PIS designed for tailored interactive systems and designed for long-term user interaction. Considering the process dimension is clearly key.

Motivational and behavior change support strategies. Although all of the classifications promote either motivational strategies (e.g., incentives, rewards, etc.) or behavior change support strategies (i.e., comparison, setting objectives, etc.), we observe that most of the classifications put a strong focus on motivation as well as on monitoring as a primary strategy to support behavior change. However, many behavior support strategies are first considered through the prism of motivation. For instance, tracking (i.e., capturing the consequences of a behavior) is a motivational affordance for Hamari et al. [71]. Another example, setting goals (e.g., planning a behavior change) is a source of motivation for Froelich et al [64]. Consequently, no classifications clearly distinguish motivational strategies from behavior support strategies as done by the PSD model [125] (PSD's primary task support is related behavior change support strategies while dialog support is related to motivational strategies). Conversely, SEPIA [102] and the work of Daniel [33] are two classifications that explicitly consider behavior change strategies based on the Transtheoretical Model of behavior change. However, SEPIA does not clearly consider motivational strategies.

In terms of behavior change support strategies, we observe that only a small set of classifications consider strategies to explain a behavior to better understand its consequences (cause-effect-causality) as well as strategies to maintain a change over time.

Human-Computer interaction. Among the interaction techniques that are considered to support persuasion, feedback and eco-feedback are the most prevalent and investigated interaction techniques. To mitigate this observation, this is a consequence of the chosen application domain (energy) in this work. Indeed, we focused on classifications found in the literature related to energy: an important body of early work focuses on eco-feedback. However, we observe that most classifications restrict persuasive user interaction to visualizing data. By contrast, gamification is mostly considered as a motivational although it has an impact on user interaction. In the same vein of the work of Cano et al. [22] and SEPIA [102], we advocate for fostering persuasion in terms of HCI.

Summary: we built a meta-classification made of three aspects: the psychological dimension, the motivational and/or behavioral change support strategies/principles, and the HCI aspects. As results, not so many addresses the psychological aspects of persuasion nor the process aspect of behaviors change. A strong focus is put on motivation as well as on the monitoring strategy to support behavior change. Moreover, feedbacks are the most prevalent and investigated interaction techniques. Furthermore, persuasive user interaction seems only considered in terms of data visualization.

2.3. UP+

Built upon the eight classifications discussed in the previous section, we propose the UP+ framework in order to conduct a state-of-the-art of existing PIS for energy. In addition, we envision this framework as a conceptual tool for structuring the exploration of the design space when designing persuasive interactive system. Indeed, compared to the classifications discussed earlier, UP+ is conceived to focus on the HCI aspects of persuasive interactive systems and it constitutes an increment of the two design spaces: UP [103] and SEPIA [102].

In a nutshell, UP+ embraces two aspects, behavior change process support (i.e., TTM [143, 144]) and psychological aspects of persuasion (i.e., motivation), considered through three dimensions:

(1) Long-term user interaction to support effective behavior change
(2) Phenomenon-based user interaction (i.e., considering the behavior under study in terms of cause-effect-causality),
(3) Psychological affordances and outcomes through user interaction.

The dimensions are independent, giving rise to a set of combinations, each defining classes of persuasive interactive functions. The two first dimensions are related to the support of a behavior change process at a macro level (long term) and at a micro level (short term). In the following, we first detail these dimensions and explain their conceptual basis. Then, we detail the classes of persuasive interactive functions.

2.3.1. Long-term user interaction: Enlighten, Recommend, Facilitate and Protect

From a user perspective, according to the transtheoretical model of behavior change [143, 144] and related models (see Pinder et al. [140]), behavior change is a process made of stages through which, at coarse grain, a person:

- Often starts to **understand** the current situation about his/her actual behavior (i.e., precontemplation and contemplation stages),
- Then **decides** for a change to target a different behavior (i.e., contemplation and preparation stages),
- And **acts** consequently to reach that new behavior (i.e., action stage),
- Trying to **protect** himself/herself from unwanted behavior (i.e., action and maintenance stages).

In their work, Laurillau et al. [102, 103] have observed that existing persuasive systems for energy mostly focus on functionalities that support the understanding of the current behavior and that support action and a very few on functionalities that support decision and protection.

From a system point of view, to support the user appropriately, we identify the four following classes of functions: **enlighten** for making the user *understand*, **recommend** for helping the user to *decide*, **facilitate** positive *actions* and **protect** from negative behaviors. We envision these classes to support the main stages of behavior change process:

- **Enlighten**. This set of interactive features aims at making observable current behavior and at making intelligible its determinants (i.e., the context and its associated cues that trigger a particular behavior). It echoes the first stages of TTM in which people in the precontemplation stage need to observe their current behavior to move to the contemplation stage. For the latter, people need to understand the pros and the cons of their current behavior to decide for a change. As well, Pinder et al. [140] underline the importance of raising awareness about undesired habits that are unconscious in order to move towards consciously desired new behaviors. Therefore, techniques/methods/strategies such as social influence, cognitive dissonance are often considered to accomplish this goal. Among Fogg's persuasive principles [56] as well as in the PSD model [125], the related principles are monitoring and self-monitoring. Indeed, these functionalities aim at helping individuals to self-reflect the situation: the identification of the causes and explanation could raise individual ability and confidence in self when they often lack knowledge about the problem, thus provoking the sense of personal control and belief in self. Last but not least, the fact that individuals fully understand their current behavior (not only the effects) could motivate themselves to decide to change. All eight classifications promote strategies (i.e., mostly feedback) to make behaviors observable through visualization interaction techniques. To support intelligibility, among the eight classifications, Pierce et al. [136] recommend strategies that "provide tools for analysis" as well as that "stimulate critical reflection". Our review shows that comparing is another strategy to make intelligible the behavior under study through multiple instantiations (i.e., temporally, socially).

- **Recommend**. This set of interactive functions aims at supporting users to decide and at helping them to prepare for a change. It corresponds to the preparation stage of the TTM in which people organizes the actions they plan to take such as "baby steps" as identified by Fogg. The objective is, thus, to encourage people to develop a plan to take their first concrete action in the direction of the change. For instance, suggestion and simulation are recurring strategies among the recommended strategies [56, 125] to support decision. Indeed, in previous section, we observe that recommending actions or giving generic advice are two of the strategies uncovered by Froehlich et al. [62] and by Hamari et al. [71], including simulation through "projecting and cultivating sustainable lifestyles and values" [136].

- **Facilitate**. This set of interactive functions aims at helping users to plan, to facilitate their engagement to achieve a new and desired behavior, and to support the achievement of actions over time. It echoes the action stage of the TTM. It is also related to Fogg's principles (persuasion as a tool [56]) and to the PSD model (primary task support [125]). However, by contrast, we consider these principles through the prism of the process of behavior change. Setting goals or defining objectives is the most common strategy (e.g., [22, 64, 71]). Besides, while goal setting seems to be an effective strategy for this stage, external psychological factors could also be employed including the sense of community, adherence. Moreover, the use of positive reinforcement (compliment, rewards etc.) could stimulate intrinsic motivation and satisfaction.

- **Protect**. This set of interactive functions aims at keeping users in the process (i.e., stay motivated), at protecting users to give up the current process of change but also to alert if the current behavior is moving towards an undesired behavior. It corresponds to the maintenance stage of the TTM. According to Fogg’s principles and to the PSD model, rewards are a means to sustain behavior change. The eight classifications provide many strategies related to the rewarding principle. However, only a few consider prevention (i.e., "Push/pull feedback on excessive usage" [62].

We consider this process approach and the stages as iterative and incremental, which seems adequate to one of the Oinas-Kukkonen postulate [125]. In order to build a desired habit, the desired behavior must go through the cycle and repeat sufficiently in stable contexts [140]. Therefore, the interaction system should be designed to operationalize this macro process of behavior change. Moreover, we claim that the user interface should adapt its content as well as the user interaction depending on the current stage in order to push the relevant features and to maximize the persuasive effect and to keep the user in the process of change over time.

2.3.2. Phenomenon dimension: Cause, Effect, and Causality

The second dimension is phenomenon-oriented as it considers behavior occurrences at a micro level in terms of cause, effect and causality. According to the Oxford dictionary, a phenomenon is defined as "*a fact or situation that is observed to exist or happen, esp. one whose cause or explanation is in question*". To understand a behavior and to support the achievement of new behaviors, not only the consequences should be observable and explained but also the causes as well as their relationship (i.e., causality). This point of view is fully in line with the persuasive principles recommended by the literature (i.e., primary task support principles of the PSD model, Fogg's "cause and effect" principle). However, as highlighted in previous sections, we observe that one limitation of current classifications is to focus too much on the consequences (effects). We therefore consider the necessity of exploring the process of cause-effect-causality. We believe that, in order to decide to change, individuals not only need to observe the consequences (on environment, financial situation etc.) but also to understand how and why it occurs.

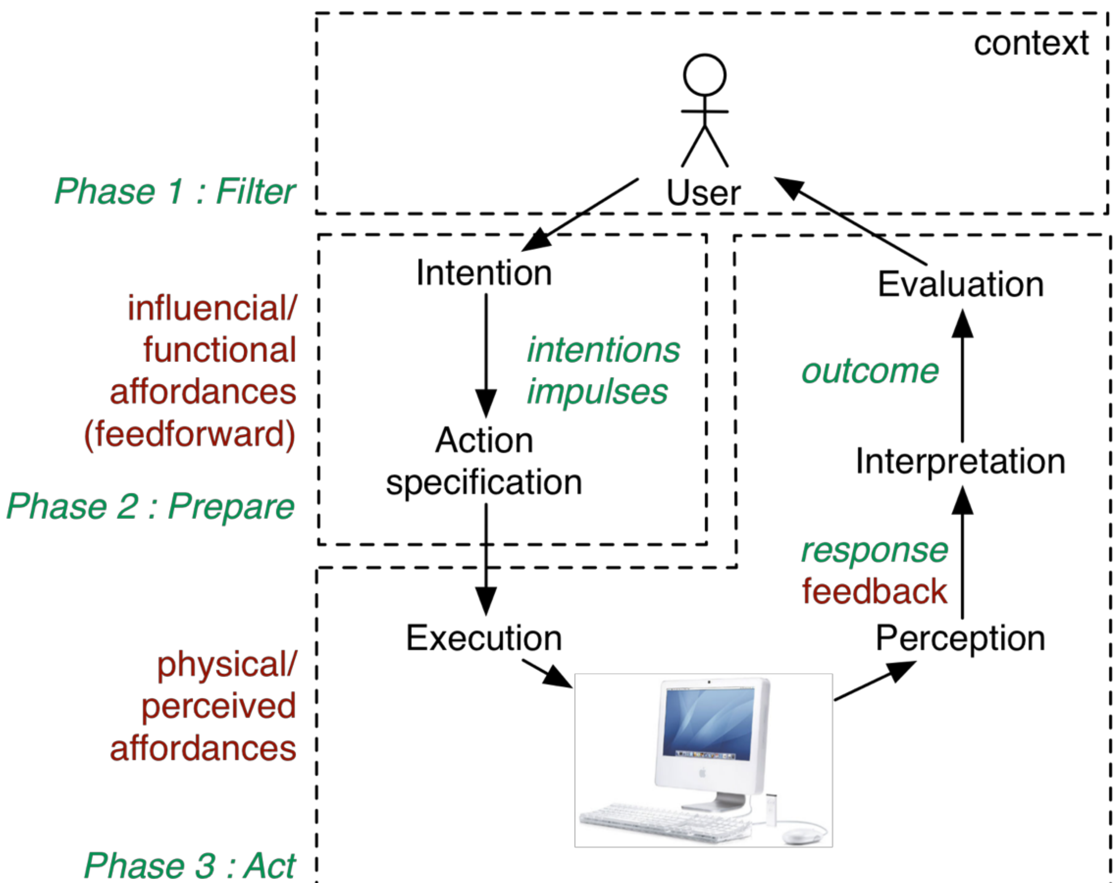


Figure 2.5. Norman's gulfs of execution/evaluation coupled with the HAM model

For Pinder et al. [140], behavior change is an iterative process (macro process), made of sequences of habits (micro process), that requires to be repeated in various steps during the formation of habit change. We draw a parallel with Norman's action theory [120], that is the micro process aspect of user interaction, in order to identify intervention points in terms of user interaction. Figure 2.5 illustrates a mapping of the HAM model with Norman's model. We observe that both models consider the forming of intentions and the execution of a sequence of actions. The causes of a behavior are these intentions and actions but also the determinants of behavior (i.e., the context and input cues). The consequences are the responses (i.e., feedback) obtained through perception and interpretation, and the outcomes obtained through evaluation. Therefore, causality is the relationship between the top-down part of the micro process and the bottom-up part. This is Norman's "gulf of execution-gulf of evaluation".

While designing an interactive system, Norman et al. [120] recommends to design a user interaction that minimizes the "gulf of execution". Similarly, persuasive strategies such as tunneling and reduction are "primary task support" principles (PSD model [125]) that aim at facilitating achieving a behavior. Consequently, such perspective allows supporting the intelligibility of behaviors but also the facilitation of achieving a behavior. Taking apart SEPIA [102] and Cano et al.'s work [22], some of the classifications consider the cause-effect-causality perspective. For instance, Pierce et al. [136] recommend the strategies consisting in "offering behavioral cues and indicators", "connecting behavior to material impacts of consumption", and "projecting and cultivating sustainable lifestyles and values". Froehlich indirectly considers the cause/effect perspective in terms of incentives/discentives and rewards/penalties [64].

Another property of this mapping allows us to identify interventions points to instantiate "motivational", or more generally psychological, affordances and outcomes. This aspect constitutes the third dimension discussed in next section.

2.3.3. Psychological impact: affordances and outcomes

The third dimension is related to psychological aspects of persuasion and behavior change. We consider this dimension orthogonal and complementary to the two other dimensions. Instead of using the term “motivation”, we prefer reasoning in terms of psychological impact. Indeed, in psychology, attitude has three components: cognitive (thoughts or beliefs about someone or something), affective (feelings, emotions), and conative (inclination to act). As observed by Pinder et al. [140], the support of motivation by persuasive systems is often reduced to the conative component and emotions are often forgotten. But, according to psychologists [16], there exists multiple sources of motivation: physiological, emotional, cognitive and social. Therefore, we observe that the eight classifications mostly consider strategies related to the conative component as well as to social motivation. However, some classifications consider emotions and feelings with strategies such as artistic feedback (e.g., [45, 62, 136]), playfulness and gamification (e.g., [33, 136]).

As illustrated in Figure 2.5, inspired by Hamari et al's decomposition [71], combining the usual approach in HCI and the HAM model, user interaction may be designed to have a psychological impact at three levels in terms of affordance, of response, and of context. In HCI, affordance plays a role in intention forming and execution. A well-designed user interaction with the right affordance helps to reduce the gulf of execution (there are often two levels of affordance: functional affordance while intentions are forming; and physical affordance while executing the action). Similarly, an effective persuasive user interaction requires the right motivational affordance (e.g., playfulness through gamification, social comparison). As well, to reduce the gulf of perception, feedback should be designed appropriately (e.g., understandable messages). Similarly, an effective persuasive user interaction requires delivering the right psychological outcome (e.g,, reward, greetings). Finally, as underlined by Pinder et al. [140], the context plays a key role in persuasion: adapting user interaction depending on the context (including user's cognitive availability) is key to build successful persuasive interactive systems.

2.3.4. Classes of interactive persuasive functions

User / System / Phenomenon	**Understand**	**Decide**	**Act**	**Protect**
	Enlightener	Recommender	Facilitator	Protector
Cause (Behavior)	Reflect behavior	Recommend actions	Engage	Prevent
Effect (Situation)	Reveal situation	Suggest situation	React	Alert
Causality	Explain	Simulate	Manage	Anticipate

Figure 2.6. UP+

By crossing the two first dimensions (macro x micro processes of behavior change), UP+ invites to investigate the cause-effect-causality in depth thanks to a set of functions corresponding to the roles user and system will play in the interactive system. Figure 2.6 summarizes our core functions. We refine each role of a persuasive system (Enlightener, Recommender, Facilitator, Protector) into classes of functional features for each aspect of the phenomenon it addresses (Cause, Effect, Causality).

Enlightener

We refine the enlightener role into three classes of functionalities: reflect behavior centered on causes; reveal situation centered on effects; and explain centered on causal relationship between cause and effect.

- **Reflect behavior**. Functionalities that make observable the human activity that causes the phenomenon. For instance, providing indicators (i.e., consumption average) would make better understand if a behavior is appropriate by making sense of the information.
- **Reveal situation**. Functionalities that give users access to raw data or information that inform about a current state or reached situation (i.e., the effect) due to user activity related to the problem tackled by persuasion.
- **Explain**. Functionalities to explain the causal relationship given the current state (i.e., the induced effects), to make explicit the causal relationship between human activity and observed facts. For instance, such functions may illustrate how a phenomenon occurs such as system-based explanation engine.

Recommender

We refine the recommender role into three classes of functionalities: recommend actions centered on causes; suggest situation centered on effects; and simulate centered on causal relationship.

- **Recommend actions**. Functionalities to recommend alternative behaviors (i.e., causes) suitable to solve the phenomenon tackled by persuasion.
- **Suggest situation**. Functionalities to suggest alternative situations (i.e., effects) to be reached. For instance, indicating a social norm provides a comparison means to suggest an alternative situation to be reached.
- **Simulate**. Functionalities allowing users to conduct and iteratively evaluate inductive-deductive cycles in order to identify relevant and desired user-defined behaviors and effects.

Facilitator

We refine the facilitator role into three classes of functionalities: Engage centered on causes; Reward centered on effects; and Manage centered on causal relationship.

- **Engage**. Functionalities allowing users to engage in a desirable change of behavior.
- **React**. Functionalities making the user aware of desirable effects now or in the future and reacting through, for instance, rewarding, greetings, etc.
- **Manage**. To maintain ability, a learning machine-based system engine could be employed to facilitate users with automatic actions while keeping users in control. Functionalities making possible for users to manage the behavior change process in a way that balances actual behaviors and the desired outcomes. Mapping with Fogg’s behavior model, the system may

allow the user to plan and to set intermediate motivation and ability levels to reach an intermediate behavior change.

Protector

We refine the protector role into three classes of functionalities: Prevent centered on causes; Alert centered on effects; and Anticipate centered on causal relationship.

- **Prevent**. Functionalities that prevent users from unwanted behaviors.
- **Alert**. Functionalities that alert users in case of unwanted consequences compared to a desired goal.
- **Anticipate**. To maintain ability, a learning machine-based system engine could be employed to make the user aware of appropriate (respectively inappropriate) behaviors or of behaviors suitable to become valuable (respectively risky) in the near future.

2.3.5. Projecting the Psychological dimension of motivation

In our approach, we project the psychological dimension on each of the twelve classes of persuasive functions. As highlighted in section 2.3.3, the user interface may be designed to convey these psychological factors at three levels: in terms of motivational affordances, motivational outcomes, and context alteration. In our review of the eight classifications, three main psychological factors are found to be among the most effective [33, 71]: Social influence, Gameful experiences and Aesthetics. Persuasive functions, thus, can take advantage of these factors in order to be more effective but other psychological factors could be considered to reinforce persuasion and to convey motivation. In the following, we illustrate the mapping of these three psychological factors onto the four main classes of persuasive functions.

Social influence. Social influence theory has a long history in psychology [24, 60, 61]; In the four dimensions of PSD [125], one dimension is dedicated to social influence. According to [71], the social features are widely employed in persuasive system in energy such as social support, social comparisons, social feedback, social interaction and social sharing. In addition, social features can be used in conjunction with feedback or other techniques to enhance the persuasion means. Social influence may be projected on each of the four classes. For instance, social comparison is employed in revealing user's current consumption to better display how this consumption comparing with others, thus increases user's understandability and awareness. As well, it may help to drive action through settings goals (based on what others are doing) or making observable progress of the change towards a desired behavior. Indeed, strategies such as social incentives, challenges or leaderboard can also be used to drive decision and action. Social sharing is another strategy to support decision through advice. Social agent feature is a strategy that can be implemented (i.e., social pet) to protect users from relapse.

Aesthetics. Multiple classifications, especially the classifications related to eco-feedback, promote aesthetics (including ambient, metaphorical, symbolic representations) as a mean to improve persuasion through appealing representations. It triggers the affective component (intrinsic motivation): pleasure, beauty, calm, etc. Indeed, attractiveness is one of Fogg's design principles [56]. Pierce et al. [136] propose the aesthetic approach as one solution to provide alternative and meaningful way to communicate data with users. Froehlich [62] finds that users appreciated both artistic metaphors and numeric presentation as they complement each other. Fang [45] investigates the aesthetic aspect as one dimension of their design space. Consolvo [27] introduced goals/strategies for promoting everyday behavior change in which aesthetic and abstract/reflective happens to be the two key principles for designing a persuasive system. Attractiveness is a strategy to support awareness (i.e., to understand a current behavior) as well as to maintain the change over time (i.e., protect).

Gameful experience. Gamification has been considered as medium "to engage people and enhance positive patterns in using service, such as increasing activity, interaction, or quality and productivity of actions" [126]. It is believed that persuasive gameful systems are effective tools for motivating behavior change [126]. Thus, many studies have featured the gamification functions into the design of persuasive system. For instance, Daniel [33] identifies seven functions: challenge, competition, collaboration, progression, reward, achievement, personalization, and social interaction. Orji [126] chooses to investigate ten persuasive strategies often employed in gameful systems. Tondello [169] presents a novel model of eight groups of gameful elements into three categories individual motivations, external motivations and social motivations. It conveys playfulness, enjoyment, and social interactions. Such features are an approach to support action (i.e., goal setting, challenges, rewards, greetings, etc.) and to prevent relapse (i.e., social inclusion). Virtual reality-based simulator may be considered as a gameful experience and often used to fight fear when to coming to action in the real world.

Other psychological factors. Trust and credibility are other important psychological factors (i.e., PSD model) when designing PIS. However, in their review, Hamari et al. [71] have not found any PIS addressing trust or credibility. Some classifications target the cognitive component to make understandable feedback with pragmatic representations [64]. As well, reminders, that support action and prevention, are means to reduce the cognitive overload. Strategies such as behavioral cues (i.e., understand) and the projection of sustainable lifestyles (i.e., decide) also triggers the cognitive component of attitude.

Summary: We present a conceptual tool for structuring the exploration of the design space when designing PIS. It constitutes an increment of the two design spaces: UP [103] and SEPIA [102]. UP+ embraces two aspects, behavior change process support and psychological aspects of persuasion, considered through three dimensions:

(1) Long-term user interaction (macro level) involves four classes of functions **enlighten**, **recommend**, **facilitate** and **protect**; these stages are considered as iterative and incremental.

(2) Phenomenon-based user interaction considers behavior occurrences at a micro level in terms of cause, effect and causality.

(3) Motivational affordances and outcomes through user interaction complement the two other dimensions. Three psychological factors are found to be among the most effective: Social influence, Gameful experiences and Aesthetics.

2.4. Synthesis

In this chapter, we presented eight classifications found in literature on persuasive interactive systems. Moreover, we analyzed each classification through a cartography structured on three major aspects: psychological factors, behavior change support and motivational strategies, and user interaction. We pointed out their complementarities as well as their limits about the design of interactive systems: process dimension of behavior change, focus mostly put on the consequences of behaviors (e.g., feedback); psychological factors mostly limited to the conative component of attitude; persuasive user interaction mostly limited to feedback through visualization techniques.

To overcome these limits, built upon these classifications, especially UP [103] and SEPIA [102], we presented a new framework, named UP+, centered on persuasive user interaction. UP+ combines three dimensions: long-term user interaction to support behavior change over time (macro process), phenomenon-based user interaction considered in terms of cause-effect-causality (micro process), and psychological affordances and outcomes through user interaction. The first goal of this classification is to serve as an analysis grid to review existing PIS for energy, presented in the following chapter. We also envision UP+ to serve as a conceptual tool for the designer of PIS.

3. Analysis of persuasive interactive systems using UP+

3.1. Introduction

In this chapter, we focus on existing studies of PIS for energy. Before featuring UP+ as analysis grid to review current PIS dedicated to energy, we will explain our reviewing methodology and present an overview about our selection corpus.

3.1.1. Review Methodology

Our review process draws primarily from publications in well-known conferences of Human Computer Interaction research such as CHI, Interact, DIS, Ubicomp, IHM and the annual conference dedicated to persuasive technology (PERSUASIVE). We target some of the largest database of the domain including Google Scholar, ACM digital library or Springer to perform the search. Some important keywords are “persuasive interactive system”, “eco-feedback”, “captology”, “ambient awareness”, “persuasive sustainability” etc. We also look for the referenced papers in the design spaces, classifications and other reviews of Persuasive Systems, Eco-Feedback studies (e.g., the classification of Hamari [71], the works of Cano [33] and Daniel [22]). In all, 54 PIS are selected (see Table 3.1). In the review we will refer to the number in Table’s first column instead of the bibliography reference number (second column).

No	Ref	Name	Type	Targeted Behavior	Interface
P1	[75]	7000 oaks and counting	feedback	Co2 emission	Public display, Graphic
P2	[152]	Abstract ambient	feedback-based	Electricity	Ambient, Graphic
P3	[28]	Agent B	forecasting /scheduling	Specific Behavior	Mobile, Graphic
P4	[101]	CasaCalendar	feedback	Water	Ambient, Graphic
P5	[149]	ClockCast	shifting	Electricity	Daily object + Web portal
P6	[90]	Coralog & Timelog	feedback	Specific Behavior	PC, Graphic
P7	[50]	Customisable Dashboard	feedback	Electricity	Mobile, Graphic
P8	[113]	DigitalCalendar	feedback	Electricity	Daily object, Graphic
P9	[42]	Dubuque Water Portal	others	Water	Web Graphic
P10	[91]	EcoIsland	others	Co2 emission	Ambient, Graphic,
P11	[93]	eForecast	shifting	Electricity	Ambient, Graphic
P12	[19]	Energy Aware Clock	feedback	Electricity	Ambient, Daily object, Graphic
P13	[47]	Energy Orb	shifting	Electricity	Ambient, Daily Object, Physic
P14	[135]	Energy Tree	others	Electricity	Ambient, Graphic
P15	[41]	EnergyDub	others	Electricity	Web, Graphic
P16	[176]	EnergyHome	others	Specific Behavior	Mobile Graphic
P17	[66]	EnergyLife	others	Electricity	Mobile, Graphic
P18	[133]	EnergyViz	others	Electricity	Mobile, Graphic
P19	[167]	Feedback Interventions	others	Electricity	Web, Mail Service, Graphic
P20	[29]	Figure Energy	others	Water	Web, Graphic
P21	[155]	Fore Watch	shifting	Electricity	Ambient, Daily object, Graphic
P22	[111]	Green Machine	others	Electricity	Mobile, Graphic
P23	[177]	Handy Feedback	feedback	Electricity	Mobile, Graphic
P24	[85]	Heat-Dial	shifting, scheduling	Specific Behavior	Mobile Graphic

P25	[157]	HEMS	feedback	Electricity	Tablet, Graphic
P26	[186]	Hydrao	feedback	Water	Daily object, Mobile
P27	[89]	In Air	feedback	Air	Graphic
P28	[5]	It is too hot	scheduling	Specific Behavior	Tablet Graphic
P29	[139]	Local Energy indicator	shifting	Electricity	Object, Physic
P30	[154]	MAID	others	Electricity	Graphic Virtual
P31	[43]	Nuage Vert	feedback	Electricity	Public display
P32	[147]	Pereira eco-feedback	feedback	Electricity	Mobile, Graphic
P33	[134]	Personalised eco-feedback	others	Electricity	Mobile, Graphic
P34	[94]	Power Advisor	others	Electricity	Mobile, Graphic
P35	[69]	Power Aware Cord	feedback	Electricity	Ambient, Physic
P36	[178]	Power Pedia	others	Electricity, Specific behavior	Mobile, Graphic
P37	[128]	PowerViz	feedback	Electricity	Tablet Graphic
P38	[78]	Reef	others	Specific Behavior	Mobile Graphic
P39	[174]	Reveal-it	feedback	Electricity	Projection, Public display, Ambient
P40	[18]	ShareBuddy	shifting	Electricity	Mobile Graphic
P41	[119]	Sinais	feedback	Electricity	Ambient Graphic
P42	[6]	Tariff Agent	scheduling	Specific Behavior	Tablet Graphic
P43	[88]	Tenere Tree	feedback	Electricity	ambient, graphic
P44	[97]	TherML	scheduling, others	Specific Behavior	Mobile Graphic
P45	[141]	Thermo Coach	scheduling	Specific Behavior	Email Graphic Tablet
P46	[165]	Tiree Energy Pulse	shifting, forecasting	Specific Behavior	Ambient + Web, Graphic
P47	[98]	UpStream	feedback	Specific Behavior	Daily object, Physic
P48	[17]	Wash Machine	shifting, forecasting, scheduling	Specific Behavior	Tablet, Graphic
P49	[63]	Water display	others	Water	Ambient, Graphic
P50	[8]	WaterBot	feedback	Water	Daily object, Physic

P51	[131]	WattBot	feedback	Electricity	Mobile Graphic
P52	[83]	Watts watt	others	Electricity	PC, Graphic
P53	[148]	Watts Burning	feedback	Electricity	Ambient Graphic
P54	[58]	Wattsup	feedback	Electricity	Mobile, Graphic

Table 3.1 Overview of selected persuasive interactive systems

3.1.2. Overview of selected PIS for energy

Most of our selected studies are papers published during the last ten years (2008 – 2018). This is consistent with Hamari's observations [71], although persuasive technology began to be considered as a research field since the beginning of Captology in 1997. This period of time marked some notable key points such as the works of Oinas-Kukkonen [124], numerous feedback-based approaches, or the changing towards sustainability studies etc. To conduct this review, we considered four aspects to distinguish these works (see Table 3.1): **type, target behavior** and **interface**. These aspects are not necessarily mutually exclusive as one PIS might satisfy multiple criteria.

Type

We target the PISs that share similar ideas of approaching the problem of energy consumption. In other words, PISs attempt to generally form and solve the behavior issues by using relevant design methods. We classified our selection set in terms of the primary service it offers. Four categories are identified: *feedback-based*, *ambient awareness*, *predicting/shifting/scheduling energy usage* and *others*.

Feedback-based studies consider feedback as the core functionality to engage users into more positive behaviors. One extension of this branch is the highly considered *eco-feedback* approach [64]. Although most of the selected studies employ feedback features in the design, 20/54 of them (36%) consider this feature as the leading one (see table 3.1). For instance, P51 and P54 visualize current and past consumption through representations of graphical measures (e.g., graphs). P43, P8, P41, P53 and P2 employ a metaphorical approach in which consumption information is represented as trees, animals, or clouds. PowerViz (P37) combines a classic visualization (e.g., graph, bars, chart) with an abstract illustration to display energy consumption for different use-contexts.

Ambient awareness concerns an approach of utilizing feedback that does not interrupt users' daily life. As "*ambient information consumes little or no awareness*" [46], an ambient display offers information in the periphery of user's attention. The main goal is to raise awareness about current behaviors in order to promote more sustainable energy usage. 12/54 of them are in this category.

For example, Power-Aware-Cord (P35) makes energy consumption observable thanks to an illuminating cable, Energy-Aware-Clock (P12) reveals hourly/daily energy consumption in its surface, and Local-Energy-Indicator (P29) is a device that uses leds to make observable current consumed or stored energy.

Predicting/shifting/scheduling energy usage. This category targets features that anticipate low-cost periods towards the shifting consumption behaviors (P5, P11, P21). Besides, tools that help inhabitant to optimally schedule their energy usage (e.g., heating, laundry) are intensively exploited (P3, P48). Besides, automation features such as using machine learning to predict user's occupancy or routines are regularly employed (P42, P28, P38, P45). This category of features aims at reducing energy impact while still being able to afford the consumer demand. In all, fourteen systems falls in this category.

Others's category targets the combination of different techniques or strategies to effectively support persuasion. Persuasive functionalities are incorporated with motivational techniques in order to assist people towards the desired behaviors. For instance, Green Machine (P22) enables users to visualize current household energy use and compare with their friends. Users can access to contextual advice/tips about how to effectively consume energy. Green Machine also allows users to take a pre-defined goal and challenge their friends on Facebook. ShareBuddy (P40), in the other hand, combines fun and enjoyment elements to motivate users to take energy appointments. It also provides access to current consumption and recommended actions etc. Reef (P38) is an e-coaching prototype that learns and predicts user patterns. It then proposes appropriates actions to reduce heating consumption in household. 18/54 PIS are in this category.

Targeted Behavior

The second aspect are PISs that target similar behavior change. We consider four categories ***electricity consumption, water consumption***, and *specific behavior*. For electricity and water consumption, the PISs target at the reduction of the consumption. For example, EnergyLife (P17) features carousel views to help users to better observe their electricity consumption breakdown into appliances. Water Display (P49) is an eco-feedback system that represents water consumption at different level of granularity (i.e., consumption breakdown to each member of the family, hot/cold water consumption, consumption by appliances, time, space etc.). In all, 32/54 of them focus on electricity consumption and 6/54 of them target water conservation. A few studies target the reduction of CO_2 emission in residential context (P1, P10). Other PISs (14/54) endeavor specific behaviors change such as laundry, computer usage and heating practices.

Interface

A PIS may share similarities in terms of design type and style. Several categories are considered, including *mobile and tablet-based interface*, *ambient devices*, *public display* and *daily-object oriented*. These PIS offer either graphic or tangible interface.

Our analysis shows that most of the UIs are mobile and web-based (24/54). With the rapid development of the IoT technology, tangible devices have also received a considerable attention. Over the 54 studied PIS, 16 of them rely on a tangible user interface, such as PowerChord (P35). Energy Tree (P14) employs a lighting tree to represent accumulated results of energy saving challenge.

The tangible devices are also considered under the form of everyday objects such as a clock, a meter, a calendar or a showerhead. Nine of them (9/54) are found to augment these everyday devices with various interaction techniques. For instance, Hydrao (P26) is an augmented showerhead product that projects colored light: it blinks to alert on water consumption. P5 and P21 are two PISs that transform a wall-mounted clock into a forecast device that informs users about the best time to consume energy. Last but not least, three PISs feature public displays to raise people awareness about energy consumption (P1, P31, P39).

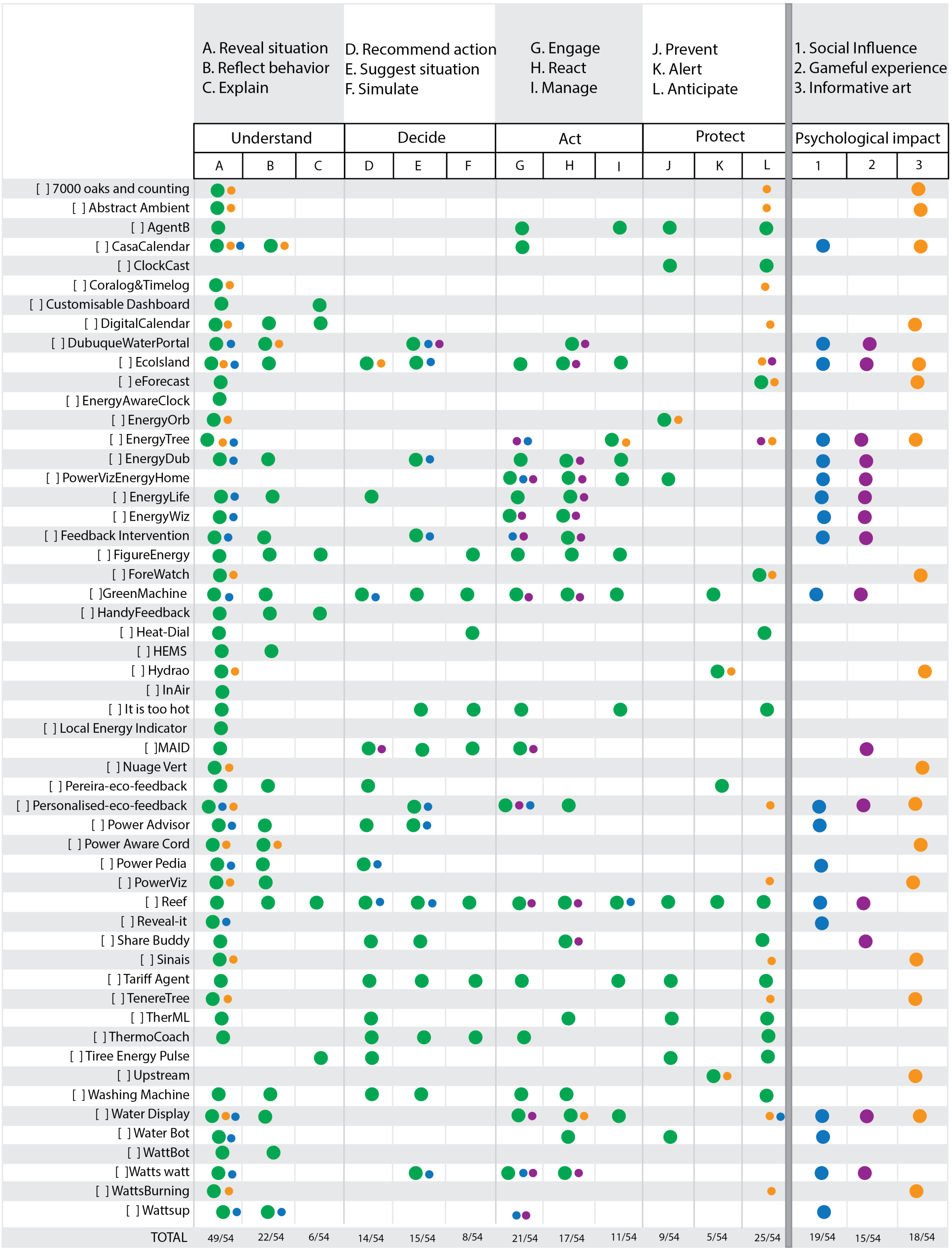


Figure 3.1. Characterization of 54 existing works using UP+

3.2. Characterization of current studies using UP+

In this section, we review our selection PISs dedicated to energy using UP+ as an analysis grid. The objectives of this section are to 1) better understand to what extent the process dimension of behavior change (at both macro and micro levels) and psychological impacts are currently covered and 2) unveil open areas that can be deeper investigated for the design of PISs. We have carefully examined the design of each PIS and mapped them into the UP+ framework. Figure 3.1 summarizes the characterization of these studies: a green circle indicates that the related persuasive function is considered for a PIS; an associated small circle with specific color indicates the consideration of psychological impacts (also summarized in the last column): blue for social, purple for gamification and orange for aesthetic artistic factor.

3.2.1. Overview

Figure 3.2 maps the persuasive functions and the psychological impacts of each PIS into UP+ framework for better illustrating how these elements are covered. For each tile, background darkness is used to pinpoint the density; the numbers in the brackets indicate the number of PISs that employs the corresponding function.

User / System / Phenomenon	**Understand**	**Decide**	**Act**	**Protect**
	Enlightener	Recommender	Facilitator	Protector
Cause (Behavior)	Reflect behavior (22)	Recommend actions (14)	Engage (21)	Prevent (9)
Effect (Situation)	Reveal situation (49)	Suggest situation (15)	React (17)	Alert (5)
Causality	Explain (6)	Simulate (8)	Manage (11)	Anticipate (25)

Figure 3.2. Characterization of persuasive functions employed by 54 existing studies using UP+. The numbers in brackets indicate the number of studies that cover the corresponding function. Background darkness is used to pinpoint this density

In general, in terms of macro process of behavior change, 91% of them (49/54) employ persuasive function(s) to make the user's behaviors observable. One third considers the *Recommender* and *Facilitator* features and about half of them (25/54) are found to implement features that protect people from unwanted behaviors or that support them at the maintenance stage of behavior change. In addition, only 22% of these systems (12/54) has combined all the features *Understand*, *Decide*, *Act* and *Protect* in their design. Of the 12 studies, we note that one study (P38) covers all the functions of our analysis grid.

Although almost of the studied PISs are found to include enlightener features in their design, the functionalities covered by these PISs are quite diversified. For instance, with 49/54 of them being eligible, we conclude that the primary focus of current PISs is at revealing user's situation or in other words, making effects of current behaviors observable. Besides, human activities related to a particular behavior are also intensively exploited, 22/54 of them attempts to make it observable. This finding is consistent with our observations in the previous chapter (see section 2.3).

However, the second-most targeted function is *anticipate*. About half of the selected PISs (25/54) intent to protect users from relapsing in near future, and provide functionalities to maintain high ability and motivation. Various approaches have been proposed. Promoting affective components (i.e., intrinsic motivation) is the commonly employed method: twelve PISs feature this technique. Providing automation functionalities (e.g., machine-learning based) to assist the user in maintaining desired behaviors is found to be frequently utilized (8/25). Moreover, through prediction engine, 5/25 of them enable the capacity to anticipate unwanted behaviors or risky contexts.

The causality aspect is rarely considered not only to enlighten but also in other categories at the macro level of behavior change. This lack of functionalities is reflected through the limited number of PISs that targets the micro process level of behavior changes. For instance, only 6/54 of them aims at explaining the relationship between human activities and their consequences. As a recommender, 8/54 of them provides simulation tools allowing users to identify their desired behaviors and effects. 11/54 of them facilitates the action taking process by enabling users to manage their actual behaviors and their outcomes. Other less considered areas involve functionalities to prevent users from unwanted behaviors (9/54), alert about risky consequences (5/54). Last but not least, despite the importance of tools that helps users in decision-making process, functionalities recommending appropriate actions (14/54) have not been properly considered.

Next sections report this review in more detail per classes of persuasive functions.

3.2.2. Enlightener

Reveal Situation

Previous section highlights the strong focus of current PIS on making user's consumption observable. 91% (49 of the total 54) of them cover this revealing function. This finding is relevant to our first observations (section 2.2.2). To make observable the phenomenon under study, designers have proposed a variety of approaches.

The most common technique is to provide direct feedback about user's consumption in its context (e.g., electricity, water, financial etc.). It corresponds to the *observe* branch in our analysis of persuasion techniques and strategies (see mind mapping in section 2.2.2). As an example, EnergyWiz (P18) and Green Machine (P22) visualize user's energy consumption in kWh unit, financial cost, and the amount of CO_2 emission. Visual elements such as graphs or bar charts are used to illustrate the current situation. Other PISs such as Personalized-Eco-Feedback (P33), 7000 oaks and counting (P1) offer represent the environmental impact of current behaviors (e.g., number of trees necessary to compensate energy consumption or how the behavior affects climate change).

Among the popular techniques, comparisons are found to offer more insights about the current behavior, making sense of feedback information. Self-comparison and social comparison are the two frequently applied techniques in current studies. The former method often relies on the capacity to browse past consumptions, allowing users to compare their performance over time, and facilitating self-evaluation and learning. For instance, Watts watt (P52) provides users with three views to visualize their behaviors: hourly, weekly and overall. Energy Dub (P15) offers five insights about current energy usage including options to zoom in/out on past consumptions. The latter method allows users to compare their results with other people. For instance, the comparison can be done between friends with Green Machine and Watts watt; EnergyDub (P15) allows comparons between similar households; and PowerAdvisor (P34) allows users to situate their consumption compared to certain averages.

Reflect behavior

About half of them (22/54) claims to cover the *reflect* persuasive function, which is described as means to provide comprehension support to understand the currently targeted behavior (causes), making sense of the revealed information (effects). Many studies provide cues and indicators (e.g., user's average consumption of similar period) to better reflect how current behaviors are efficient. Meter augmented with color-coded representations is often considered as an implementation for PISs such as Power Advisor (P34), Wattsup (P54) and Power Pedia (P36). Another worth mentioning technique is to target consumption in a more detailed manner. For instance, Handy feedback (P23) allows users to interactively detect different states of energy consumption (active or standby modes of appliances), and to supervise the performance of the appliances. EnergyDub

(P15) and Water Display (P49) offer different energy consumption insights including the consumption broken down by appliances or members of the household.

Explain

Six systems make observable the relationship between user's activities and their effects. They provide features able to explain or allow users to self-explain explicitly the causal relationship For instance, Digital Calendar (P8) lets users to annotate an unusual peak of water consumption, self-detect the possible causes triggering this current problem. Figure Energy (P20) allows inhabitants to tag the consumption peaks and self-explain such events that induced an overconsumption. The thermostat Reef (P38) is designed to generate reasons to achieve a proposed action such as lowering the temperature, changing heating plan. Tiree Energy Pulse (P46) explains why users should consume energy at specific moments.

3.2.3. Recommender

Recommend actions

Fourteen PISs provide features designed to help users in decision-making by recommending alternative behaviors. Towards this goal, Power Advisor (P34) offers different type of advice based on user context. Green Machine (P22) and Energy Life (P17) integrate contextual tips explaining how to reduce energy consumption. Moreover, Wash Machine (P48) and Tiree Energy Pulse (P46) indicate best moments for laundry in order to save energy. Eco Island (P10) utilizes a virtual avatar that suggests actions related CO2 emission reduction. PowerPedia (P36) provides not only hints on the usage of certain devices but also allow users to learn and take advice from other people who perform similar tasks.

Suggest Situation

Sixteen PISs provide features to situate users' actual effects of their activity and suggest alternative situations. Social norms are regularly employed to this end. For instance, Personalized-eco-feedback (P33) indicates the average electricity consumption in the neighborhood; EnergyDub (P15) allows users to see electricity usage for similar classes of household. Besides, allowing users to observe what others' behaviors is an effective technique (P9, P19, P34, P38, P52). About suggesting alternatives, Thermo Coach (P45) suggests a variety of solutions to manage home comfort, each solution representing a trade-off between the cost and the level of comfort in the household. Tariff Agent (P42) and It is too hot (P28) let users to choose among multiple settings to request a certain level of comfort in terms of temperature, cost, etc.

Simulation

Eight studies use simulation to facilitate the decision-making by helping users to identify their desired behaviors and their possible outcomes. For instance, Figure Energy (P20) allows users to remove or add virtual activities in the practice view, to see how it affects the energy usage and to identify desired outcomes (e.g., financial saving). The slider widget in Heat-Dial (P24) allows users to simulate and find trade-off between cost of thermal comfort for the next 24 hours. MAID's (P30) counter gauge indicates the annual saving for taking each of the suggested actions. Last but not least, Tariff Agent (P42) allows users to estimate the cost of each possible plan.

3.2.4. Facilitators

As indicated in Figure 3.2, one third of the examined PISs attempts to engage, motivate users to take serious actions, rewarding positive behaviors and allowing users to manage their behaviors and the actual outcomes.

Engage

21/54 of them is found to include functions to engage people in a desirable behavior change. Among these, goal-setting is regularly implemented. For instance, Green Machine (P22) allows users to set personalized goals (e.g., setting electricity consumption limit for a month), provides insights and comparisons for keeping track of the goal. It also engages users through challenges. Figure Energy (P20) lets users to self-set goal to reach through a practice tub. EnergyWiz (P18) offers to users the possibility to challenge their friends, to view their ranking and to share their results on Facebook. In addition to the goal-setting technique, another prominent way is to support user in scheduling/planning for actions. For instance, Washing Machine (P48) lets users to set the desired starting/stopping time for laundry behaviors. It is too hot (P28) allows the scheduling of temperature set points for heating actions, either manually or automatically. Reef (P38) engages users in a schedule in which they are obliged to manage it by themselves.

Reward

Gameful elements are often considered for this purpose. For instance, Green Machine (P22) rewards sustainable actions with points; EnergyLife (P22) utilizes the notion of levels as in games to award users for their good performances; Watts watt (P52) offers points and prizes; Share Buddy (P40) offers electricity points as a reward. Alternative features are positive messages, compliments (P38, P48, P50), possible savings (P20), decorative elements (P10, P49). In all, 17/54 of the studied PISs makes use of the reward function.

Manage

Functionalities allowing users to adapt their behaviors (cause) with the actual results (effects) can be found in Green Machine (P22): the application provides real-time tracking and indicators for the taken goals/challenges, the user can adjust his/her energy consumption to achieve them. Similarly, in EnergyHome (P16), users can self-set their goals according to their expectation and self-evaluation ability. Figure Energy (P20) lets user set a desired saving and then practices with what-if scenarios to find the appropriate sources of consumption for. Some of the PISs assist users with automated features: the system acts on behalf of the user to better achieve the user's goals (P3, P42, P48). Eleven studies are reported to take advantage of the manage functionalities.

3.2.5. Protectors

Prevent

Nine systems employed functionalities to protect users from risky contexts or undesired behaviors. For instance, AgentB (P3) implements a notification engine to remind users of the booking schedule as well as in Green Machine (P22) and EnergyHome (P16). In Water Bot (P50), the system notifies users when they use the sink and reminds them of closing the tap to save water. With Tariff Agent (P42), users are notified via SMS about tariff change. Reef (P38) uses a machine-learning algorithm to predict user routines in order to notify users of anomalies or unusual events related to inappropriate actions.

Alert

Five studies aim at alerting users of undesired outcomes. For instance, UpStream (P47) relies on a traffic light metaphor in order to inform users of the overconsumption. Similarly, Hydrao (P26) includes a monitoring functionality that keeps track of water usage and alerts people on any unwanted events (i.e., overconsumption when taking a shower). Pereira-Eco-Feedback (P32) and Reef (P38) notify users when their consumption surpasses the defined threshold.

Anticipate

Twenty-five studies have implanted functions to strengthen users' motivation and maintain high ability. For instance, automatic systems have been proposed in eight PIS, these functions assist the user in maintaining a desired behavior and in enhancing users' ability. For instance, it is too hot (P28) offers direct/indirect learning engine to effectively schedule temperature set points for heating practices. In TherML (P44), an automated function detects when the user is at home to control the thermostat, keeping always the requested level of comfort. Moreover, prediction plays a mandatory role in anticipating future unwanted events/outcomes, such elements are featured in five PIS. For instance, eForecast (P11) and ClockCast (P5) highlight upcoming time periods that are favorable for energy consumption. Some other studies aim at keeping users motivated by suggesting alternative behaviors to be realized (P16, P38). Current regularly implemented elements are informative but often using in an aesthetic or playful manner in order to trigger as means to prevent from relapse (12 PIS). For instance, Digital Calendar (P8) incorporates a calendar with consumption events based on a glanceable, ambient and artful illustration.

3.2.6. Psychological dimension

To be effective, persuasive functions are related to psychological factors in order to convey persuasion and to induce motivation. This section explores how the concerned factors are shaped in current PIS. Three factors are considered.

Social factors show their effectiveness in revealing user's current consumption through comparison functionalities. As previously mentioned about *reveal situation* functionality, allowing users to compare themselves with other people (i.e., friends, other households, etc.) or a normative (i.e., average of a city) is often considered. 15/54 of them includes these factors to better underline current users' behaviors. Precisely, five systems provide comparison with friends (P19, P22, P33, P52, P54) while five target similar households for comparison (P9, P10, P14, P15, P49); five rely on social norms (P9, P10, P19, P34, P39). In particular, P4 and P49 allow family members to compare their performance between them. In addition, social sharing and interaction have been also well conceived. For instance, several systems offer functionalities allowing users to share advices (P17, P22, P32, P36), results and achievements (P7, P9, P17, P18, P22, P52) with others.

For the playful and fun aspect, gameful experience is often considered to encourage users in taking action. In order to strengthen user's engagement, goals and challenges are the regularly featured components. For instance, MAID (P30) offers users with specific electricity reduction tasks to be accomplished; Green Machine (P22), EnergyWiz (P18) and Watts watt (P52) let users to propose and take challenges and provide means to monitor the competition (e.g., progress, ranking, leaderboard). However, rewarding is the most frequent gamification approach used to induce motivation: reward function often reacts on users' actions through awarded points (P15, P22), game levels (P17), medals, redemptions (P52), decorative items (P10, P22) and greetings (P33, P38, P46, P50).

Inducing well-being feelings, aesthetic is often considered to both making visible user's behavior and enduring user's motivation. Eleven systems rely on this approach (P1, P2, P6, P8, P10, P14, P33, P41, P43, P49, P53). Indeed, by way of reinforcing the revealing of user's consumption, the design is frequently featured by metaphoric representations, everyday elements or abstract, artful items. In term of maintaining desired behaviors, designers believe that artistic helps at retaining people's attention over time and motivating for a long-term behavior change based on intrinsic motivations.

Summary: we used UP+ as an analysis grid to review 54 PISs dedicated to energy. Each PIS is analyzed in terms of its covered persuasive function and psychological impacts. The analysis reveals several important key points. The primary focus seems to be the revealing of user's situation. Recommender dimension appears under explored. Automation features to assist users are frequently utilized. Besides, many consider means to target the affective component (i.e., intrinsic motivation) to maintain motivation. Social factors, gameful experience and aesthetic representations are often considered in current studies. Interestingly, aesthetic factors seem to enhance the observation of user's behavior and endure user's motivation.

3.3. Discussion

From this review of persuasive interactive systems for energy with UP+, we highlight in this section a set of representative examples and several takeaway messages about their design. As a reminder, figure below (Figure 3.3) illustrates how the PISs we reviewed covers the persuasive functions. We uncover five takeaways addressing the well-covered functions as well as the insufficiently covered ones.

User / System / Phenomenon	**Understand**	**Decide**	**Act**	**Protect**
	Enlightener	Recommender	Facilitator	Protector
Cause (Behavior)	Reflect behavior	Recommend actions	Engage	Prevent
Effect (Situation)	Reveal situation	Suggest situation	React	Alert
Causality	Explain	Simulate	Manage	Anticipate

Figure 3.3. Persuasive functions covered by 54 existing studies using UP+

3.3.1. The takeaways

Enlighten: Offering simple, comprehensible insights of user's behaviors

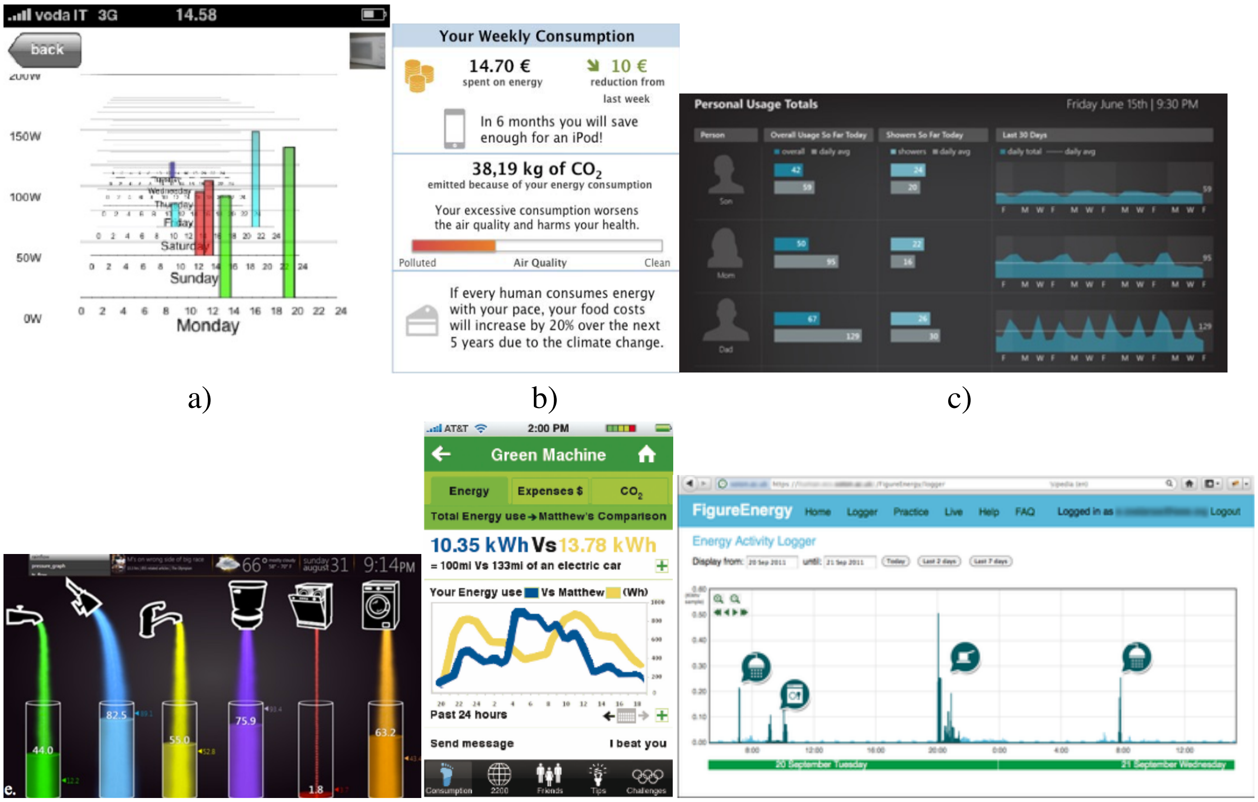
Our analysis shows a great deal of effort on making user's behaviors visible in order to raise user's awareness and promote the understanding of the problem tackled by persuasion. One compelling approach to motivate for sustainable energy consumption behaviors is to provide real-time, contextual feedback. This is consistent with the first strategy of Pierce et al. [136]. Yet, studies have indicated that savings of 5-15% [34] can be achieved by offering real-time feedback; the attractive, simple and understandable characteristics might increase opportunities to catch the right moment (trigger) for raisening intrinsic motivation and heightening ability. Several studies are reported to follow this approach. For instance, Power Advisor (P34) uses a familiar meter representation and a smiley to indicate how current consumption is comparing to a baseline (Figure 3.3-a). Sinais (P41) features a digital illustration of the landscape in which electricity usage is represented through the movement of clouds or the appearance of animals (Figure 3.3-b). PowerViz (P37) illustrates energy consumption through aesthetic lighting bulbs: the abstract interface provides glanceable and attractive views on current situation (Figure 3.3-c).

a) b) c)

Figure 3.4. a) PowerAdvisor (P34) consumption view b) Sinais's (P41) illustration of electricity consumption, c) PowerViz (P37) abstract representation

Enlighten: Providing tools for analysis and exploration

Our analysis shows that tools are provided to help users to explore in-depth their usage patterns (effects), factors that cause problem (causes) and how the problem occurs (causality). As an example, consumption histories are found to raise awareness about the consumption patterns of electricity consumers [177]. It is essential that analysis tools can be utilized in different use-contexts and purposes. This approach corresponds to Fogg's principles in terms of monitoring, self-monitoring and correponds to the second principle of Pierce et al. [136]. For instance, such tool could allow users to browse consumption history (Figure 3.4.a), consider consumption at different levels of granularity (Figure 3.4-b), inspect energy consumption per appliance (Figure 3.4-c), per members of the household (Figure 3.4-d), make use of social factors such as comparison, sharing or self-comparisons (Figure 3.4-e), help users detect unusual events (Figure 3.4-f).



d) e) f)

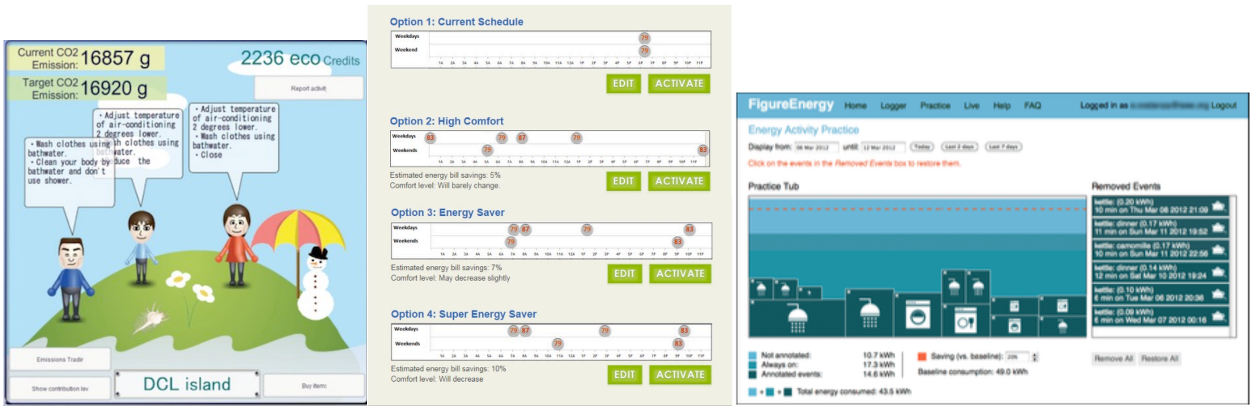
Figure 3.5. a) energy consumption week view (P17) b) Energy consumption in different granularity (P18) c) Water consumption broken down by occupants (P49) d) Water consumption broken down by appliances (P49) e) Comparing with friend (P22) f) Different sources of consumption which cause unusual events (P20)

Enlighten: Explaining the causality

Although, including SEPIA [102] and HAM [140], Fogg's 'Cause and effect' principle aims at designing PIS that allow users to observe the connection between a cause and a consequence, our review that the *explain* persuasive function is rarely implemented. We believe this function could play a more important role in making inhabitants to better understand their behaviors. For instance, an explanation engine could be used as part of the analysis tools. However, the context must also be taken into consideration. As suggested in [87], we hypothesize that contextual explanations provided with the possibility to investigate the solution space, can effectively promote the understanding towards current problem. It would allow inhabitants to apprehend their energy management system, and therefore be more opened and motivated towards the change. Moreover, it may encourage inhabitants to act in a more virtuous manner.

Recommend: Helping inhabitants to decide.

Our review also reveals a lack of support for people in TTM's preparation stage. We believe that suggestions and recommendations may significantly support users on making their decision for a change. Figure 3.5-a and 3.5-b illustrates two examples of recommendation features found in the literature (P10, P45).



a) b) c)

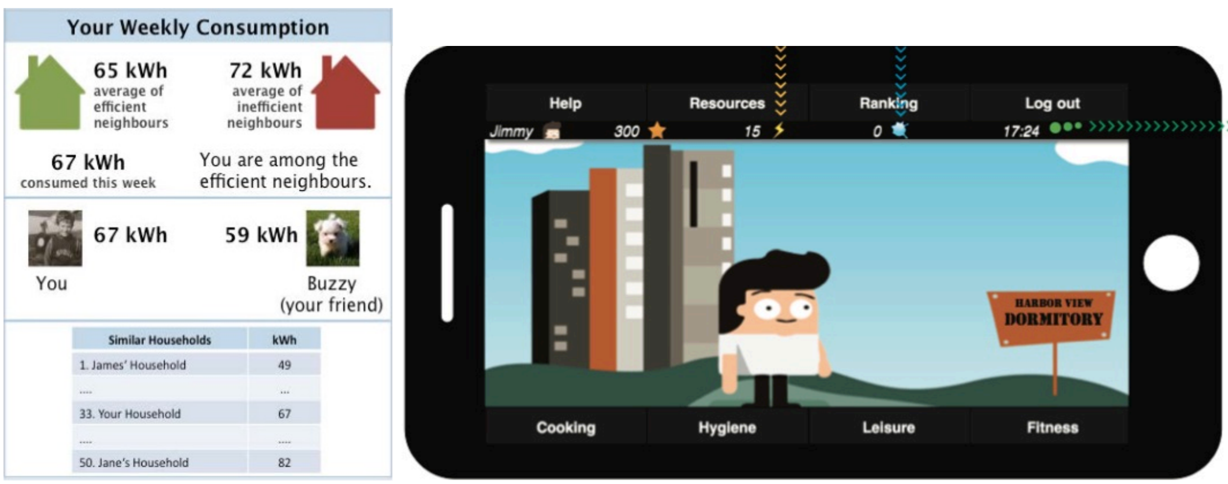
Figure 3.6. a) The recommendations proposed by avatars in EcoIsland (P10) b) Four suggestions of Thermo Coach (P45) c) What-if simulator of Figure Energy (P20)

Additionally, simulation is also a relevant approach (it also corresponds to one of Fogg's and PSD's principles). Indeed, according to Nakajima [117] "*there has been large temporal gap between users' action and its consequence and technology is considered to be the necessary factor to fill this gap through simulation techniques*". Existing studies reveal some interesting practices in designing such class of functions. The '*What-if*' approach is among the popular propositions and has been employed in many studies. Golfarelli et al. [67] define "*what-if*" approach as the analysis of behaviors of a complex system under some assumption, called *scenarios*. It studies how the changes of certain system's variables affects others variables based on simulation. In the context of PIS for energy, the goal of "what-if" approach is to anticipate the effects of different behaviors or actions, and to assist inhabitants in decision-making for planning a change. For instance, Figure 3.5-c illustrates the practice tub of Figure Energy (P20), where inhabitants can play "*what-if*" simulations by adding/removing activities and observe the impacts on global consumption.

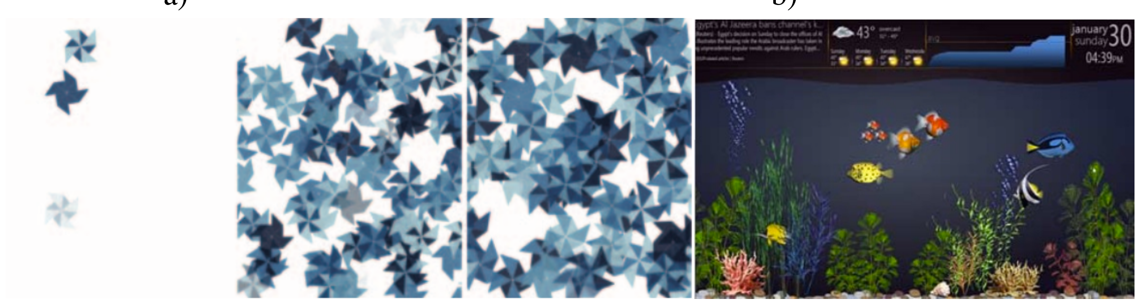
Act and protect: Facilitate inhabitants in taking actions

For a successful behavior change, a PIS should be designed to help users to adopt sustainable actions and at maintaining desired behaviors. One popular direction is to apply the goal-setting theory studied by Locke and Latham [107] (see chapter 1). Our findings indicate that giving specific tasks to be achieved or letting inhabitants to self-set goals are effective strategies. Moreover, the mapping grid (see table 3.2) indicates a dearth of functionalities in preventing/alerting unwanted behaviors/outcomes. These functions are essential means to keep maintaining desired behaviors, therefore, highlighted a need to be intensively investigated. To this end, reminders and notifications seem to be the most prevalent elements (see 3.2.5, section *prevent* and *alert*).

Besides, the analysis also pinpoints techniques for enhancing the persuasion means through psychological dimension. Social factors (e.g., Figure 3.7a), gameful experience (e.g., Figure 3.7b) and aesthetic approaches (e.g., Figure 3.7c) are some of the key elements. However, with different purpose and use-contexts, the effectiveness might vary. For instance, informative elements are often used as complement factor to both *reveal* users' situation but also to indicate a progress in a behavior change for users at maintenance stage (e.g., Figure 3.7d).



a) b)



c) d)

Figure 3.7. a) Social comparison between households, friends and ranking EnergyViz (P18) b) Share Buddy (P40) explores a gamification approach to persuade users consume less energy c) Abstract ambient (P2) illustrates users' consumption with artworks d) User's performance represented by fishes, corals elements (P49)

Summary: We outline five takeaways for the design of PIS in household. It includes the offering of simple, comprehensible insights of user's behaviors; tools to help users to explore in-depth the problem tackled by persuasion; the exploration of functionalities in making inhabitants understanding their behaviors (explain); tools to assist people in preparing for the change (e.g., suggestions and recommendations) and decision-making process; tools to facilitate sustainable actions (i.e., goal-settings or self-set goals)

3.3.2. Pitfalls of Persuasive Sustainability

Although persuasive interactive systems for sustainable behavior are becoming a popular topic within Human-Computer-Interaction (HCI), we should carefully pay attention to the design of this kind of systems. Indeed, despite of the given potential for broad impact of the persuasive sustainability approach, a growing number of voices questions the efficiency of current research in persuasive technology towards sustainable behavior (e.g., [21]). For instance, Brynjarsdottir et al. [21] warn that persuasive sustainability often narrows the focus to a limited framing of sustainability. Besides, Brynjarsdottir suggests that "*designers attempt to prescriptively persuade users to take actions consistent with their definition of how to be sustainable, which might not every time suitable with the context*" [21]. Moreover, Knowles and Strengers [95, 168] raised concerns about the long-term effects of behaviors change.

Concerns about long-term behavior change effect

A first limitation of persuasive sustainability is related to the lasting effect of behaviors change. Riche [151] raised a question about the effectiveness eco-feedback system. Strengers [168] reported a difference between designers' assumptions and actual findings from everyday life in term of eco-feedback lasting effects. As stated by Strengers [168] i) Eco-feedback is unlikely to challenge changing expectations and aspirations in households and ii) Eco-feedback may have a diminishing return as new expectations emerge.

Pereira [148] indicates that while current studies report success in increasing awareness, most of them are limited to a short period of time. Peireira [148] explicitly notices the gradual decrease of attention shown in the later study and once the effect of eco-feedback system has passed, users will relapse to their original behavior. Yang [183] in the study of *living with smart thermostat* also notices the decrease of effort and engagement overtime from users on saving energy.

Narrowing the vision of sustainability

By narrowing the vision of sustainability, Brynjarsdottir [21] first explains that most persuasive systems have chosen to focus on limited aspects of sustainability that are clearly measurable, rather than tackling the complex problem of sustainability. Purpura [145] points out that persuasive technologies frequently aim at “*mak(ing) behavioral decisions 'simpler' by eliminating complexity and often aim to enforce sublimated social goals*”. This “narrowing” leads to the incapability of preventing unintended consequences, which often lies outside of the defined frame of persuasive sustainability.

The “*narrowing*” issue also comes from how designers shape their intentions. Brynjarsdottir [21] has expressed a disagreement with Fogg on the responsibility of designers on what to consider to be a desirable behavior and how it is accomplished. Brynjarsdottir considers that current systems are employing a top-down design method rather than a start from the users themselves. In other words, Brynjarsdottir describes that it is similar to the way an expert decides whether it is “*sustainable*” and embodies this view in a technology that will judge users’ behavior along the expert’s lines. Still, “*little evidence is provided that either the designer is actually an expert or that the user is uninformed*” [21].

Distance from real-life context, consider human as rational actor

Last but not least, many persuasive systems are criticized for isolating users from their everyday life routines. As stated by Shove: *“the routine accomplishment of what people take to be the ‘normal’ ways of life”*. Strengers [168] shows assumptions about how different between user’s everyday practices, designers intent and their impacts on saving energy. In fact, several systems have attempted to schedule user’s routines [5, 183]. However, the complex and nuanced daily routines often make it difficult to effectively set an appropriate schedule.

Another critique is that designers are assuming that inhabitants act as conscious, rational actor who will do what they believed to be the rational choices [183]. Sharing the same idea, DiSalvo [37] claims that many assume people as rational actors seeking to optimize based on what they know. In this line of works, most of the studies rather than directly aim at behavioral change, try to raise user’s awareness by showing the consequences caused by user’s activities. However, DiSalvo considers that raising people awareness would not guarantee the desired change in behaviors or attitudes [37].

In order to overcome these issues, researchers have subsequently expressed concerns that HCI needed to be more sensitive to the framing of sustainability [38] [121], to the broader societal context [21], and to the design patterns of persuasive sustainability [95]. In addition, Purpura proposes to expand the criteria for evaluation to include attitudes and unintended consequences. Moreover, the design for everyday routines have also been examined [27, 151, 168, 184]. In the next section, we present a set of suggestions addressing these concerns. We consider these suggestions as means to make our persuasive system sustainable.

3.3.3. Approaches

To address the pitfalls uncovered in previous section, we identify several approaches for designing successful persuasive interactive systems for energy.

Raising intrinsic motivation

According to Knowles [95], offering features related to user values may motivate for desired behavior from current unsustainable behavior: "*unsustainable behavior is best changed through addressing the motivations that underpin such behavior*". In our opinion, raising the intrinsic values would lead users to pro-environmental behavior.

We argue that people with more intrinsic values would act in a more pro-environmental way in our context. In fact, studies show that "*even individuals who are exceptionally high in extrinsic and low in intrinsic, can be primed to demonstrate higher intrinsic values*" [95] . We, therefore, believe that intrinsic values should be considered when designing towards engaging people in both pro-social and pro-environmental behavior.

For that purpose, the intrinsic aspects such as freedom, creativity and self-respect, universalism values, environmentally-friendly behaviors should be focused. For instance, the authors of [75, 133] have designed a feedback mechanism that translate user's current consumption (i.e., kWh, Co2) into more environmentally units (i.e., trees, vision of future earth, polar bear). Energy Home [176] employs the notion of **self-set-goals** (intrinsic) rather than competition between users (extrinsic). Notably, Knowles [95] presents patterns and alternatively anti-patterns for pro-environmental persuasive technology. These patterns include broadening/self-transcendence (intrinsic) values, designing to the value and facilitating reflection from users.

Towards open-ended and cooperative systems to involve users

Dealing with the problem of how designers prescriptively shaped user's intentions, a solution, that is proposed in [13, 21, 145], would be to consider open-ended approach. **Open-ended systems** are described as "*systems that allow interactions between their internal elements and the environment*"[179]. The "*environment*" includes the users and their surrounding context tackled by the persuasion. In the context of sustainable behaviors, such system could let users self-define what they believed to be sustainable and make their actions consistent to their own definition. To this end, Brynjarsdottir proposes rather than blending user's behaviors towards the designer's way of thinking, the system should explore ways to elicit actions towards sustainability. For Baumer [13], the openness of the system allow users decide, in terms of "*flexibility, control, ownership*", over their decisions. Purpura [145] advise a design for "*mindfulness and leaving room for stories*", within this study, Purpura argues that the system should encourage mindfulness and promote reflection from users as ways to build important attitudes for sustaining long-term change.

Furthermore, beyond being open-ended, we believe that these systems should be cooperative to better involve users in the behavior change. Smart systems embed a decision loop, and users have to be part of this decision loop. Yang and Newman examined the *living with the smart thermostat* in two consecutive studies [183, 184]. Within these studies, it is reported that this thermostat could cause frustration, or even lead users to the abandon the technology because of the actions it acted on behalf of the user. Besides, Yang confirms that this lack of control is one of the reasons for the decrease of user's effort and engagement overtime towards the system. As results, Yang and Newman proposed an alternative design *mixed-initiative* system with the belief that such approach might improve the sustainability of user engagement and the system's usefulness.

Alan [6] considers the level of autonomy as vital role in the development of smart systems. In 'Tariff Agent' [6], three levels of autonomy are provided: fully autonomous, semi- autonomous, and manual. It is reported that occupants are willing to stay in control of their home. However, they appreciate also the autonomy factors and are willing to leave the system to take decisions on their behalf. As results, Alan considers flexible autonomy as promising approach to sustain users' engagement with smart systems. The author also remarks that "*users take responsibility for the undesired outcomes of automated actions when the autonomy level can be flexibly adjusted*".

In [5], three different smart systems were implemented and deployed including a *manual* one through which users specify by themselves the temperature setpoint, and two *learning-based* ones that utilize an artificial intelligence (AI) algorithm to automate the temperature settings based on learned households' preferences. All the three options required users to keep interacting and expressing their own preferences. Two interesting remarks have been drawn: first, occupants find different ways to adapt their behaviors to these options, their objective is to save money while being comfortable; and second, staying in control is a 'must' [5]. Hence, we believe this finding reinforces those from previous studies, revealing the potential of future autonomous smart energy systems not in controlling but in assisting people to control their home.

Designing for everyday routines

Another major issue comes from the focusing on individual and isolating occupants from their daily life and routines. We, therefore, consider that the user's everyday routines and habits are important factors and need to be taken into consideration. For instance, being described as highly prevalent and contribute to structure most of our daily activities, habits play an essential role in the formation/break of desired/unwanted behaviors [140]. Emerging habitual factors in the design of PIS is therefore crucial. The Habit Alteration Model (see chapter 1) presents an effective way to design behaviors interventions. In the other hand, routines are vital elements for building habits. Routines have been investigated in many studies. For instance, in Digital Family Portrait [153], it is reported that participant's schedule has patterns driven by their routines. Data based on sensors in the home allows the identification of patterns related to participants' activities, assist the auto-scheduling and detection of unusual events. In our context, it is important that the system could explore consumption patterns, learn them, and explicitly associate them with the activities in residential context (e.g., cooking dinner, washing clothes, television). Based on the patterns, such system could detect anomalies and provide adequate suggestions (e.g., close door, turn off light etc.).

Summary: We highlight three pitfalls of persuasive sustainability: the lasting effect of behaviors change, the narrow focus on limited aspects of sustainability; and isolating users from their everyday life routines, assuming that inhabitants acted as conscious, rational actor. Towards this end, we underpin our approach for designing a PIS towards sustainability: Considering self-set-goals to raise intrinsic motivation; designing open-ended and cooperative system to raise user's involvement; and designing for everyday routines

3.4. Synthesis

In this chapter, based on UP+ framework, we conducted a state-of-the-art of existing persuasive interactive systems for energy and, more broadly, persuasive sustainability. This extensive review (54 systems are analyzed) reveals that a vast majority of these systems do not cover the whole process of behavior change (e.g., decision step) and mostly focus on the consequences of unsustainable behaviors. Consequently, to fill the gap, our research focuses on the following persuasive functions: **explain** to enlighten users, **recommend** to help users to decide (particularly through exploration), **facilitate** to help users to achieve their objectives.

In order to address this research and to avoid the pitfalls of persuasive sustainability (i.e., prescriptive systems, short-term behavior change, decontextualized persuasion), we consider several approaches:

- Considering self-set-goals to raise intrinsic motivation
- Designing open-ended and cooperative system to raise user's involvement
- Designing for everyday routines

Indeed, we aim at raising intrinsic motivation for a long-term and more engaged change. Additionally, the persuasive system should also center on making the reflection from inhabitants rather than just providing information.

Secondly, we presumed designing towards open-ended and cooperative systems provide proper tool in dealing with current concerns about how the design of persuasive systems limit sustainability. As for the latter, our suggestion is that technology could play a role of mediator to help users establish their definition of how to be sustainable. For instance, in a residential context, a *what-if* scenario would help users defining their appropriate definition in terms of comfort, sobriety etc.

Finally, we believe that the appropriate persuasive system would not employ technology primarily to control the home but instead involve the occupants in the process. We believe, by getting back humans in the decision loop, the advantages are threefold: assisting occupants to manage their home, keeping occupants engaged and active; allowing occupants to learn how to control the household on their own.

In essence, our research question is "**Which interactional bricks can be considered for building interactive persuasive systems that makes causality observable, support the decision and facilitate inhabitants to change in sustainable manner**".

Part II: Contributions

In the previous part, we have examined current persuasive interactive systems using UP+ as an evaluation grid. To address our research question, the second part of the thesis targets the insufficiently investigated areas uncovered previously. Within this context, we present our three contributions:

- **Mondrian user interface** (chapter 4), a proof-of-concept of user interface designed to catch inhabitants' eyes in order to sustain daily use and to keep them motivated to achieve adopting a behavior change towards their energy consumption on long-term. It is conceived to be an ambient artistic prototype consisting of different functionalities in a way that provides coherent and composite tools for everyday multiple use-contexts and purposes. The prototype will be presented in more detail in Chapter 4;

- **Sliders4DM** (chapter 5), a widget to assist end-users in preparing to change. The focused areas of Sliders4DM are highlighted with blue border in the grid below. In brief, it revisits classical sliders to allow users to find an appropriate trade-off for them between (possibly) conflicting criteria through a "what-if" approach (Simulate). Besides, it is designed to reveal how the home values are related while hiding the system's complexities (Explain). Moreover, Sliders4DM aims at helping inhabitants to prepare and plan their actions for a change (Engage). The details of the design of this widget as well as its experimental evaluation will be explained in chapter 5;

User / System / Phenomenon	Understand	Decide	Act	Protect
	Enlightener	Recommender	Facilitator	Protector
Cause (Behavior)	Reflect behavior	Recommend actions	Engage	Prevent
Effect (Situation)	Reveal situation	Suggest situation	React	Alert
Causality	Explain	Simulate	Manage	Anticipate

The focused areas of Sliders4DM are highlighted with blue border

- **Plan4actions** (chapter 6), in order to help inhabitants to act for a behavior change, allows inhabitants to cooperate with a smart energy manager for the home and is designed to involve them in the decision and action loop. The concerned zones of Plan4actions are highlighted with green border in the grid below. We implemented functionalities aiming at generating contextual recommendations for actions along with explanations (Explain). Moreover, inhabitants can explore the technical solution space in a "what-if" manner via direct feedback about the home status (Simulate, Alert). It is indented to allow inhabitants to understand the functioning and rationale of their home, and be incited to act in a more sustainable manner. To do so, we propose a novel concept of user interface in order to plan an appropriate sequence of actions in order to manage energy consumption (Recommend actions, Suggest situation). By allowing inhabitants to adjust an action plan according to their preferences and vice versa, Plan4actions targets a flexible tool for supporting home management (Manage). The prototype as well as its experimental evaluation will be explained in chapter 6.

User / System / Phenomenon	Understand	Decide	Act	Protect
	Enlightener	Recommender	Facilitator	Protector
Cause (Behavior)	Reflect behavior	Recommend actions	Engage	Prevent
Effect (Situation)	Reveal situation	Suggest situation	React	Alert
Causality	Explain	Simulate	Manage	Anticipate

The concerned zones of Plan4actions are highlighted with green border

Constituting our research frame and leading us to these contributions, we identify two main requirements based on the analysis of existing persuasive interactive systems for energy (see part I):

- **R1: designing persuasive user interactions that take into account the long-term dimension of behavior changes**. Indeed, as highlighted in the first part, behaviors are made of habits and behavior change is a long-term process. Consequently, in our contributions, we adopt a design approach aiming at maintaining awareness and motivation through a multi-level user interaction. We aim at focusing on user's values, raising intrinsic motivation for a long-term and more engaged change. Additionally, the persuasive system should also center on making the reflection from inhabitants rather than just providing information.

- **R2: designing persuasive user interactions to get users involved in the behavior change process: explain, recommend, and support action**. Actually, many of the existing smart systems for energy management are autonomous systems taking decisions for the inhabitants. By contrast, we target cooperative persuasive smart systems that let users to decide. We believe, by putting human in the loop, the advantages are threefold: assisting occupants to control their home, keeping occupants engaged and interactive; allowing occupants to learn how to control the household on their own. Explain and recommend persuasive functions are also considered to avoid prescription: as underlined in previous part, another issue is the narrowed vision of sustainability conveyed by a prescriptive persuasive interactive system for energy being too prescriptive (i.e., prescriptions made by the designer). Our suggestion is that technology could play a role of mediator to help users establish their *definition* of how to be sustainable. For instance, in a residential context, a *what-if* scenario would help users defining their appropriate definition in terms of comfort, sobriety etc.

Application domain and context of this work

Due to the raising concerns related to household energy consumption, we target the domestic context. This work contributes to the ANR INVOLVED project funded by the French National Research Agency, and the cross-disciplinary program Eco-SESA. The objective is to revisit the energy management tools in order to better involve occupants while respecting their preferences, routines and values. The experimental platform for this project is the domestic environment (apartment). The apartment is equipped with multiple sensors (i.e., doors, windows contact sensor, temperature and Co2 etc.) to measure and record occupant practices. Tools for analyzing and estimating occupant practices as well as engine to generate explanation are also included. On top of that, within this context, our work is intended to be deployed on a tablet installed on a wall of the living room or in the entrance hall. It relies on an e-coach engine developed by the G-SCOP laboratory (Grenoble) able to capture data, to interpret and to generate action plans as well as textual explanations. Our contributions are consequently instantiated for this case study.

4. Mondrian User Interface

The content of this chapter has been partially published in:

- o The conference IEEE IDAACS 2017 titled
  Energy Consumption in Smarthome: Persuasive Interaction Respecting User's Values
- o Modeling User Contexte ISTE OpenScience Journal 2019 titled
  From Usable to Incentive Building Energy Management Systems

4.1. Introduction

Our first contribution is the **Mondrian user interface**, a concept of user interface aiming at conveying persuasion to primarily satisfy the first requirement R1 (UI for long-term) and to constitute a frame for our two other contributions in order to respond to the second requirement R2 (get users involved). As a proof-of-concept, we instantiated this concept for the user interface of INVOLVED project's e-coach for energy management.

To reach these requirements, we consider **two main features** that the Mondrian user interface's design must have: to **catch inhabitants' eyes** and to **support different contexts of use**. In terms of persuasion, the first feature aims at targeting the psychological dimension of UP+ as it is related to motivation: we want the Mondrian user interface to raise and maintain inhabitants' interest and focus on their daily goals. For the latter, we consider the time spent to use the UI (e.g., very short periods of use), the conciseness of displayed information, and user's expertise. It aims at facilitating its use (i.e., high ability) and hence behavior change.

In the following, the first section presents our design rationale that drove us to design the Mondrian user interface. Based on a proof-of-concept, the second section details its main concepts.

4.2. Design rationale

The rationale of our design is thought to take into account the particular characteristics of the design towards end-users in domestic context, for instance, occupant's availability, interaction device location, users' desires, etc.

In terms of availability, we must provide a very accessible interactive system. Consequently, it is very important where the interactive device is located to provide seamless information at all time. On top of that, the desire of inhabitants to interact with the system is one of the main components. In their daily activities, it seems illogical to add one more task to their already busy to-do list. In order to tackle these concerns, an always-on situated display on a passage area where most of household activities are taking place seems to be the most prevalent. The system will always be available whenever users want to interact. As highlighted in introduction of part II, we postulate that the interaction device is a "public" display (e.g., a tablet) located in a "public" room of the apartment (e.g., entrance hall). We mainly consider a touch gesture-based user interaction.

Next, how to present information on the always-on situated display is regarded as the core factor in order to effectively motivate occupants to interact. In UP+, various strategies have been proposed to convey information in persuasive manner. However, we believe that it takes more efforts to deliver the persuasive means to occupants due to the complexities of home settings and the involvement of occupants. For instance, traditional approaches which provide information through graphs, bars, and charts are not always suitable for everyone: it requires a certain level of cognitive efforts and knowledge from users. Additionally, this seems to oblige users to pay full attention on every context, which is obviously impracticable. To this end, calm technologies could be a promising approach. As demonstrated in [30], calm technology can effectively inspire positive engagement through the promotion of public awareness.

Moreover, we argue that the system should be integrated consistently with the house, allowing inhabitants to interact in different contexts. The system design thus involves multiple factors including user's attention (e.g., ambient, focus), device location and user's daily routines. In this context, Rodgers points out the importance of balancing aesthetic appeal and comprehension of feedback information [166]. Meanwhile, it refers to the visualization of information in a "*meaningful way and contextually appropriate*" [152]. In addition, working and non-working environments, public/private spaces, different cultures and purposes have been pinpointed [119, 166]. For instance, when users are in a hurry (leaving to work, school etc.), it is essential that the system can display the information in a glanceable manner, catch the eye at the key moment for decision-making. When they have more time (e.g., after work, weekend), the system could provide in-depth analysis of energy consumption or exploration of occupant's patterns, etc.

In summary, we consider the following guidelines as the core concepts the Mondrian user interface to have the targeted features:

- **An aesthetic and ambient user interface**. Both aspects are related as we consider a display integrated in the home. We hypothesize that an aesthetic user interface facilitates the integration in the home and, as a calm technology, constitutes a motivational affordance. Furthermore, representing information in an artistic fashion may facilitate catching the eye.
- **Combined pragmatic and artistic representations** to convey meaningful information. Related to the previous guideline, it also aims at jointly catching the eye and supporting multiple levels of interaction. We identify two classes of information: information about the behavior under study (i.e., related to energy usage and comfort level in the home) and utilitarian information such as current time and weather forecast. We envision a representation of the first class as an answer to different purposes. As an artistic representation contributes to catch the eye and constitutes a motivational affordance and/or outcome; on the other hand, pragmatic representation is one basic part to design a multi-level user interface based on the level of conciseness of the represented information. The second class also contributes to strengthening the eye catching.
- **A zoomable user interface**. Depending on the context of use, a user may either needs very concise information or very detailed information. Such an interaction technique allows a user interface to be minimalist as well as very detailed user thanks to zoom-based actions. This technique suits perfectly to create a multi-level user interface.

In the following, we discuss these guidelines in light of existing approaches.

4.2.1. Making aesthetic and ambient

Ambient displays that make use of aesthetic and lifelike form are promising for making positive changes in human behavior [82]. Indeed, designs based on this approach "*move to the center of attention only when appropriate and desirable*" [48], which seems suitable for everyday life contexts where people do not have much time. Moreover, Ambient/Artistic methods are believed to raise glanceable awareness [152], increase inhabitants' engagements and promote intrinsic motivations [82][45]. Indeed, eco-feedbacks, eco-visualization, or persuasive systems often feature an ambient/artistic approach in their design. Figure 4.1 provides two examples.

Figure 4.1. (left) ambient display shows the overall energy consumption in a kitchen (right) Ambient display illustrates the web-traffic

Design for the periphery. Ambient displays, such as *calm technology*, often display information seamlessly in a non-intrusive manner in the peripheral context of occupant's attention [82] [160]. According to [150], *calm technology* provides background information that does not continuously force the user to actively pay attention to it. Jafarinaimi [82] and Ferscha [48] noted that *calm technology* allows the users to interact with the system when they desire, rather than passively receive pushed information from the system. Paay [128] suggests that the ambient nature can keep inhabitants in context because of the persistent information update. Besides, moving attention from ambient to focus only at key moments helps to save energy usage and more importantly, to increase the effectiveness of decision-making process. It might refer to Fogg's trigger [52], which is considered as one important factor in his model of changing behaviors.

Aesthetic representations. Aesthetics and enjoyment are essential aspects of the computer experience [120]. It provides motivational affordances and/or outcomes. In fact, aesthetic is one dimension of many persuasive design spaces [45, 136]. In the other hand, attractiveness is one design principle of Fogg [56]. It is considered to be a dominant factor in the appreciation of the interactive systems as it promotes ***aesthetics of use***, rather than ***aesthetics of appearance*** [132]. In addition, aesthetic values effectively promote positive emotions and intrinsic motivations [119][75]. These effects are important to foster sustainable behavior change (see chapter 3.3.3). Artistic representations also help to avoid the appearance of negative reinforcements, which can be introduced in other visualization techniques such as *pragmatic* or *metaphoric* [44, 119]. Moreover, aesthetic display can serve as decorative object, making it easier to integrate into household decoration context.

Pragmatic and artistic representations. As highlighted in chapter 2, two main classes of representations are considered for eco-visualizations: pragmatic and artistic. In order to "*foster immediate understanding*", a pragmatic visualization aims at providing "*concrete quantitative information*" using traditional scientific visualizations such as charts, bars, etc.

On the contrary, artistic visualizations are more abstract and less explicit but are more aesthetic and more prone to raise user's interest. Two approaches are often considered:

- *Abstract representations***.** It is believed that such representations can raise curiosity, encourage users to interact, increase awareness about current behaviors [82]. In addition, the abstract nature of the display can hide personal information that users don't not want to share publicly [44], hence it would be a solution for the privacy concerns in household. Moreover, in a residential context, data often intends to be glanceable, abstract information . It suits perfectly for that purpose as it reflects relatively the data but allows users to get the overview of the data at a glance. For instance, Figure 4.1 (left) [43] highlights current city's consumption via representation of a green-cloud. In the right-hand side, a flower garden shows current interaction level of a social-environment [182].

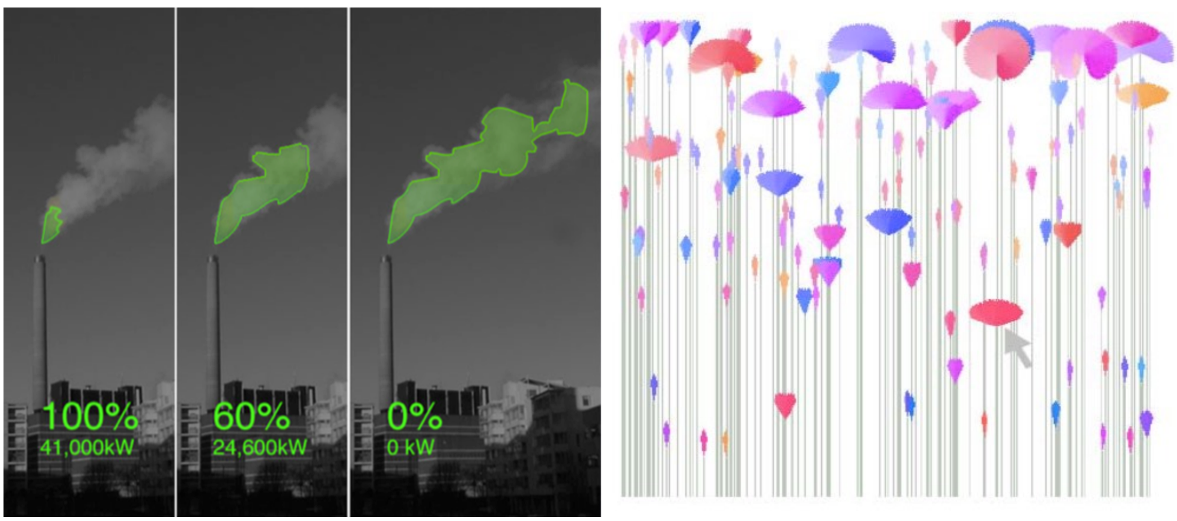


Figure 4.2. (left) Nuage-vert represents the city's energy consumption [43], (right) People Garden's [182] message board

- *Metaphorical representations***.** They are often used to visualize data in a pro-environmentally way by employing elements such as trees, animals, earth, forest etc. Indeed, according to Fang et al. [45], "*it refers to the understanding of one idea, or conceptual domain, in terms of another*". For instance, Nisi et al. [119] use a landscape representation to reflect electricity usage in the home (Figure 4.2 left). The more the appliances are turned on, the more elements (e.g., animals, flowers) appear in the landscape. Holmes [75] visualizes energy consumption with the representation of trees and buildings. The lower the energy usage is, the more trees are presented, the higher the energy usage is, the more buildings and appliances are shown. Figure 4.3 shows the energy usage at different time during the day.

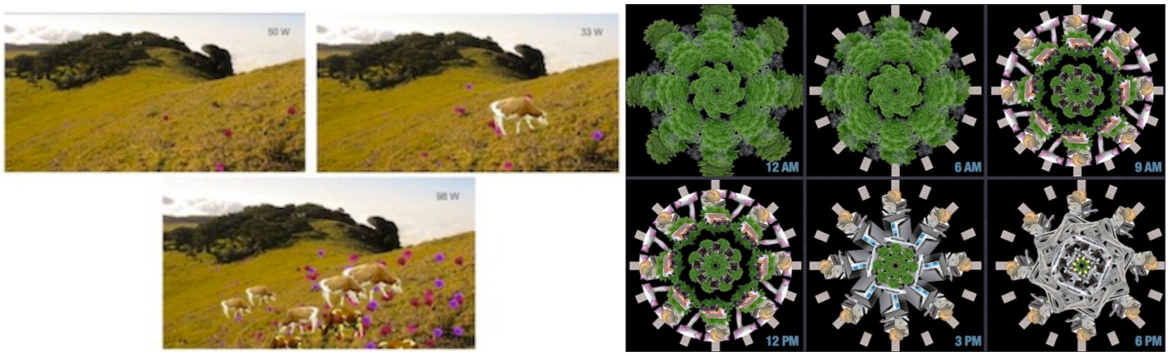


Figure 4.3. (Left) Landscape representation uses animals and flowers for illustrating household consumption [119] (right) Holmes's visualization of building's energy usage [75]

Informative art. This type of visualization augments artworks in order to convey information. Redstrom [150] indicates that *informative art* focuses on how traditional art objects, like paintings and posters, can be augmented. For instance, in order to motivate users to walk more, Nakajima [118] reflects the number of steps which users have walked through the famous painting of Mona Lisa. As shown in the Figure 4.4 (left), Mona Lisa looks older if a user does not walk enough. Another example illustrated in Figure 4.4 (middle), Redstrom employed a visualization inspired from the paintings of Dutch artist Piet Mondrian to represent the email traffic of a group of people. Each rectangle in the painting is associated with one person. Moreover, in Stone Garden [76] (Figure 4.4 right), earthquakes are presented by different types of stone. Size and position of stones represent the magnitude and latitude/longitude of the earthquake. This representation looks like the artwork of famous English artist Richard Long.

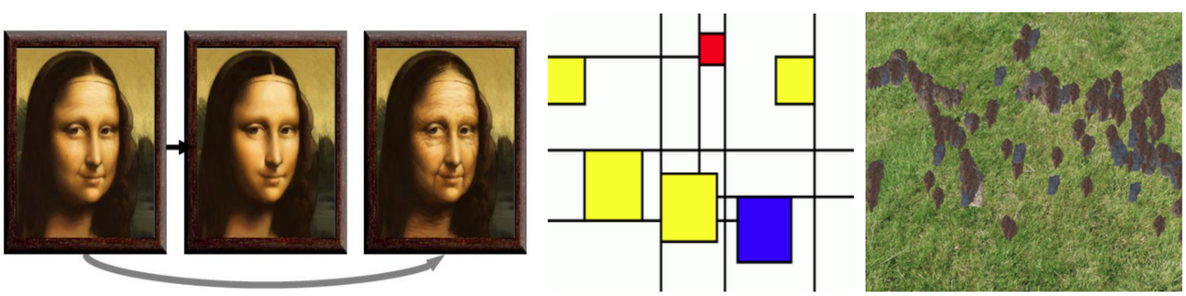


Figure 4.4. (left) Monalisa's face reflects user activities, (middle), Mondrian-inspired prototype illustrates email-traffic, (right) earthquake activities display, inspired by Richard Long artworks.

Information can also be visualized in a very abstract manner. Rodgers [152] considers this approach as a suitable solution for designing in the periphery of one's attention. Indeed, Rodgers have explored different data representations via abstract geometric shapes for a variety of contexts of energy consumption (Figure 4.5-top). Similarly, Nakajima [118] presents user activities via globular objects and its transformation (Figure 4.5- bottom).

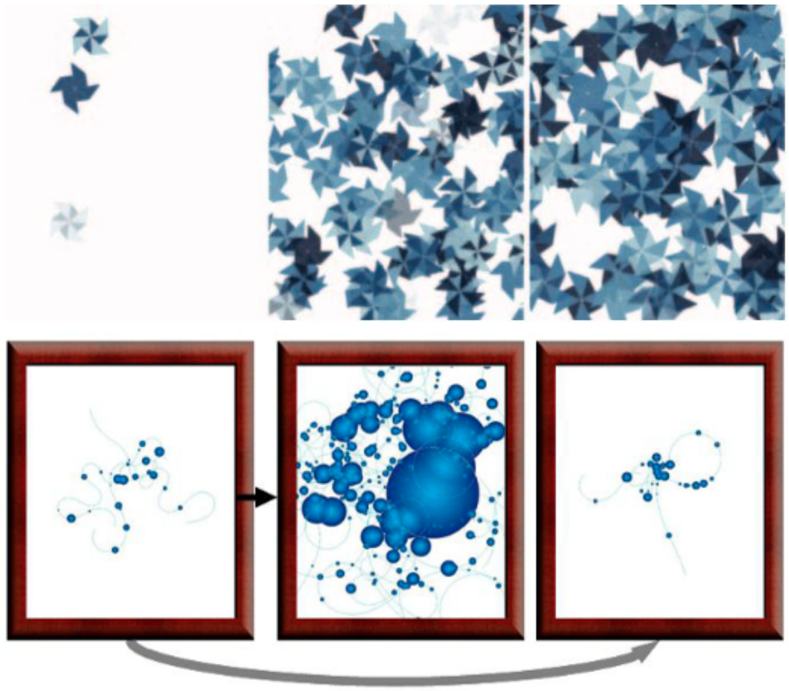


Figure 4.5. (Top) Energy consumption through pinwheels visualization, (bottom) user activities reflected globular objects.

4.2.2. Combining pragmatic and artistic representations

Ambient aesthetic techniques are often used as a part of a more complex interactive system. As this technique aims at promoting glanceable awareness and providing simple insights of inhabitant's current behaviors, other utilities must be complemented in order to guide occupants towards sustainable change. For instance, the system could include a more detailed, quantitative analysis of information for helping occupants understand more their current behavior in a concrete and exact manner.

In the *Heuristic Evaluation of Ambient Displays* [110], the author suggests the "*easy transition to more in-depth information"* as one criteria for evaluating the usability and effectiveness of Ambient Information Systems. The fact of having this criterion could make it easy for the user to interpret the information. Rodgers [152] confirms that even when participants enjoy the artistic feedback, they still want to "*see the numbers*" in some situations. Rodgers, thus, considers the ambient characteristic as a part of an ecosystem, which consists of other techniques to support sustainable behaviors. Similarly, Nisi [119] indicates that even when occupants understand the mapping of the energy usage and its artistic illustrations, they seem to need more clear quantitative information. In [30], besides a metaphoric interface, Coutaz et al. provide users with a numerical histogram and a physical cairns-board for more energy usage information. These complementarities are found to support for energy consumption awareness and understanding [30].

Many studies feature ambient/ artistic as complement factor in the design. For instance, Spark [44] is an informative display which employs abstract art to visualize user physical activities. This study confirmed that while traditional visualizations are effective for information seeking, informative illustrations are better choice for display purposes. Towards this end, Spark features shapes of different colors and sizes to represent users' daily activities and a chart visualization for more quantitative information. Figure 4.6 shows these views.

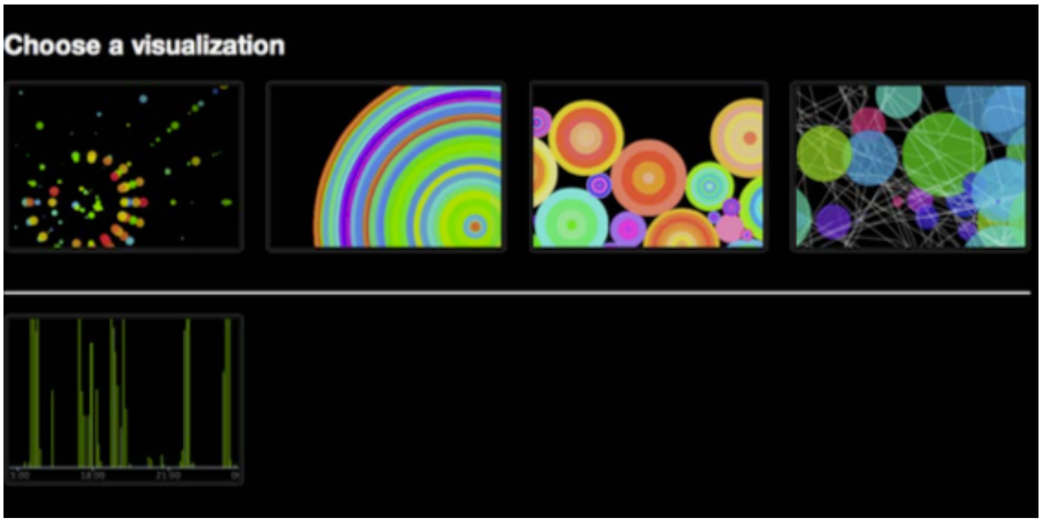


Figure 4.6. Different art-based visualizations of people activities through various type of shapes (top, left to right): Spiral, Rings, Bucket, Pollock. Users can also track their activities via a chart-based visualization (bottom)

In PowerViz [128], Paay combines a metaphoric interface and analytic tools to promote better understanding of current domestic appliances. The system allows users to detect/isolate the unusual high-consuming appliances. PowerViz consists of four different screens: *screen saver, usage history, appliance usage* and *appliance history*. The screen saver is a metaphoric visualization, which represents overall consumption through light bulbs. According to Paay, the objective of this ambient display is to "*create ongoing engagement with the system while giving a playful overview of total household energy consumption*". Other three screens are for an analysis purpose (i.e., appliance usage screen shows energy consumption of each appliance in the home). A touch on the display changes the view from ambient view to analysis screens. Figure 4.7 illustrates these four views.

Figure 4.7. (top) PowerViz [128] screen saver: overall consumption represented by light bulbs, (bottom) in-depth analysis screens: (left to right) Usage History, Appliance Usage and Appliance history.

4.2.3. Zoomable user interface

Our objective is to provide multiple levels of interactions associated to different degrees of information while preserving a stable and coherent context of use. Hence, in terms of navigation, it implies to carefully design the transition between different views (e.g., from ambient to focus) and the structure of the design elements and information within a view (e.g., when focusing, user interacts with different components on the current view). Moreover, the aesthetic and artistic aspects must be preserved not only for ambient purpose but also when interacting with the system to provide the ***aesthetics of use*** rather than ***aesthetics of appearance***. Zoomable user interface is considered as a promising candidate.

Focus + Context technique

The Focus+Context technique allows creating stable and coherent contexts of use when interacting within different views. As indicated by Corkburn [25], "*this technique integrates the focus and its context into a single display where all parts are concurrently visible*, *the focus is displayed seamlessly within its surrounding contexts*". In fact, the Focus+Context technique is found to effectively minimize the user's memory load by making the focus object and other enclosing elements available. As the result, Corkburn believes that Focus+Context technique might enhance the "*user ability to comprehend and manipulate information"* [25].

Research on Focus+Context technique often endeavors the utilization of *fisheye* interfaces, which refers to enlarging the item of focus while the neighbor items are shrunken in various ways. In a review of different systems employing Focus+Context technique, Cockburn [25] illustrates how the *Fisheye* views are applied in current works. Among the examined studies, two appears to be relevant for our Mondrian User Interface.

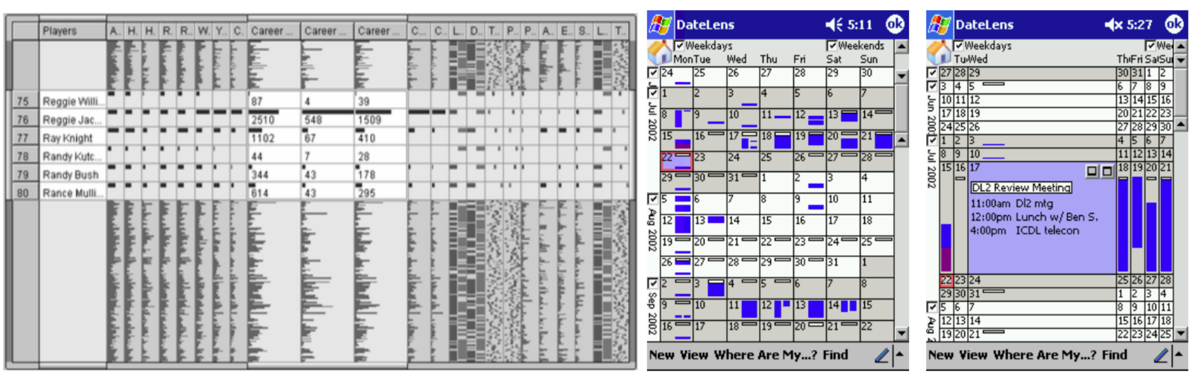


Figure 4.8. (left) TableLens [99] provides an overview of large datasets, (right) Datelens [14] explores the Focus+Context approach in a calendar display.

As shown in the left-hand side of Figure 4.8, TableLens [99] provides a condensed overview of large datasets by displaying rows and columns through the shape of rectangular bars. Users can expand a specific block of information based on its row and column; the zoomed block reveals more of the attribute values and its associated data. This function helps accessing data in more detailed manner while preserving the familiar shape of other blocks. Similarly, Datelens [14] (Figure 4.8-right) explores the Focus+Context approach in a calendar display. Users can zoom in a specific time span to obtain more related information without losing the context.

Zoomable User Interfaces

Applying Focus+Context approach implies enlarging in size the focused zone, and shrinking the others. One important aspect is to adapt the representation to the change of the interface. We consider the study of Zoomable User Interfaces as source of inspiration [77]. Indeed, the author employs Semantic Zoom method to deal with the visual representation of the Zoomable interface where objects are visually represented differently based on the available space. As example, when a user zooms on one day of Datelens [14], other non-selected days shrink into smaller rectangles while providing key information content such as the date, number of reminders for keeping the context (Figure 4.9).

Summary: In Mondrian UI, we consider two main targets: to **catch inhabitants' eyes** and to **support different contexts of use**. To do this, three approaches are considered in the design: 1) using aesthetic and ambient user interface to facilitate the integration in the home, constitute a motivational affordance and catch the eye; 2) Combining pragmatic and artistic representations to convey meaningful information; and 3) Zoomable user interface for creating a multi-level user interface.

4.3. Design of the Mondrian User Interface

This section describes our design solution for the Mondrian user interface concept. It lies on the considered approaches highlighted in previous section.

4.3.1. Mondrian Style

The concept of Mondrian user interface is inspired by the abstract compositions created by the Dutch artist Piet Mondrian. In his famous artworks, Mondrian featured rectangles filled mostly with colors like red, blue, yellow combined with black or gray lines on a white background. These works are found to be the pure abstraction art, which were part of the larger art style “de Stijl”. We justify below the reasons for this choice.

Easy to map with blocks of information

Mondrian style facilitates the mapping of information into existing elements of the artwork. As defined by Redstrom, informative art aims to augment existing elements of the artwork to display information [70]. As the Mondrian style relies on colored rectangles, it facilitates the mapping of information into these rectangles in many different ways. Moreover, the use of rectangles associated to different blocks of functionalities resembles to many software interfaces including *windows* applications, where the screen space is splitted into tiles, which are familiar to many users. Figure 4.8 illustrates the similarities between these two types of interface.

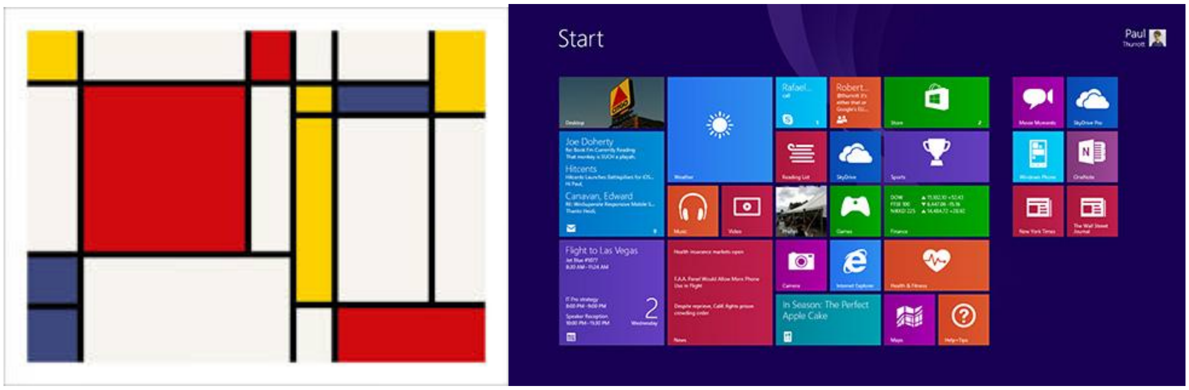


Figure 4.9. (left) Mondrian painting style (right) Windows 8 screen consists of tiles, each tile refers to one block of function

Keeping the context coherent when switching between ambient and detailed views
The transitions between these screens must be considered. For instance, through a tap on the screen, Spark [44] let users choose different type of visualizations from art-based to graphs display. PowerViz [128] features an ambient view as a screen saver display: user needs to tap on the screen for more detailed views. However, the design of the ambient display and other displays are systematically irrelevant (e.g., light bulbs versus traditional bar charts in PowerViz). The inconsistency in the design can cause cognitive load problems because of the change in the interaction context [77]. The Mondrian style allows to create multiple users' interactions levels while keeping the user interface consistent, avoiding the loss of user context.

4.3.2. Multi-level user interface

We apply Semantic Zoom method and Focus+Context approach into our Mondrian interface to provide a multi-level user interface. We illustrate our ideas through the design concept of different interactions. The UI is intended to support multiple use-contexts. For instance, there are moments of the day (e.g., before going to work, when the children are home): inhabitants may not have enough time to interact with the home system. Meanwhile, they might be interested to explore more of its functionalities for some specific contexts (e.g., weekend, holidays). We argue that the capacity to adapt to different contexts of use can effectively increase inhabitant's ability and motivation. Besides, it enhances the possibility of catching the right moment for providing inhabitants with useful information. Three levels of UI have been considered.

Three levels of interaction

Glanceable UI.
Within this level of interaction, the UI is intended to provide home information or about behavior change progress in a glanceable manner, the user might access to related information by just taking a look at the interface (e.g., checking weather, obtaining the home overall status).

One-click UI.
It implies a simple and short interaction with the home management system (e.g., accepting a challenge, browsing another view of energy consumption). This class of interaction aims at involving the user in more complex process.

Zoomable UI.
In this level, the UI involves the user in the exploration of the home management system. Tools for in-depth analysis are provided. It offers access to system's multiple functionalities in a coherent and stable context.

Transition of components

This section describes the transition of UI components between the different UI levels. Figure 4.10 illustrates two transitions in the interface: the transition from ambient to focus (a) and the transition of elements within the focused view (b)

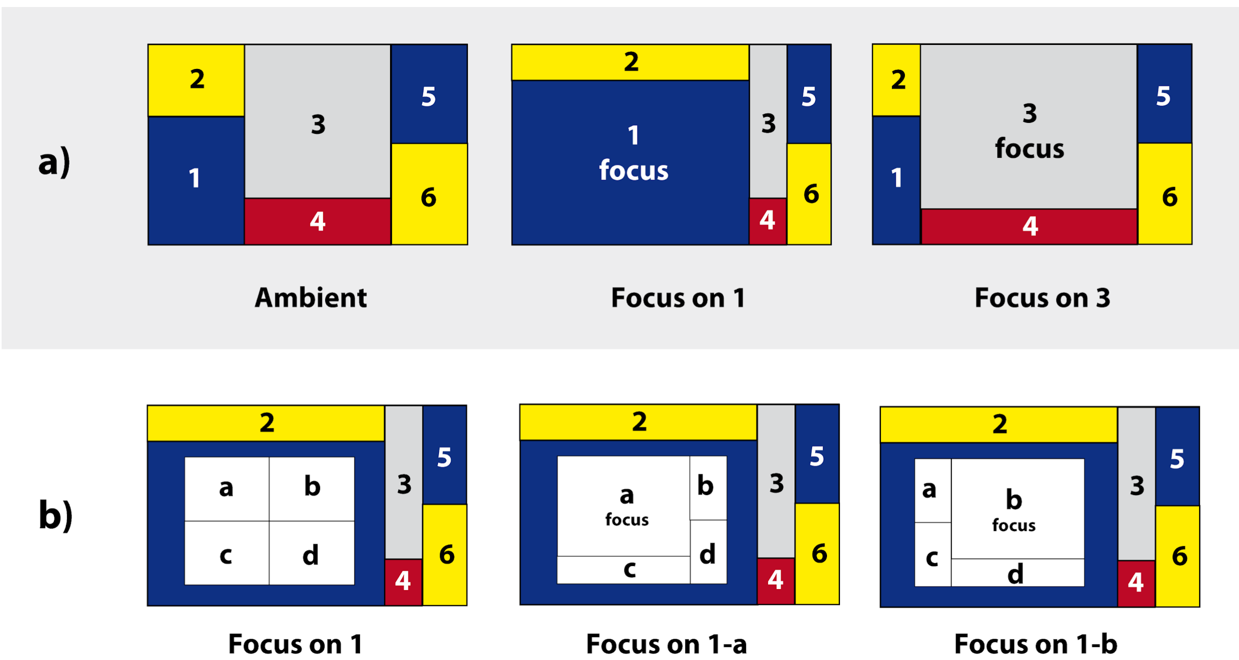


Figure 4.10. (a) Transition from ambient to focus view, (b) transition of elements within the focused view

In Figure 4.10-a, the left view is the ambient screen, middle and right screens are respectively the focused views of two different zones. Indeed, we mark 6 zones of interest filled in Mondrian colors with the index number from 1 to 6; these 6 tiles are associated to 6 blocks of information. The transition between the ambient view and the focused view happens when occupants want to interact more with the system. For instance, they may need more detailed information about energy consumption: the second view (middle) indicates how the interface has changed when applying Focus+Context and Semantic Zoom approaches. The focused block (zone 1) is enlarged to take more space for displaying its content. Simultaneously, other surrounding zones (2-6) are shrank in a way that keeps the principal information while preserving the context. Animations are implemented to keep occupants in the track.

Besides, the adaptation of Mondrian tiles in this way allows users to change the focus easily just by tapping on any zone of interest. For example, tapping on the zone 3 leads to moving the focus from zone 1 (second screen - middle) to zone 3 (third screen - right). The others, therefore, are minimized in size to fit in the current view. Moreover, as the shape and color of these tiles are preserved, the aesthetics and artistic aspects of Mondrian design are somehow retained.

In a similar manner, Focus+Context and Semantic Zoom techniques are applied throughout the interaction process. Figure 4.10-b shows the elements for the focused tile (zone 1), which are referenced as *a, b, c* and *d*. These four blocks are zoomable for obtaining different levels of content. For instance, middle view indicates that the focus is on block a), other blocks are shrunken while the focused block (1-a) is enlarged. Similarly, users can move the focus to another block with ease (as illustrated in the right view, when the focus is now moved to block b)

4.4. Proof-of-concept: Mondrian user interface for the e-coach

As a proof-of-concept, we applied these guidelines to instantiate the Mondrian user interface for the user interface of INVOLVED project's e-coach engine. Hence, this section illustrates the UI of our prototype in detail. We describe the interface according to the three intended levels of user interaction: glanceable UI's home screen, one-click interaction, and detailed zoomed parts of the UI. We start with the home view of the interface.

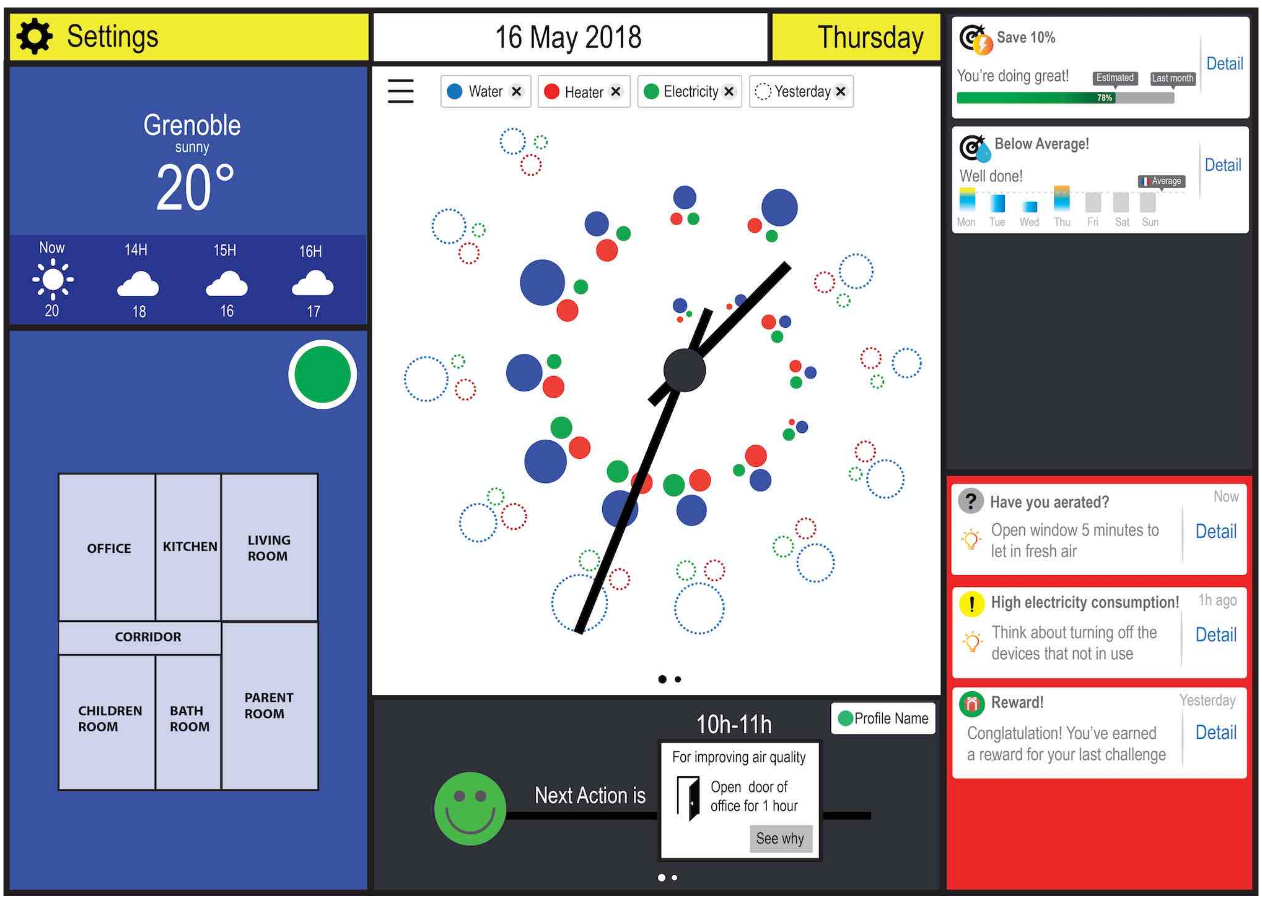


Figure 4.11. Prototype Mondrian: Home screen

As shown in Figure 4.11, the Mondrian style has been adopted in the User Interface, it creates a way to display blocks of information within the rectangle tiles where each tile corresponds to a specific functionality. We present four different views of the UI: *spatial view of the habitat, temporal view of energy consumption evolution, recommender view and social view of notification and challenges*. Besides, daily activities such as consulting time, checking weather are included in the UI. The following describes how these views are used for different use-contexts.

4.4.1. Home screen: at a glance

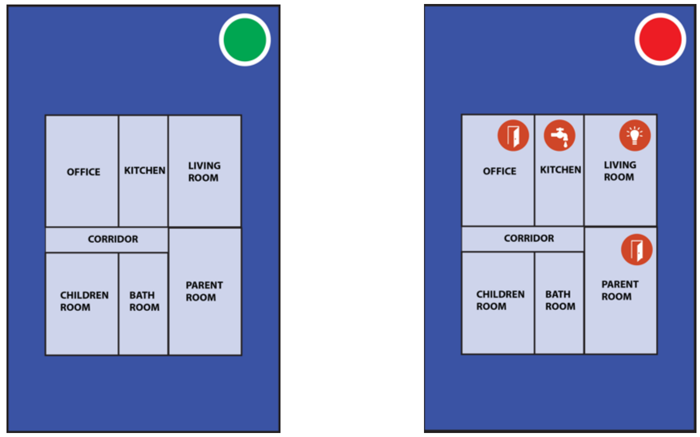


Figure 4.12. Green circle means everything is fine (a), flashing red circle signifies problem(s), icons represented the source of issues in each piece of the apartment (b)

Spatial view: status of the habitat.
Information about the household could be provided in a glanceable manner via a map of the habitat (i.e., bottom-left of the UI). For instance, in case of unwanted event (e.g., water is running in the kitchen where no one is present), the system notifies the user by marking the location with a red icon showing the potential source of the unwanted event (e.g., an icon shows water leaking from the tap). Besides, a small circle located at the top-right corner provides a global status of the home. We applied the traffic-light metaphor to show this status effectively. Indeed, a green light means everything is fine. Meanwhile, the flashing red circle alerts for an unwanted situation. This function aims at catching key moments to inform the user, one way to help moving the attention from periphery to focus.

On top of the habitation plan, we provide information about the outside conditions (e.g., current weather condition and forecast). At a glance, inhabitants can check the weather forecast before leaving the apartment.

Temporal view: consumption Clock.
At the center of the screen, we present an augmented clock illustration. Clock-based visualizations are utilized in many persuasive interactive systems for different purposes in addition to the time-checking function. For instance, eForecast [93] and Clock Cast [149] both employ this object for indicating the period of time when energy price is cheap. EnergyAwareClock [19] utilizes a clock to display a 24-hour of home electricity usage evolution. Besides, a clock-based representation also supports the moving attention of occupants from ambient to focus as many people have the habit of checking time on a wall clock, thus motivate occupants to interact.

In this approach, we augment the clock to provide different time-based visualizations about household consumption. To illustrate this, the spiral-based visualization presented in Figure 4.11 shows real-time and past consumption in terms of electricity, water and heater, each associated with a colored circle (of course, we do not guarantee the effectiveness of this spiral-based visualization: it is purely illustrative). For ambient purpose, the visualization aims at providing at a glance an overview and progress of the consumption in a way that does not overload the interface and that keeps the aesthetic pleasant. Different visualizations should be also envisioned. These visualizations may represent information about domestic activities, daily objectives, or reminders.

4.4.2. Home screen: one-click interaction

Meanwhile, other activities may need a bit more attention from occupants. This section implies activities that require very short user interaction with the system.

Decision/Recommender tile: next action.
At the center bottom of the interface, the UI presents a view of next action to be achieved by the occupants. With just one click, occupants can obtain detailed information about actions, their impacts on home comfort and energy consumption, and the related explanation. More details are provided in chapters 5 & 6.

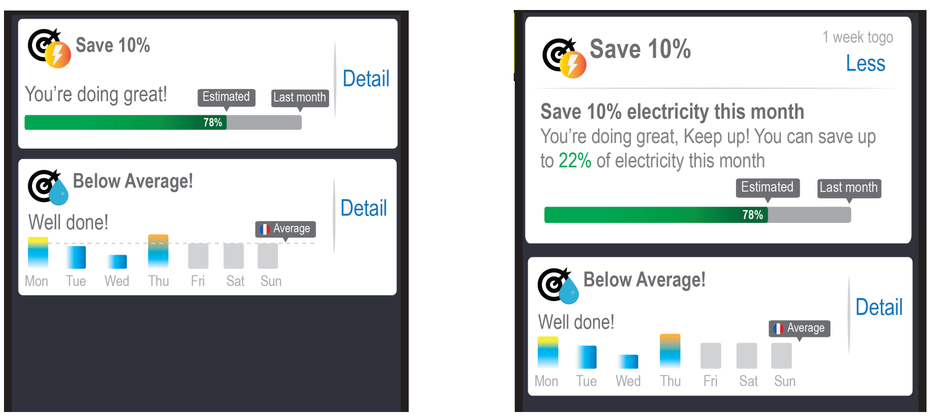


Figure 4.13. (Left) Simple list view of Goals & Challenges, (Right) Detail view of a specific challenge or goal.

Situative tile: goals, challenges and notifications.
The tile on the top right gives an overview about current goals and challenges. In the theory of behavior change, Goal-Setting is described by designers as an effective source of motivation [64]. Our analysis of persuasive interactive systems in energy suggests that goals and challenges are among the most featured to effectively engage and encourage occupants. Besides, it is believed that goals are more effective when coupled with feedback, which aims at tracking progression, performance and consequently, allow people to self-monitoring their behaviors [21, 98, 127].

Moreover, in Habit Alteration Model (HAM), Pinder et al. consider self-monitoring as one strategy to form desired habit [140]. By facilitating the performance and status tracking, this strategy allows people to adjust their efforts, and strategies based on the tracking information, thus increase ratio to obtain the predefined goals.

Therefore, we envision simple visual representations of feedbacks related to goals and challenges. In addition, self-comparison and normative comparison are also coupled with the feedbacks. We argue that this function could facilitate and motivate inhabitants to achieve their goals. At a glance, occupants can track the goals progression, how it compares with themselves or others (Figure 4.13 - left). By tapping on the item, detailed information is provided (Figure 4.13 - right).

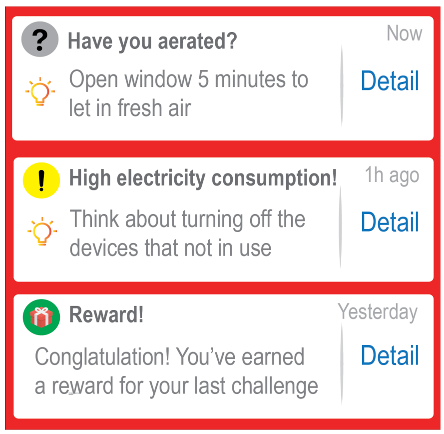


Figure 4.14. Simple list view of notifications and reminders from the system

Below the goal list, we present notifications generated by the e-coach engine. A notification could be a reminder for closing the window, suggestion for turning off the lights when the e-coach engine detects no presence in a room or a greeting message when occupants accomplish a specific task. Mapping into functionalities of UP+, these notifications can serve as protect, reward or alert functions. Besides, it could also be useful in keeping users motivated and to maintain their ability high. The capacity of providing notifications at key moments and conveying information in a glanceable manner also reinforce interactions between occupants and the e-coach engine. Similar to the goals & challenges, a simple tap is sufficient to get more information out of the notification.

4.4.3. Tile zoom-in: detail on demand

The user interface is designed to support the semantic zoom on most of the tiles. Indeed, from a behavior change perspective, inhabitants might need to fully understand their behaviors in order to start a change, to set goals, etc. In particular, as illustrated in this section, we provide design elements to assist people in expressing their preferences, recommend actions and facilitate the decision-making process. These elements aim at satisfying our initial requirements for making durable and sustainable persuasive system for energy.

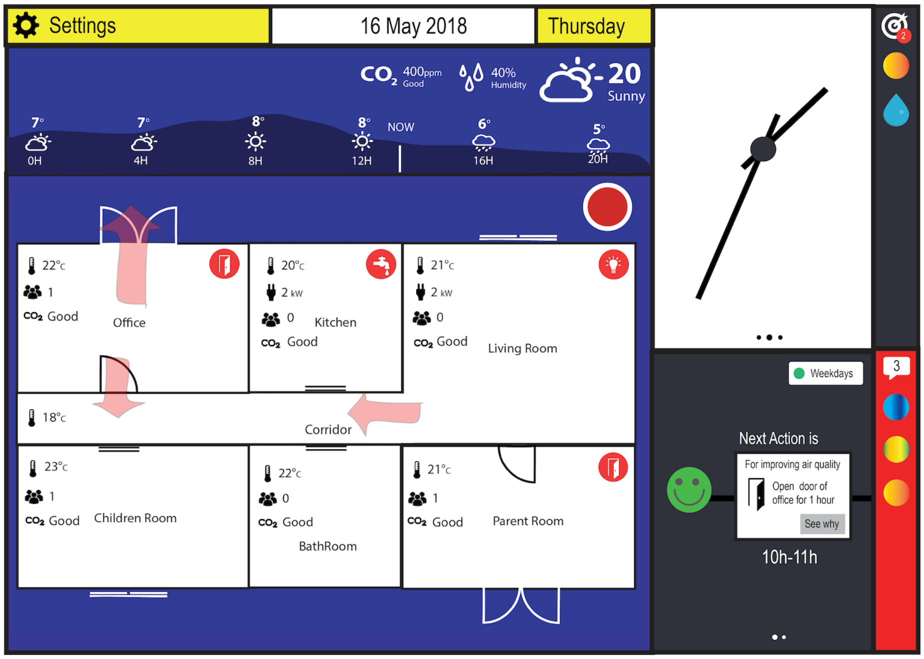


Figure 4.15. Spatial and temporal analysis of data: zoom-in of the apartment

Spatial and temporal views: explaining causality.

A double-clicking (or tapping) on one of these tiles expands it; the other tiles are shrunk and organized around constituting the context. For instance, Figure 4.15 shows an expansion of the home habitation plan. The map of the home is augmented in a way that provides more information about current temperature, CO_2 level or number of people at home. In addition, arrows represents how airflows circulate inside the home.

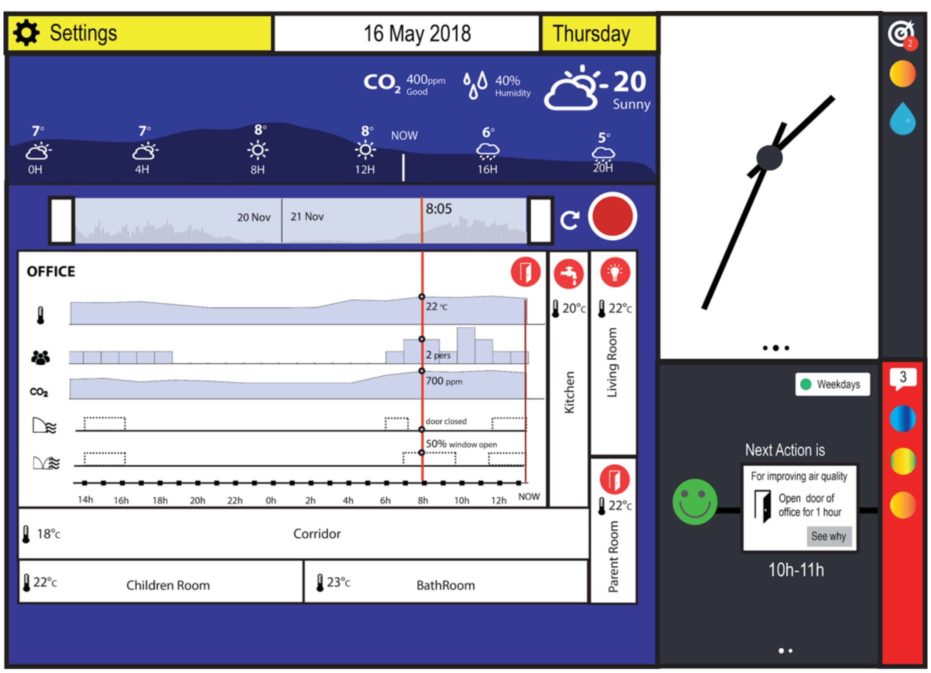


Figure 4.16. Spatial and temporal analysis of data: zoom-in of the office

Within the habitation plan, each room is zoomable. This characteristic suggests another level of feedback visualization. Figure 4.16 shows a zoom-in of the office (top-left corner). The enlarging of office creates more space to display temporal evolution of relevant indicators.

Figure 4.17. The Sliders4DM, 3 sliders allow users to find the tradeoff between conflict criteria in the household

Decision/recommender tile: support decision making and action.
Here, we present tools for supporting occupants in decision-making. Many studies show that people desire to stay in control and be involved in the housing management process. Giving the control to occupants is one way to motivate them towards sustainability. Our intention is to introduce a novel widget, Sliders4DM, which does not take over occupant's control but rather assist them towards their objectives. It revisits the traditional sliders to allow users to find the preferred tradeoff between thermal comfort, cost and air quality (Figure 4.17). With this widget, we want to give occupants tool to interact with the system and express their preferences. Our interest is to assist occupants to find optimal compromises between tightly coupled parameters in their home settings. This widget constitutes the topic of chapter 5.

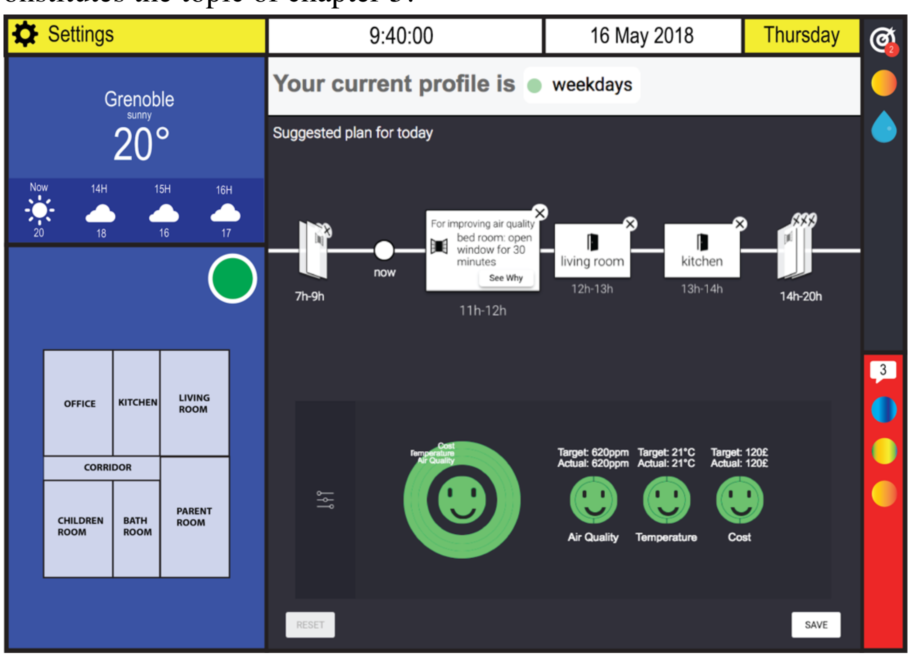


Figure 4.18. Action plan consists of recommended action to be achieved in order to obtain the defined trade-off

Once an occupant defines his/her trade-off criteria using Sliders4DM, the e-coach engine generates a list of recommended actions. It represents the optimal tasks to be accomplished in order to obtain the requested trade-off. A zoom-in on the action tile (bottom center of the home interface) shows the list of actions recommended for the day (Figure 4.18). A widget called Plan4Actions features dedicated techniques to help occupants navigate through a set of recommended actions of the day based on their defined preferences. The interactive widget allows inhabitants to cooperate with a home management system as they are involved in the decision and action loop. Moreover, explanations are coupled with each recommended action, explaining the nature of the suggested task. The action plan constitutes the topic of chapter 6.

Summary: We have presented the Mondrian UI as a proof-of-concept. Three levels of user-interaction are considered for different use-purposes:

- Glanceable for home screen UI with information related to global home status and evolution of energy consumption as well as weather forecast etc.
- One-click UI for short interactions with the system; it includes interaction related to next action to be done, current goals or challenges progress, notifications etc.
- Zoomable UI for longer interactions such as expressing preferences related to home comfort, exploring the recommended action plan and its impacts etc.

4.5. Summary

Our first contribution is the conceptual Mondrian user interface aiming at supporting long-term user interaction to accompany a behavior change and supporting multiple contexts of use. The design rationale relies on applying ambient/artistic approaches in an always-on display, on the combination of pragmatic and artistic representations, and on semantic zoom techniques to provide a multi-level user interaction. As a proof-of-concept, we instantiated this concept for INVOLVED project's e-coach engine, aiming at supporting end-users in promoting sustainable behavior in energy in residential context. Household contexts introduce various constraints such as appliance placement, visibility, aesthetic choices, and interactive affordances [152]. Besides, home settings include issues related to how occupants are willing to interact with the smart system, and how to effectively design user interface that adapt to these constraints and complexities.

We emphasize that the purpose of this study is an exploration of practical design approaches and the identification of very basic interactional bricks rather than an evaluative study. We conducted a literature review about current persuasive system for energy in household. We present our design solution and some interactional bricks with justification of chosen approaches. However, there exist some aspects that could be improved.

Personalization

As an e-coach system for household, it needs to adapt to different contexts, purposes and especially people. It is relevant to one criticism of persuasive technology about how designers define what is ‘good’ or ‘bad’ for users (see chapter 3.3). Because there is no “one-size-fit-all” solution, hence the needs to personalize the system in terms of functionalities, design elements are obvious. For instance, in our case, rather than Mondrian style, alternative modes could be given for customization purpose. Besides, we could imagine artistic styles as items that can only be unlocked for usage when occupants accomplished certain tasks and challenges.

Long-term study

As behavior change is a long-term and complex process, the study must involve a longitudinal evaluation in order to measure the persuasive aspect and more importantly in our case, how chosen design elements affects the change. Therefore, future works includes a longitudinal study of whether persuasive interaction respecting on user values actually promoted desired change in energy consuming behaviors. Currently, a long-term evaluation is out of the scope of this thesis but constitutes a mandatory perspective.

In the scope of this thesis, we focus on providing guidelines, design solutions, and an identification of very first interactional bricks for building persuasive interactive system that support the sustainable behavior change. In order to achieve this goal, beside the general design solution presented in this chapter, we investigate in-depth two of these bricks: the interactive widgets Sliders4DM and the Plan4actions. These bricks aim at recommending and facilitating occupants towards desired behaviors. Next chapters explain these two widgets in more detail.

5. Sliders for Decision Making (Sliders4DM)

The content of this chapter has been partially published in the ACM conference NordiCHI2018 titled **the Sliders4DM for Multi-criteria Decision Making by Non-Specialists**

5.1. Introduction

Our second contribution is the Sliders4DM widget, a novel multi-slider-based interaction technique. It aims at simplifying complex task by allowing users to find the preferred tradeoff between conflict criteria such as thermal comfort, air quality and cost. It is designed in a way that helps non-expert users in making informed compromises. The sliders are augmented with tightly coupled visual features to support decision making through a "what-if" process. We instantiated this concept for the user interface of INVOLVED project's e-coach engine for energy management and conducted two experimental evaluations: a qualitative one to assess its affordance and usability; and a quantitative and comparative one to assess its effectiveness compared to a close but different solution, the Pareto Sliders for Surgery [156].

The Sliders4DM widget is designed to reach the first requirement (R1) as it is envisioned as a means to facilitate decision making towards behavior change (e.g., as a first step to set goals). Also, regarding UP+, it should reach the second requirement (R2) as it primarily targets the recommend-related persuasive functions. Moreover, as we consider co-decision with the system, the widget is designed to make observable and **intelligible** system's underlying optimization model. It constitutes one of the interactional bricks we consider.

5.1.1. Motivation

The Sliders4DM widget aims at addressing, as observed in chapter 3, the lack of guidance and tools for supporting occupants in obtaining sustainable behaviors. Indeed, existing studies show that people are desiring to stay in control and be involved in the housing management process ([183], [5, 6, 78, 81]). The Sliders4DM are designed to not take over occupant's control but rather assist them towards their objectives. Thus, we investigated in-depth the interactive widgets to guide occupants towards their desired lifestyles in consuming energy. In fact, as some criteria in the home settings are often conflicting (e.g., in the winter, turning on heater to provide better thermal comfort often leads to higher financial cost, opening window can refresh the air but also decrease thermal comfort), we believe there is a gap between the occupant's desire and capacity of the system. Our solution to bridge this gap is the exploration of the "What-if" approach, that has been introduced in many existing (see chapter 3). Moreover, to reach the second requirement, we want to give occupants tools to interact with the system and express their needs. Our interest is to target the multi-criteria decision-making problem, assisting occupants in the decision-making process in order to find optimal compromises between tightly coupled parameters in their home settings.

In psychology, decision making is a cognitive process that results in the selection of an alternative between multiple possibilities. Multi-Criteria-Decision Making (MCDM) studies had developed notable methods and algorithms that could provide solutions for tackling problems that involve multiple, possibly conflicting criteria [175]. Rather than a unique solution, it often implies alternatives solutions from which Decision-makers must choose the solution that best fits their preferences. Moreover, it is impossible to find a solution that gives the optimal value for all of the conflicted criteria. These so-called Pareto-optimal solutions are equally good from the mathematical point of view, DMs have to identify the preferred "best" solution. Methods, algorithms, and interactive tools have been developed in the field of engineering design but mostly to support domain experts in making informed decisions [115]. Through the Sliders4DM widget, we target these decision-making tasks of normal users in their everyday life context, which also involves multiple tasks that required compromises to be made. For example, to obtain a bank loan, one must deal with multiple criteria to obtain the best compromise that minimizes the cost of the loan and its duration while maximizing the amount of the loan.

Supporting non-expert users to make decisions for optimization problems raises the following research questions, in particular for situations where there are more than two criteria: How can we represent the Pareto front in an effective way? How can we support the exploration of the Pareto front to identify the "best" solution? How can we inform the user when moving away from the Pareto front? How can we hide the complexity of the optimization problem while facilitating understanding of the mutual influence between the criteria?

The Sliders4DM addresses this challenge as its design targets non-experts to aid decisions for optimization problems with a small number of criteria. Furthermore, we will present the method used to develop Sliders4DM along with metrics for assessing interactive techniques for multi-objective optimization problems.

5.1.2. "What-if" approach to support decision-making process

As discussed in chapters 2 and 3, for assisting people in preparing for the change, suggestions and recommendations are among the main elements for achieving these tasks. Besides, as discussed previously, one of the most popular way to deliver suggestions and recommendations is through simulation or "What-if" approach.

The remaining of this chapter is organized as follow: we first define "multi-criteria choice tasks" and discuss the problem of evaluating tools for supporting these tasks. We then provide an overview of related work before presenting Sliders4DM followed by a detailed description of the experiments used to assess Sliders4DM.

5.2. Tools for multi-criteria tasks

A *"multi-criteria choice task"* is either a *"multi-attribute choice task"* or a *"multi-objective choice task"*. As defined by Dimara et al. [36], a "multi-attribute choice task" consists of choosing "the best alternative among a fixed set of alternatives where alternatives are defined across several attributes". We define a "multi-objective choice task as a task that consists of choosing the best alternative from a continuous possibly unknown in advance set of alternatives where criteria are strongly interdependent".

In their analysis of evaluation methods of tools for multi- attribute choice tasks, Dimara et al. [36] observe that "there is a lack of methodological guidance in the information visualization literature on how to do so." The problem is twofold: (1) Objective measures are not enough to capture the quality of a decision, given that "finding a good trade-off" is by essence, subjective. Subjective measures such as self-reported satisfaction is useful, but unreliable. (2) There is a lack of clear references for identifying an appropriate baseline for comparative assessment.

As a first step towards a more rigorous approach to the evaluation of tools for multi-attribute choice tasks, Dimara et al. [36] propose a combination of objective and subjective metrics for comparing parallel coordinates, scatterplot, and tabular visualizations, three commonly used elementary visualization techniques: accuracy and time-on-task as objective metrics; technique preference, satisfaction, confidence, easiness, and attachment as subjective metrics. These authors report that, for decision making, the three techniques are comparable across the metrics with "a slight speed advantage for the tabular visualization”. Therefore “time-on-task can be a useful differentiating factor”. Another interesting conclusion is that “testing real decision tasks can provide more insights”. Although table-based visualization techniques seem more effective for decision making than scatter plots and parallel coordinates [80] they are not applicable to optimization problems where the set of alternatives is continuous and possibly unknown in advance. As we are concerned with multi-criteria choice tasks, which include choice tasks for optimization problems, we have elected the slider, another commonly used elementary interactive tool, which supports choosing a value in a range of continuous numeric values. Sliders are also suitable elements for exploring “What-if” approach as its functionalities have been shown in many research and commercial products. Next sections reveal our solution of employing sliders as means for multi-criteria choice tasks when using “What-if” approach.

5.3. Sliders and Multi-criteria choice tasks: Related studies

Sliders are a very basic and common widget in human-computer interaction, which enable users to specify a single input value from a defined range. In our daily lives, sliders are widely used in all user-interface systems from physical to graphical, mobile application to web browser. Sliders are easy to use, intuitive and provide a sensitive mechanism for specifying values [40] Since its introduction in graphical user interfaces (GUI), the slider widget has been extended in various ways to support multi-criteria tasks. A multi-criteria task is a task that involves the simultaneous consideration for multiple criteria to reach a particular goal. These tasks include data filtering and exploration of multidimensional datasets, and choosing a preferred solution among a fixed set of alternatives as in multi-criteria decision making.

5.3.1. Sliders Augmentation for Data Filtering and Exploration

The classical GUI slider has been augmented in a number of ways to facilitate the exploration of multidimensional datasets, using additional cursors combining the slider with another visualization technique (such as a histogram), exploiting color-coding and brushing, or binding several sliders in a tightly manner.

Ahlberg and Schneiderman [3] proposed the QuerySlider widget to specify a sub-interval of values by the way of two cursors, as well as the AlphaSlider [2] to specify an index in a list of alphanumeric data (Figure 5.2a). They are connected such that one change in a slider may affect the others. As shown in Figure 5.2b, the Dynamic Query Slider [105] extends QuerySlider by displaying a histogram in the sliding area to express the data distribution for the associated attribute in that interval.

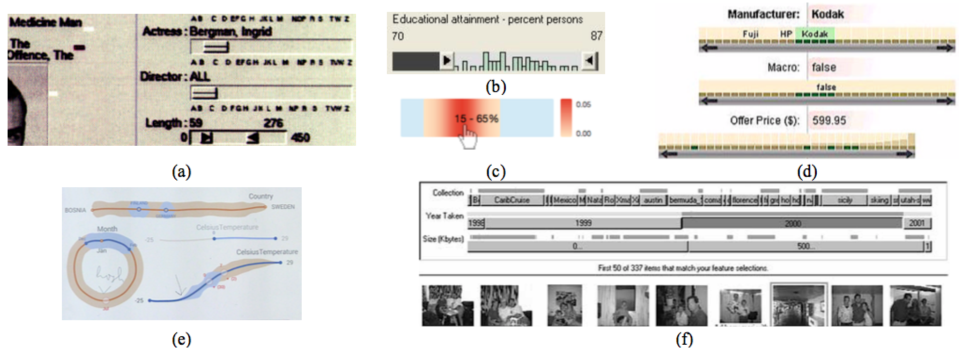


Figure 5.1. (a) FilmFinder (b) Dynamic Query Slider widget, (c) Uncertainty slider, (d) Sliding Rods widget, (e) SketchSliders, (f) EZChooser

Eick [40] proposes four versions of the slider widget to support data visualization. Eick [40] supposed that providing appropriate visualization to the slider may increase its effectiveness while preserving the intuitive interface. For instance, the sliding area may embed a color scale, show data distribution, or allow turning on or off regions of interest based on colored (on) or grey (off) areas.

Scented widgets [180] augment the familiar GUI widgets (e.g., check buttons, lists, hierarchical lists) with visual information scent cues as "*appropriate visual navigation cues can support users by guiding and refining their exploration*". In particular, the slider is augmented with a bar chart that encodes two variables with visual cues (i.e., height of a bar and color opacity). The authors have identified seven scent encodings and associated guidelines.

Greis et al. [68] (Figure 5.2c) go one step further with the investigation of entering uncertain data: the slider bar displays a color gradient to visualize an underlying probability distribution function that reflects the level of uncertainty.

Shown in Figure 5.2e, SketchSliders [171] are flexible sliders, sketched by the user, aimed at exploring multidimensional datasets on large wall displays. The SketchSliders are flexible enough to support multiple branches for a more precise exploration.

Multiple sliders may work in a tightly coupled manner where a change in one slider may have an impact on the others. Their interdependency may, or may not, be expressed explicitly. In the FilmFinder application [3] setting a value on one slider impacts the others but the relationships are not explicitly visible. Influence Explorer on the other hand [173] uses color-coding (i.e., "color linking") to make the relationships observable, and when one selection has been made on a slider, the histograms of the other sliders are updated automatically. Based on crossets, Perin et al. [130] promote a new interaction technique to manipulate multiple sliders simultaneously by crossing gestures: a single crossing gesture suffices to select and modify all the sliders simultaneously.

5.3.2. Sliders for Multi-Attribute Choice Tasks

In addition to the extension techniques mentioned above, binding multiple sliders has been extensively used for multi- attribute choice tasks using one slider per attribute. Some notable examples are EZChooser [181], SGViewer [164] and Sliding Rods [100].

EZChooser allows users to select an item (for example, a car) from a database, based on the specification of multiple attributes to form a query. Horizontal bargrams are used in parallel to represent these attributes, one bargram per attribute. A bargram is similar to a histogram slider. As shown in Figure 5.2f, within a bargram, bars are represented by a set of contiguous and horizontal clickable buttons whose size is proportional to the associated bar. Clicking a bar allows users to restrict their selection. Similar to EZChooser, SGViewer improves filter coordination among bargram widgets.

In Sliding Rods, to help users to "understand global information and their relationships", Lanning et al. propose multidimensional data exploration and querying using augmented sliding rods. In their MultiNav tool, each Sliding Rods widget, organized in parallel rows, is associated with an attribute of the data space. As shown in Figure 5.2d, the sliders are horizontally moveable in order to keep the focused item in the center of the screen.

Moreover, in some situations, the decision maker needs to specify the relative importance of criteria so that the system can rank the solutions according to these preferences. This capacity is provided in WeightLifter [129] where users are able to set relative weights between the criteria using sliders. As shown in Figure 5.3b, similar to parallel coordinates, a column represents a criterion, one color per criterion (e.g., light green for car price). It represents the weight space constraints.

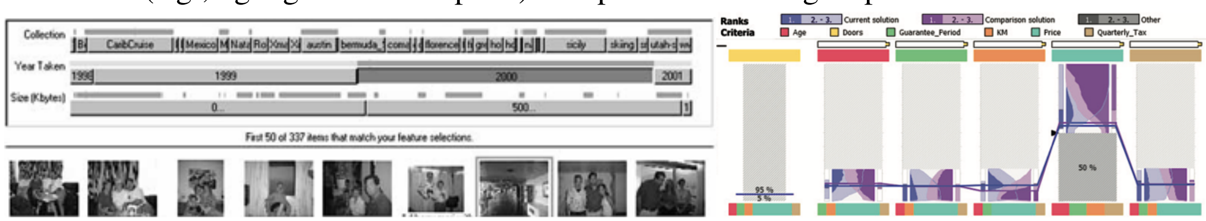


Figure 5.2. (a) EZChooser (b) WeightLifter

5.3.3. Sliders for Multi-Criteria Optimization Choice Tasks

A number of methods have been developed to visualize Pareto fronts for complex optimization problems. In particular, 3D-RadVis [79] maps large dimensional objective spaces to 3D representations while preserving the shape of the Pareto front. However, these techniques are intended for trained users in optimization problems. For novice users, we hypothesize that the implicit representation of Pareto fronts is more comprehensible and engaging than visual renderings of 3D surfaces that require specific training for interpretation.

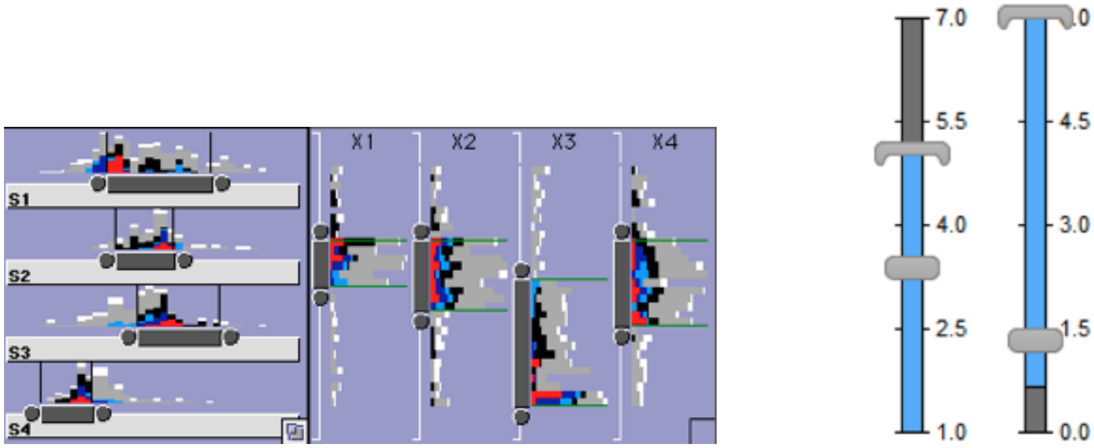


Figure 5.3 (a) Influence Explorer b) Pareto Sliders for surgery

Value Paths [9] visualizes Pareto optimal solutions where each criterion is represented by a bar whose size and location on the y axis express the range (provided that it is known) of the criterion in the Pareto optimal set. Alternatives are represented by polygonal lines (i.e., value paths). Similar to the parallel coordinate's technique, the number of criteria can be increased to a certain degree, but having too many alternatives makes interpretation and comparison difficult.

Influence Explorer [173] and *Pareto Slider* [156] both use sliders to allow users to specify attribute ranges. In the former, sliders are augmented with histograms and color linking to make explicit the relationships between the attributes, aiming at exploring relationships between parameters within a multidimensional dataset. As for the latter, when one selection is made on a slider, the other sliders are updated accordingly.

The Pareto Slider was designed to support the exploration of Pareto optimal solutions for planning medical radiofrequency ablation. As shown in Figure 5.4b, each criterion is represented by a slider that includes two types of cursors: the usual cursor and a restrictor. The lower bound of a slider is the best value for the criterion whereas the upper bound denotes the worst value. By moving the restrictor, the user can limit the range of acceptable values for the criterion. A "blue color-coding" denotes the range of acceptable values whereas eliminated ranges are colored in grey. Consequently, a cursor cannot be moved outside its blue range. In addition, the restrictor impacts the other sliders as it may reduce their blue range of acceptable values. Then, moving the cursor of one slider moves the cursor of the other sliders automatically so that the new position of the cursors corresponds to a Pareto optimal solution. The strategy used for choosing the new Pareto optimal solution among the possible ones is decided by the designer, not by the end-user.

Both *Influence Explorer* and *Pareto Slider* for surgery (in short, *PSS*) target domain-experts in specific application domains (engineering and medicine). To the best of our knowledge, no slider widget has been used to explore Pareto fronts by novice users.

Summary: We present the Sliders4DM widget, which aims at addressing the lack of guidance and tools for supporting occupants. Our intention is to explore the "What-if" approach in assisting people in decision making process. The Sliders4DM targets non-experts to aid decisions for optimization problems with a small number of criteria. The literature review shows that Sliders are common widget in human-computer interaction and has been augmented in a number of ways for different purposes and tasks related to multi-criteria optimization. However, no slider widget has been used to explore Pareto fronts by novice users.

5.4. The Sliders4DM

As the Sliders4DM are instantiated to be a part of the INVOLVED's e-coach engine, it relies on the chosen optimization model: a Pareto front: it allows users to interactively explore the Pareto front computed by the e-coach engine and to select a satisfying compromise between thermal comfort, air quality, and financial cost. As uncovered in chapter 4, its design must fit coherently into the smart home system in a way that respect the Mondrian style and Context-Focus technique. With Sliders4DM, one of the objectives is to help occupants express their preferences in terms of comfort and financial cost in the household through "What-if" approach. Then, based on the preferred solution selected by the end-user, the e-coach engine is then able to suggest optimal actions, such as opening/closing doors and windows, to optimize energy consumption (see next chapter). Before describing the Sliders4DM *per se*, we need to illustrate what "exploring a Pareto front" means.

5.4.1. Exploring a Pareto Front

As a simple illustration, the Pareto front of Figure 5.5 shows the set of optimal solutions for two conflicting criteria, thermal comfort and financial cost. The front delimits the frontier between the set of feasible but not optimal solutions (the grey zone) from the set of inaccessible solutions (the red zone). The yellow zone corresponds to unwanted ranges of values for the criteria. For example, temperature is not comfortable when below 16 °C. The shape of a Pareto front is generally similar to a convex or concave monotonic function.

As there is no unique solution to an optimization problem, it is up to the user to explore the Pareto front to find the preferred tradeoff between the criteria. For instance, from the non-optimal solution A of Figure 5.5, several optimal solutions may be reached: B1 as a significant reduced financial cost at constant thermal comfort, B3 as a significant increase in thermal comfort at constant financial cost, or B2 as a small reduction of the financial cost for a small increase of thermal comfort.

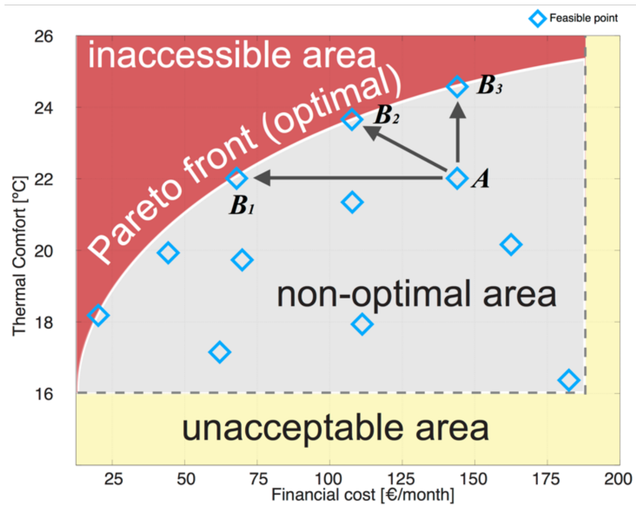


Figure 5.4. Example of a Pareto for two objective functions: cost and comfort

5.4.2. Requirements and Design of Sliders4DM

As we target non-expert users, Sliders4DM should satisfy the following high-level requirements: It should (R1) afford interactive exploration, (R2) make the interdependence of the criteria intelligible, and (R3) motivate users to find a suitable compromise between the criteria. The design of Sliders4DM is grounded on the "conceptual integration" or "blending" cognitive theory [172] as we associate a familiar widget, the slider, with an optimization problem. In addition, sliders being widely used for interactive visualization, it is reasonable to hypothesize that Sliders4DM supports the incentive to explore the solution space through a "what-if" process.

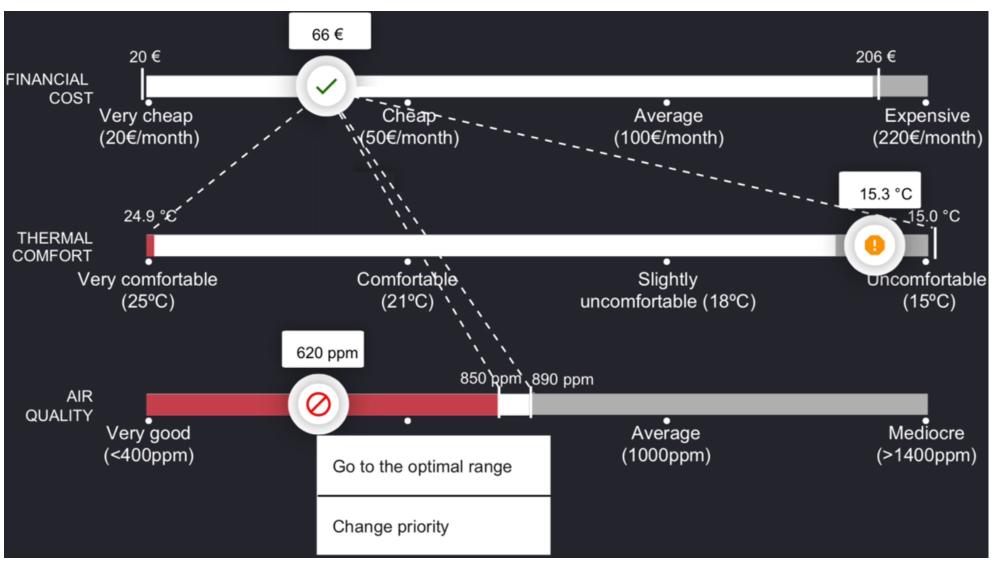


Figure 5.5. Sliders4DM with three criteria: financial cost, thermal comfort, and air quality (design used for the qualitative evaluation)

Sliders4DM is composed of a set of parallel sliders, each of which is associated to a criterion of the optimization problem (see Figure 5.6 as an illustration with three criteria: financial cost, thermal comfort, and air quality). The position of the cursor on a slider denotes the currently selected value for that criterion.

The sliders are augmented with tightly coupled visual features to support decision making through a “what-if” process. These features represent (1) the interdependence between the criteria, (2) the impact of the modification of the value of one criterion on the others, (3) and for each criterion, the current ranges within which its values may fall, each range resulting from the Pareto front calculated for the current optimization problem.

Color encoding is used to discriminate the three sorts of “Pareto ranges”: white denotes a range of values situated on the Pareto front; grey, a range of feasible but non-optimal values, and red for ranges of unfeasible values. As a result, the shape of the Pareto front is represented implicitly as the set of “white ranges” while non-optimal or impossible choices are made observable. For example, in Figure 5.6, the choices for financial cost (66€) and thermal comfort (22.4°C) are optimal whereas air quality is impossible to satisfy (620 ppm).

The interdependence between the criteria is made explicit with pairs of dashed white lines where a pair pops up when a cursor is selected and links this cursor to the boundaries of the optimal range of the other sliders. For example, in Figure 5.6, the cursor of the financial cost is currently selected: two pairs of lines have appeared to show the impact of the current choice on the range of the optimal values for the other two criteria. In addition, as the cursor of a slider is moved, the ranges of the other criteria are updated according to the underlying Pareto model. Tight coupling between cursor movements and Pareto ranges makes explicit the impact of a selection of one criterion value on the remaining criteria. In order to allow users to explore trade-offs that are not necessarily Pareto optimal, and contrary to PSS, moving one cursor does not move the other cursors.

Three icons are used as additional cues: a warning sign (!) to recommend the user to choose an optimal value; a forbidden sign (Ø) to indicate that the current selected value is impossible to reach; a check mark (✓) when the cursor lies within an optimal range. When a cursor is positioned in a non-optimal range, a pop-up menu is accessible to automatically move the cursor at the closest value of the optimal range or to change the priority between the criteria, that is, their subjective relative importance. Section 8.1.2 of the Annexes describes in detail the interaction and functioning of the Prototype utilized for experiment.

5.4.3. Evaluation Method

Building on Dimara et al. [36] analysis discussed above in section 5.2, we have combined formative qualitative and quantitative objective evaluations, using scenario-based tasks grounded in people everyday lives:

1. First, qualitative evaluations involving a limited number of participants were performed in the early phase of the development process to improve the design of Sliders4DM until the requirements were met satisfactorily. This has also served to identify the strategies that users developed to find their preferred solution. The last qualitative study performed in this phase of the development process and results are summarized in Section
2. Then, an objective quantitative evaluation involving a large number of participants was performed to compare Sliders4DM with PSS. Our hypothesis was that comparative assessment based on quantitative objective data with a large number of participants is one approach to measure subjective criteria such as satisfaction.
3. For both experiments, Sliders4DM and PSS were presented to the participants as tools to tell the e-coach of a smart home the preferred compromise between thermal comfort, air quality, and financial cost.

5.5. Qualitative Study

5.5.1. Experiment Method

Participants and Apparatus

We recruited 16 subjects by email and word of mouth (12 men and 4 women). Ages ranged from 17 to 71 of which 6 over 40, with an average of ~38. 10 were computer scientists (1) and students (9), and 6 were family members (of which 4 retired healthy persons), but none of them was involved in the project. All of them were confident in using computers and tablets. The subjects signed consent, and were not paid for their participation in the experiment.

Most of the participants were familiar with digital sliders and/or with physical sliders as in cars to control air stream. No participant has ever used tightly coupled sliders. 7 participants have concerns with energy consumption and financial cost and 3 of the retired participants use a technical solution to manage their own consumption at home (e.g., programming heating periods).

The 16 participants performed their tasks with an iPad 2 (9,7") running the user interface of the Sliders4DM shown in Figure 5.6. The Sliders4DM is implemented in JavaScript as the client of a web application using the Polymer programming toolkit. Users' actions are time-stamped and logged on a secure server. The Sliders4DM is model agnostic. In this experiment, the Pareto front is computed based on a piecewise multivariate function (hyperplanes) represented in Figure 5.7. For the e-coach application, it is implemented to support the exploration of a mathematical model of a Pareto front obtained by interpolating a set of measures that characterize the actual physical conditions of the habitat.

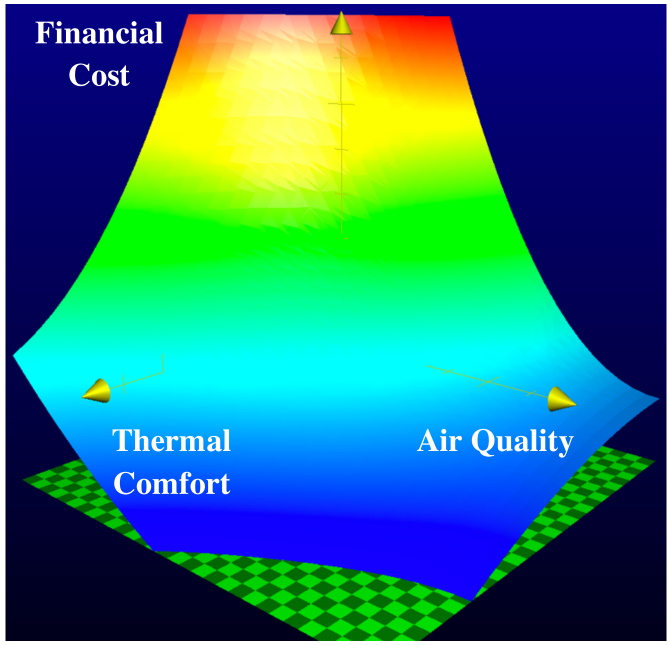


Figure 5.6. The 3D Pareto model used in the experiment (the color gradient highlights the z-axis)

Task domain and Scenario-based Tasks

Energy consumption, which has become a major societal challenge both at the political and individual levels, was selected as the task domain. For context of use, we chose a smart home augmented with an e-coach that provides end- users with suggestions for actions (e.g., opening/closing doors and windows) based on their preferred compromise between thermal comfort, air quality and financial cost.

Using the Sliders4DM shown in Figure 5.6, all participants were asked to perform the same task – to find a preferred compromise for three scenarios of increasing difficulty: easy, medium, difficult. Each scenario was designed to cover an area of the Pareto Front.

Procedure and Data Collection

The experiment was organized into four successive phases to collect both quantitative and qualitative data: (1) Introduction, (2) training, (3) task execution, (4) semi- structured interview and SUS-based questionnaire (System Usability Scale).

#1 Introduction. The experimenter presented the 4 steps of the experiment as well as the context for the task domain – a smart home augmented with an e-coach, and a tablet to interact with the system. No details were provided about the user interface, nor about the underlying Pareto model. Participants were made aware that the session was audio- recorded and that interaction with the device was captured.

#2 Training. This phase was meant to get users familiar with the Sliders4DM through a free and decontextualized exploration. No objective was specified. Participants were instructed to think aloud as they were interacting with the device. The goal of this phase was to elicit the perceived affordance of the Sliders4DM and make sure that the participants had discovered the visual elements of the Sliders4DM. No time limit was imposed. The participants were told to start phase #3 when they felt confident.

#3 Scenario-based task execution (phase #3). The goal of this phase was to observe how manipulation and visual UI elements helped users to find a suitable and satisfying combination for each interdependent criterion. The 16 participants were instructed to think aloud as they were executing the task "express your preference" for the three following scenarios:

- **Easy**: The requirements of the scenario map to criteria values that all belong to an optimal range (optimal compromise) "*It is winter. You are financially well off but you are not wasteful. At home, you prefer to live with a reasonable temperature (norms recommend 21oC), and a standard air quality suits you (European norms recommend a level of particulate matter between 400 and 600 particulates per m3 of air). How do you communicate your preferences to the system?*"

- **Medium**: Although participants are implicitly asked to find a combination on the Pareto front, the requirements target solutions in the non-optimal but feasible area. "*You are concerned with air quality. As this is important for you, you open windows and doors every morning to renew the air inside your home, even in winter. You also like feeling very comfortable with regard to temperature (you do not care if the temperature is above the norm – 21oC). However, you control your energy consumption to avoid a heavy bill. How can you express these preferences to the system?*" In this scenario, financial cost is constraining (i.e., "to avoid a heavy bill"). Participants have to decide how to lower their requirements in terms of thermal comfort and/or of air quality.

- **Difficult**. In this case, the requirements target solutions in the non-feasible area. "*In your daily living, you save money as much as possible. It is winter. You are back home after a cold day. You feel sick with flu. You want to be warm, with very good air quality because of the flu.*" This scenario, which stipulates "*best comfort and air quality at lowest financial cost", requires the participants to find a compromise between the three criteria.*

#4 Semi-structured interview and SUS. The interview was guided by a questionnaire covering the following categories:

- **Affordance**. (1) Do you see the visual elements while moving a cursor? (2) What do you understand about the animation of visual changes?
- **Intelligibility**. (1) How did you proceed to make a choice? (2) How did you manage to find a suitable/appropriate choice? (3) Does the ability to freely move the cursors motivate you to test different combinations? And to find the best combination for you?
- **Utility**. Generally speaking, what do you think of the use of a slider to manage your own energy consumption?
- **Energy management**. How do you manage energy consumption at home?
- **Use of sliders in general**. Have you ever used sliders in your daily life? Can you give examples?

Detail of the questionnaire can be found in Annexes (Section 8.1.1). To conclude this phase and the experiment, we submitted a non-modified standard SUS questionnaire (See Annexes 8.3) with a discrete scale ranging from 1 (strongly disagree) to 5 (strongly agree).

5.5.2. Results

Raw Data

All participants, but one, filled in the SUS questionnaire. A total of ~336 minutes of audio recording has been transcribed into quotes annotated according to the following coding scheme: affordance and manipulation, intelligibility, utility for energy management, and experiment-related issues (such as understanding the scenarios and/or the context of use). For each topic and participant, we have counted positive and negative quotes. The result is the extraction of 291 quotes of which 5 are out of context and thus discarded; 42 quotes were related to energy management and the use of physical and/or digital sliders in daily life. Table 1 shows the resulting distribution of the quotes. We applied a binomial test on the positive quotes over the number of participants/categories with a 95% confidence interval.

The average number of actions per scenario is the following: Easy: 8.33 actions; Medium: 16.93 actions; Difficult: 20.06 actions. The average interaction duration per scenario is: Easy: 2 mins 1 sec; Medium: 2 mins 56 sec; Difficult: 2 mins 21 sec. We have no clear explanation why the mean duration for completing the difficult scenario is less than that for the Medium Scenario – although they performed more actions for the difficult task. A possible hypothesis is that subjects abandoned the difficult task more quickly. Testing in real world conditions with an e-coach running would provide more insights.

Overall Feedback

The experiment *per se* went well for most of the participants. Although they provided positive feedback at the end of the experiment, two participants (P1, P6) had difficulties in understanding the scenario-based and role- play approach. Four participants (P2, P13, P15, P16) had difficulties to imagine themselves in a fictitious situation and reasoned based on what they would really do in their own home: "*for my personal use, I want 21°C and nothing else*" (P16). One participant (P11) complained about the imprecision of the finger-based interaction.

Category	Total # of quotes	# of part	#of positive quotes	# of negative quotes	p-value (95%)
Useful	13	13	11	2	0.02
Satisfaction	24	13	11	2	0.02
Easy to use	14	11	9	2	< 0.01
Links	27	14	14	0	< 0.01
Red zone	47	14	14	0	< 0.01
White zone		14	14	0	< 0.01
Grey zone		9	7	2	0.18
Check icon	32	13	13	0	< 0.01
Forbidden icon		8	9	0	< 0.01
Warning icon		13	10	3	0.09
Coupling	61	16	15	1	< 0.01
Compromise	42	14	11	3	0.05
Priority	37	16	16	0	< 0.01
Motivation	17	15	13	2	< 0.01

Table 5.1. Categories of quotes and their distribution. For the quotes that cover multiple topics, one quote for each topic (one per row) is counted. #part. column represents the number of participants having spoken about the category. Among this number, we have counted the number of positive (# of positive) and negative (# of negative) quotes related to satisfaction and/or intelligibility depending on the category. Only one positive or negative quote is counted in case of multiple quotes for the same participant and topic. P-value column is the result of a binomial test with a 95% confidence interval (# of positive vs. # of negative quotes)

Thirteen participants referred to the utility of the Sliders4DM (13 quotes) and the majority of them (11/13, p=0.02) clearly found it usable: "*It is clear, intelligible*" (P2); "*It is very good. I like very much having lines between the slider widgets with the slices. And to see what is possible*" (P4); "*It is intuitive. It is very well designed although it took me some time to understand*" (P7); "*It allows me to make a choice depending on the different constituents*" (P10). This is consistent with the results of the SUS questionnaires with an average score of 77.2/100. In detail, except for Question #1 ("*I think that I would like to use this system frequently*"), the score is very good (between 80/100 and 90/100) indicating that the Sliders4DM is easy to use and to learn. As for Question #1, we hypothesize that the result is rather a consequence of the application domain than that of a major usability issue, as in real life, 3 participants asserted that they were not concerned with energy consumption at home.

With regard to finding compromises, thirteen participants made comments about their satisfaction (24 quotes). Most of the participants (11/13, p=0.02) were satisfied: "*Yes, that's a good one [i.e., combination]*" (P5); "*Here, I'm good [...]. It is the best compromise*" (P8); "*If I play [with the cursors] [...], yes, it is a good one*" (P13). Two participants (P6, P7) were not fully satisfied: "*There is no ideal solution, it is embarrassing*" (P6); "*I had only one choice [...] but it is nice*." (P7).

Eleven participants mentioned the usability of the TOP- Slider (14 quotes). Nine participants (9/11, p<0.01) found the widget easy to use: "*It indicates me how to modify*" (P2); "*It is fluid*" (P3); "*We can see very well [how it works]*" (P10); "*It is clear, intuitive*" (P12); "*I quickly understood [...]*" (P14). Two participants (P6, P11) had difficulties: "*The intervals worried me at the beginning*" (P6); "*The white interval is very narrow*" (P11). For the latter, this is due to the finger-based interaction already mentioned above.

Perceived affordance

Pairs of lines. Fourteen participants referred to the dashed lines and their meaning (27 quotes). All participants (14/14, p<0.01) understood that the slider widgets are tightly coupled: "*Visually, it is nice, there are funnels and the sliders show in which area we can go and how it influences*" (P3); "*we can see easily the links*" (P6); "*The lines are very clear. When you move a cursor, I see the lines moving. It is not visually disturbing*" (P7); "*There are multiple dashed lines and lines between the circles [cursors], we clearly see they are linked*" (P10); "*I saw lines of correlation*" (P12).

Among these participants, twelve participants noticed the tiny vertical lines coupled to, and terminating the dashed lines. They (12/12, p<0.01) understood that they represent and delineate an interval of recommended values: "*It moves simultaneously, and we see the boundaries at the same time*" (P1); "*There are lines that delimit the intervals depending on the [financial] cost*" (P2); "*There is an area of possible values with boundaries that are displayed [...]*" (P5); "*You have limits, boundaries, it helps to optimize*" (P14).

Color-coding of the Pareto ranges. Fourteen participants spoke about the colored intervals and their meaning (47 quotes). All the participants (14/14, $p<0.01$) understood that a red interval indicates an incompatible range of values: *"When we are in an impossible zone [...]*" (P3); "*I saw with the red zones that I could not optimize [...]*" (P5); "*Red, we can't go there, it is impossible*" (P10). Similarly, all participants found white intervals obvious: "*The white zone is what is possible*" (P4); "*The white areas, it is when the three variables are compatible*" (P8); "*White is acceptable*" (P10). Only nine participants referred to grey intervals and seven did not pay attention to them. Seven participants out of nine understood its meaning: "*The grey zone is an overcharge compared to what we can get*" (P4); "*Here [grey interval], I think this is a useless overcharge*" (P8); "*The grey part on the right, it is the value we should not go beyond*" (P9); "*The grey [interval], after the white [interval], it is not acceptable*" (P10). Two participants (P7, P16) had difficulties with the grey intervals: "*I have not well understood the grey zone*" (P7); "*The red, it is not good, the two others are better*" (P16).

Icons. Thirteen users mentioned icons and their meaning (32 quotes). All the participants (13/13, $p<0.01$) found the 'check' symbol obvious, clearly indicating that the cursor was in the optimal interval. Some participants did not pay attention to the 'forbidden' symbol. As this symbol is complementary to the red zone, it did not harm the interaction significantly. However, one participant (P3) did not understand its meaning.

Thirteen participants paid attention to the 'warning' symbol. Ten participants (10/13, $p = 0.09$) understood that this symbol indicates a non-recommended area: "*The orange icon tells me 'warning'*" (P2); "*The /!\ tells me that I'm over the limit*" (P7); *"/!\ if I'm not in a valid area*" (P11); *"/!\? It means warning?*" (P13). However, three participants (P3, P8, P16) had troubles in identifying its meaning: "*The orange thing [/!\ symbol], I don't know what it is*" (P8); "*There is the /!\ symbol. I do not understand, I don't care*" (P16).

Intelligibility

Interdependent sliders. All the participants spoke about their comprehension of the coupled sliders (61 quotes). A wide majority of participants (15/16, $p < 0.01$) inferred without obvious difficulty that the criteria, each represented by one slider widget, are interdependent and have mutual influence: "*A good thing, when I move one, the others react*" (P1); "*Each factor influences the others [...]*" (P3); "*These are coupled variables*" (P5); "*I need to make a choice to make it compatible between them*" (P8); "*If I lower it [air quality], the financial cost will increase*" (P9); "*If I raise it [thermal comfort], the financial cost will augment*" (P14). Although P16 understood the coupling ("*Temperature influences air quality and how much it will cost me*"), this participant had difficulties in understanding how criteria are mutually influenced: "*It doesn't work [...] I have finished [scenario #1] but I have not understood why*". This may explain the relatively low SUS score for participant P16.

Need for a compromise, finding a preferred compromise
Fourteen participants referred to their need for finding a compromise and/or a suitable/optimal choice (42 quotes). The majority of the participants (11/14, p=0.05) inferred without obvious difficulties that:

(1) They had to find a compromise between the criteria to stay on the Pareto front (optimality): "*[we can] sacrifice air quality if we don't have the budget for*" (P3); "*I choose to make a compromise among the three [criteria]*" (P6); "*If I set [air quality] to 400 ppm, I have to pay more. I will set [air quality] to 500 [ppm] with the lowest cost*" (P7); "*I can make a sacrifice on temperature*" (P11); "*I have to come to a compromise*" (P16).

(2) They could iterate to find a more appropriate combination (i.e., optimization): "*As we can see all the possibilities, it incites me to seek for different combinations*" (P4); "*I tried multiple combinations, we are free [to move the cursors] and I don't want to miss one*" (P10); "*It incites me to search for [the best] ratio among solutions*" (P11); "*If I have the budget, how much air quality can I gain [...]?*" (P12); "*You have limits, you have boundaries, it helps to optimize*" (P14).

However, three participants (P1, P7 P15) had difficulties to find a compromise and/or to infer that they had to make a compromise: "*It is very difficult to obtain what we want*" (P1); "*It is very difficult to save a lot of money. I will keep the maximum [value] but I still have the exclamation point [/!\ sign]*" (P7); "*Why can't I have everything I want?*" (P15).

Priority-based manipulation. All the participants (16/16, p<0.01) made explicit the method they used to set the cursors (37 quotes). Two strategies were considered: (1) to choose a first-class criterion (i.e., cursor) and to set the others consequently; (2) to order the criteria by priority, starting with the criteria with top priority: "*The price is the most important criteria. I depend on it primarily*" (P1, P4); "*I focused on air quality and it guided me for the others*" (P2, P14); "*I created a hierarchy of my priorities*" (P7); "*My priority was the temperature*" (P12).

Motivation for testing multiple combinations. Fifteen participants spoke about how the system motivates them to test several solutions. Most of the participants (13/15, p<0.01) positively stated that they were motivated to search for a better combination of criteria. However, two participants (P1, P5) out of fifteen were not motivated: "*I stayed focused on the first criteria [financial cost]*" (P1); "*No [about searching for another solution], I have just narrowed down my limits*" (P5).

Main results

Overall, the results of this study are consistent with the requirements presented in 5.4.2. Additionally, the participants have developed strategies for finding compromises by setting priorities between the criteria.

R1 - Effective Affordance. Participants felt confident moving the cursors of Sliders4DM, as they could reuse their previous experience with GUI sliders. A large majority of the participants appreciated the graphical design of Sliders4DM, as well as the graphical animation. They found the graphical design clear without overloading the individual sliders. In terms of affordance, the dashed lines that make concrete the actual coupling between the criteria as well as the colored intervals that represent the Pareto ranges, were sufficiently comprehensible. Although the 'check' and 'forbidden' icons were found meaningful, half of the participants did not pay attention to the 'warning' icon or had difficulties to understand its meaning. Correlatively, similar issues were raised with the grey intervals for the non-optimal intervals of values. In addition, the 'go to the optimal range' contextual menu entry was rarely used.

R2 - Intelligibility. The participants discovered tightly coupled sliders for the first time. Although they found it unusual and quite disturbing during the training phase, most of the participants inferred and understood the underlying logic/model of Sliders4DM. In particular, they understood that (1) each slider represented a criterion, that (2) each slider included three types of intervals of values (optimal, non-optimal overcharge, impossible); and that (3) trade-offs were necessary to set all the cursors in a white interval. In addition, most of the participants were satisfied with their solutions. However, two participants had difficulties due to the lack of concern for energy consumption. As well, two participants found it hard to set a compromise: one of them had difficulties with the 'warning' icon, and the other one completed the scenarios very quickly.

R3 - Incentive to Explore. The capacity to manipulate Sliders4DM has motivated most of the participants to improve a selected combination for either a slightly better one, or for a very different but more satisfactory one. In addition, the audio records showed that these participants adopted a 'what-if' approach. At the opposite, three participants stayed stuck on one criterion. Again, based on their statements, we hypothesize that this is due to the application domain and personal situation.

Priority-based strategy. The participants developed a priority-based strategy to find a suitable compromise. In the version used for the experiment, Sliders4DM supported priority setting, but it did so implicitly when its associated cursor was moved. This design solution, which was somewhat disturbing for some participants, was revised for the comparative experiment presented in the next section.

Summary: A qualitative experimental study with 16 participants has confirmed the usability of the Sliders4DM as well as the intelligibility of the visual design. The experiment results are consistent with the requirements for the design of Sliders4DM.

- Participants felt confident using the widget, they found the graphical design clear and sufficiently comprehensible;
- Participants understood the underlying logic/model of Sliders4DM; for the tasks of making compromise, most of participants are satisfied with their solutions;
- Sliders4DM has motivated most of the participants to explore more the solution space though 'what-if' approach;
- The participants were also be able to develop a priority-based strategy to find a suitable compromise.

5.6. Quantitative Study

This section reports the details of the experiment conducted with 177 students to compare Sliders4DM with PSS. In this experiment, objective quantitative data was logged automatically then processed to measure subjective criteria. The choice for PSS as the baseline for comparison with Sliders4DM is two-fold: (1) PSS and Sliders4DM both address multi-objective choice tasks using sliders as the elementary interactive technique. (2) They both use color-coding, but they differ in the way criteria interdependence is reflected.

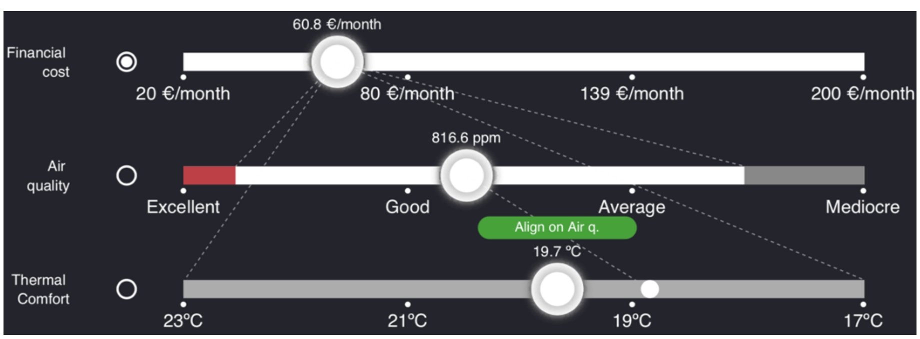


Figure 5.7. Instantiation of the Sliders4DM for specifying preferences to an energy management system

5.6.1. Sliders4DM revisited and PSS adapted

Sliders4DM Design Revisited.

Results of our first experiment reveal some limitations in the design of the Sliders4DM. Firstly, it is related to the priority-setting. While other widgets such as Influencer Explorer [173] and Pareto Sliders for Surgery (PSS) [156] allow users to define the domain of values for any criteria, Sliders4DM provides this option based on the priority of the criteria. The slider priority is set implicitly based on when its cursor is moved. In order to change a slider priority, users have to access to the contextual menu associated to its cursor. This design solution is found to be somewhat disturbing for some participants.

The second issue is linked to the use of contextual menu. This contextual pop-up menu is accessible to automatically move the cursor at the closest value of the optimal range or to change the priority between the criteria. However, these functionalities are scarcely used during the experiment. In our view, the fact that users have to click on the cursor to open the pop-up menu prevents them from using it regularly. It is against the normal ways of thinking for using the slider cursor as a button. Besides, no instructions or guidance information are provided for facilitate the access to the pop-up menu, make it harder for users to make use of this element.

The revised version of Sliders4DM used for this experiment and illustrated in Figure 5.8 addresses the issues raised by the qualitative experiment presented above. Firstly, radio buttons have been added on the left-hand side of the sliders to support the priority-based strategies revealed by the qualitative experiment. The radio buttons allow users to specify which criterion is primary while the other criteria are left on equal footing as secondary.

Secondly, a contextual 'Align on ...', green button replaces the contextual pop-menu of Figure 5.6. The green button, which appears only when the cursor of a secondary criterion is moved, has been introduced to facilitate the alignment of the cursors on the Pareto front while leaving the user free to explore non-optimal solutions.

For example, “Financial cost” is primary. As the user moves the cursor of a secondary criterion, here “Air quality”, the "Align on Air quality" button appears close to the cursor of the third criterion, “Thermal comfort”. In addition, a white circle, tightly coupled to the movements of the “Air quality” cursor, appears within the slider of “Thermal comfort” to suggest the user an optimal choice. Clicking the green button would then move the cursor of “Thermal comfort” to the current position of the white circle.

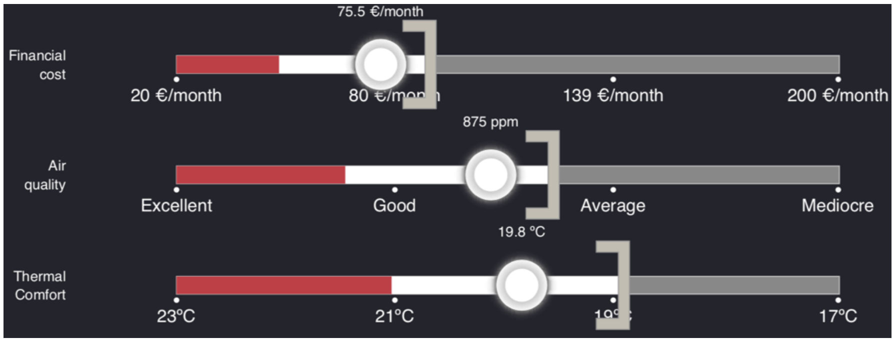


Figure 5.8. Screenshot of the adapted version of PSS

PSS Design adapted.

We have re-implemented the original PSS shown in Figure 5.4b [156] to keep PSS as consistent as possible with Sliders4DM to facilitate comparison. The adapted design of PSS have been shown in Figure 5.9. The two techniques now share the same color-coding scheme as well as the same Pareto front modeled[1] by Equation (1) where each criterion is represented by a normalized value between 0 and 1. The model can compute the Pareto front to satisfy the "real decision task" condition put forward by Dimara et al [36].

$$4((x-1)^2+\frac{1}{5})(y-1)^2-\frac{8}{15}x^2-2z+\frac{3}{10}=0 \text{ with } (x,y,z)\in[0,1] \qquad (1)$$

The major difference between PSS and Sliders4DM lies at the interaction level. In PSS, each slider is composed of two cursors: a round cursor to select a value, identical to that of the Sliders4DM; a square bracket shape cursor, named "restrictor knob", that delimits the white from the grey ranges. By moving the restrictor of a slider, users can exclude values for the corresponding criterion. In addition, the restrictor impacts the other sliders as it may reduce their white range of acceptable values and augment their red range of unfeasible values. As a result, a cursor cannot be moved outside its white range. In addition, moving the round cursor of one slider moves the cursor of the other sliders automatically so that the new position of the cursors corresponds to a Pareto optimal solution.

In PSS, the strategy used for choosing the new Pareto optimal solution among the possible ones is decided by the designer of the algorithm, not by the end-user. In our re- implementation, we have reproduced the strategy described in [156]: a point on the Pareto front is selected so that the movement of the two untouched cursors is kept minimal.

[1] The model has been developed in collaboration with our colleagues from G-SCOP laboratory.

5.6.2. Apparatus

Using standard web browsers, Sliders4DM and PSS were both available as web applications developed with JavaScript (client and server), SVG (visual rendering), NodeJS (storage of interaction traces, and participant authentication). Both user interfaces were designed with a minimal 900x560 pixels footprint. Therefore, the participants were asked to use a standard desktop computer with mouse for input connected to the Internet with regular communication speed (i.e., no tablet or smartphone device). Logs show an average resolution width of 1419 px (σ=168 px).

The code of the two interaction techniques was instrumented to collect mouse events where a log entry includes: a timestamp, an event type (motion, press, release) and the widget concerned (slider cursor, priority button, alignment button), the slider index, and the cursor position (value normalized between 0 and 1). The log files, one per participant, were stored on a server in JSON format. Logged data was analyzed with Python scripts using the SciPy library.

5.6.3. The Decision Task

Students were asked to perform the following decision task: "*As a student with limited financial resources, you are asked to select the values that best suit you for your flat, concerning financial cost, air quality and thermal comfort. When you have found a combination that satisfies your objectives, please click the* 'validate' *button*".

As shown in Figures 5.6 and 5.9, financial cost ranged between 20 €/month (23 $/month) and 200 €/month (230 $/month), air quality between excellent (400 ppm) and mediocre (1400 ppm), and thermal comfort between 17 ºC (62.6 ºF) and 23ºC (73.4 ºF). The maximum and minimum values for air quality and thermal comfort were chosen to be consistent with the outdoor condition when the experiment was performed (i.e., early April).

5.6.4. Participants

We recruited 177 participants (99 male, 78 female) among students (average age: 21.35) studying economy and/or management (81), literature (36), law and/or politics (33), and sciences (27). Table 5.2 shows the distribution of the participants. We used a between-subjects approach with the interaction technique as the independent variable [59]. Thus, participants were randomly assigned into two groups, one per interaction technique. In the following, we identify S4DM as the group of participants that used Sliders4DM and PSS as the group of participants that used PSS.

Group	# Part.	Mean age	Studies			
			Eco.	Lit.	Law	Sci.
S4DM	91 50 m./42 f.	21.3 σ=2.1	45 49.45%	16 17.58%	16 17.58%	14 15.38%
PSS	86 49 m/ 36 f.	21.4 σ=1.6	36 41.86%	20 23.26%	17 19.77%	13 15.12%

Table 5.2. Group of participants: mean age and studies

5.6.5. Experiment Design and Procedure

The experiment was the third and last session of a larger experiment that involved 201 students for a two-month period. The subjects were told that they could earn up to 20€ (~23$) for participating in the first two sessions and that they could earn a 5€ (~5.75$) bonus if they achieved the task of the third session, the scope of this article. Students were told that payment will occur at the end of the third session. In addition, they did not know how much they had already earned in participating in the first two sessions before the end of the third session.

The first step of our experiment (i.e., the third session) consisted in providing the participants with the necessary information displayed on their screen, including a detailed description of the interaction technique to be used (either S4DM or PSS), color-coding schemes, tight-coupling of the sliders, and the task to achieve. In particular, the participants were informed that: (1) the goal was to **set the cursors on a position suitable** for them; (2) the **initial position** of the sliders cursors corresponded to an **arbitrary choice** (i.e., minimal cost, bad air quality, and cold temperature); (3) there was **no time limit** to achieve the decision task but one trial only was taken into account; (4) they had to click the "validate" button when **satisfied with their choice**; (5) **validating was mandatory** to record their choice and to earn the bonus; (6) all their actions were recorded automatically; and (7) that the session will start in two days and will be available **online for 24 hours only**. In the second step of the experiment, each participant had to authenticate using an identification number and a password in order to be able to interact with one of the two interaction techniques.

For both PSS and Sliders4DM, the sliders were displayed in the same order as follows: cost (top), air quality (middle), thermal comfort (bottom).

5.6.6. Criteria for Comparison and Metrics

We have devised the following five key criteria to compare Sliders4DM with PSS: decision accuracy, satisfaction, time-on-task, incentive to explore, and interaction workload.

C1 - Decision Accuracy and Satisfaction. As pointed out by Dimara et al. [36], defining a measure for decision accuracy and satisfaction in decision-making is challenging because of the subjective nature of a decision task and because of the difficulty to find "good" solutions without objective methods such as Pareto-based models.

For decision accuracy, we propose the choice made for the financial cost as an objective measure. This is motivated in the following way: in our experiment, (1) the solution space is already Pareto optimal, so the difficulty in identifying optimality is alleviated and (2) the participants share the same profile: students with limited financial resources. Only 24 over 201 students indeed chose not to participate in our experiment. It is thus reasonable to consider that money was the motivation for the remaining 177 students. In addition, the students interviewed in the qualitative experiment, all asserted that financial cost was more important than thermal comfort. Therefore, for this experiment, in the context of saving energy, the expected correct answer is a low financial cost.

For decision satisfaction (or choice assessment), we propose the final position of the sliders as an objective measure. This is motivated by the following observations: the participants were asked to validate when they “were satisfied” with their choice. In addition, according to Cialdini's influence principles [24] a person always tries to seek for consistency while taking decisions, especially when a decision is recorded – which was the case, as the participants were made aware that their choice was recorded. Based on the same Cialdini’s principle, we decided not to submit a post questionnaire to assess subjective choices. Referring again to our qualitative experiment, all interviewees but one, indicated that they were satisfied with their choice.

C2 - Time-on-Task. We considered the time to achieve the task including at a fine grain using the time spent to drag cursors or to reach and click buttons.

C3 – Incentive to Explore. For this criterion, we used the order in which the participants manipulated the sliders. In particular, we focused on the order of the first three sliders used to analyze exploration and possibly detect corrective actions.

C4 - Interaction Workload. For the purpose of comparing PSS and Sliders4DM at the interaction level, we considered the number of atomic actions (e.g., dragging a cursor or a restrictor knob, clicking a button), the number of mouse movements to drag a cursor or a restrictor knob, as well as the trajectory length (in pixels) of cursors when moved with the mouse.

5.6.7. Results of the Comparative Experiment

This section reports and analyzes the data logs. Interval estimation is used to interpret the inferential statistics [39]. In the following, graphs that report a mean value also display a 95% BCa bootstrap confidence interval 6 [92], graphically and numerically (within square brackets). In addition, the following color-coding scheme has been used: dark grey for S4DM, light grey for PSS.

Decision Task. The results are shown in Figure 5.10. Each of the three horizontal panels corresponds to one of the three preferences: financial cost, air quality, and thermal comfort. Each horizontal panel reports the mean final position of the cursor for both interaction techniques, representing the result of the decision task.

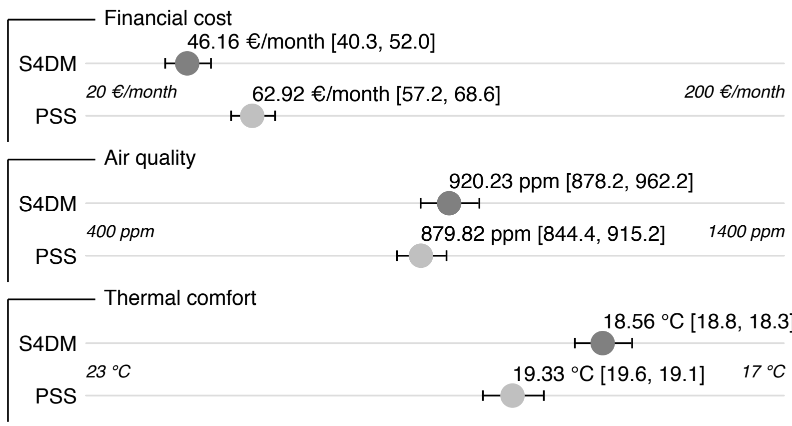


Figure 5.9. Final cursor position for each slider denoting the choice of the decision task

For financial cost, there is strong evidence that the PSS group is willing to spend more money (62.92 €/month) than the S4DM group (46.16 €/month), by 36% (16.76 €/month).
For thermal comfort, there is strong evidence that the PSS group chose a more comfortable level of thermal comfort (19.33 ºC/~66.8 ºF) than the S4DM group (18.56 ºC/~65.43 ºF), by 8.4% (0.77 ºC/~1.38 ºF).

For air quality, with strong evidence, both groups chose a similar level of air quality between good (733 ppm) and average (1066 ppm), respectively ~920 ppm for the S4DM group, and ~879 ppm for the PSS group.

In summary, we observe some correlation between financial cost and thermal comfort: a better financial cost for the S4DM group; a better level of thermal comfort for the PSS group.

The first three used sliders. The results are reported in Table 5.3 as well as in Figure 5.11. Table 5.3 shows the numerical values used to generate the graphs of Figure 5.11. Figure 5.11 shows three graphs, one per slider, respectively from left to right: financial cost, air quality, and thermal comfort. Each graph represents the number of participants (vertical axis) using the related slider for their first three uses (horizontal axis).

	First use		Second use		Third use	
Group	#1	#2	#1	#2	#1	#2
Financial cost	52	65	28	40	24	29
Thermal Com.	20	16	45	27	27	31
Air quality	18	5	16	18	35	18
χ^2 test (p-value)	0.010		0.036		0.054	

Table 5.3. Statistics for the first three used sliders

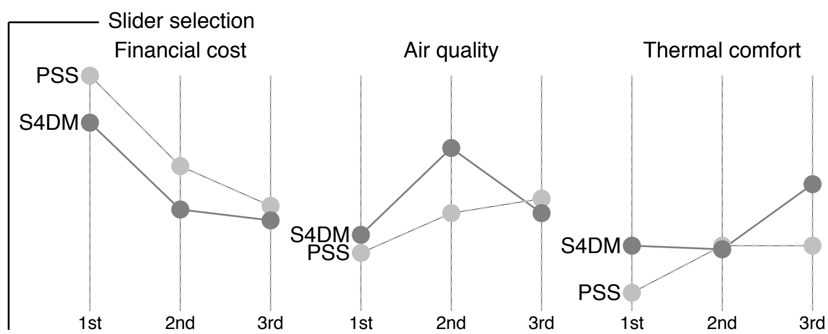


Figure 5.10. First three uses of sliders

In order to identify differences between the two groups, we have applied a multivariate statistical test using 3x2 contingency tables based on the χ^2 probability law. The bottom row of Table 5.3 reports the computed p-value of the statistical test.

For the first use, with strong evidence, both groups use the **top** slider related to financial cost. In addition, we observe that: (1) a higher number of users (u.) of PSS (65 u.) used the slider related to financial cost first compared to S4DM (52 u.); (2) a very few numbers of users of PSS (5 u.) used the **bottom** slider related to air quality.

For the second use, with strong evidence, a majority of the S4DM group (45 u.) used the **middle** slider related to thermal comfort while the majority of the PSS group (40 u.) still used the **top** slider related to financial cost.

For the third use, with some evidence, more than a third of the S4DM participants used the **bottom** slider related to thermal comfort while the PSS participants mainly used the **middle** slider related to air quality. In addition, for both interaction techniques, the number of participants that used one of the three sliders is almost equal to a third of the total number of participants. An additional χ^2 test confirms this with strong evidence.

In summary, the “first three uses” pattern for the two groups is the following:

- For S4DM: **top** slider / **middle** slider / **bottom** slider
- For PSS: **top** slider / **top** slider / **middle** slider

Completion Time and Duration. The results are reported in Figure 5.12. With strong evidence, both groups achieved the decision task by the same amount of time (Figure 5.12, top panel): 2 minutes and 32.92 seconds for the S4DM group and 2 minutes and 30.01 seconds for the PSS group.

At a finer grain, though, with strong evidence (Figure 5.12, middle panel), the S4DM group achieved atomic actions faster (3.34 seconds) than the PSS group (4.47 seconds). This result is based on measuring the time spent to achieve actions including time used to drag cursors between two positions and time to click a 'priority' or 'align' button

We calculated the active time ratio as the total of every action duration divided by the total duration of the task. With strong evidence (Figure 5.12, middle panel), the PSS group (61.49 %) spent more time to interact than the S4DM group (52.83 %), by 16.4 %.

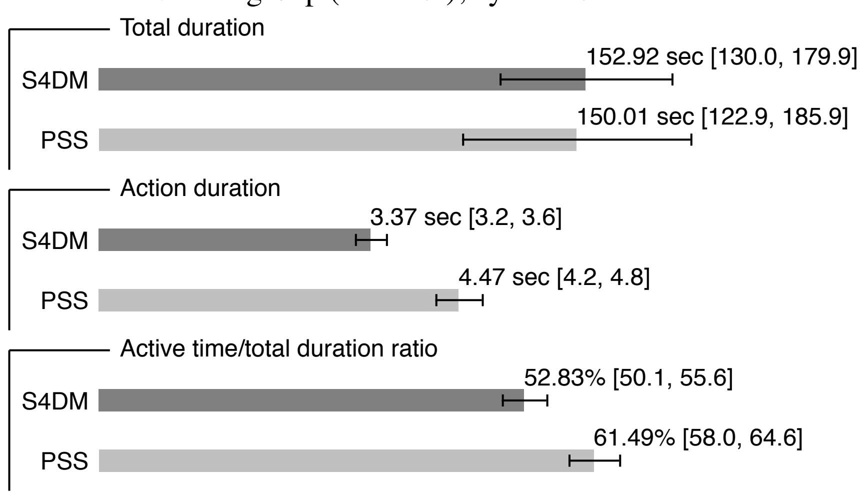


Figure 5.11. Duration of the decision task and of action

Interaction Workload. As shown in Figure 5.13 (top panel), the S4DM group achieved the decision task with a mean number of ~22 actions while the PSS group used a mean number of 18.78 actions, without significant differences.

Focusing on raw mouse events, we considered the number of mouse movements performed during the decision task (Figure 5.13, middle panel). We considered mouse movements for dragging cursors or restrictor knobs. The S4DM group moved the mouse ~1616 times while the PSS group moved the mouse ~1500 times, without significant difference.

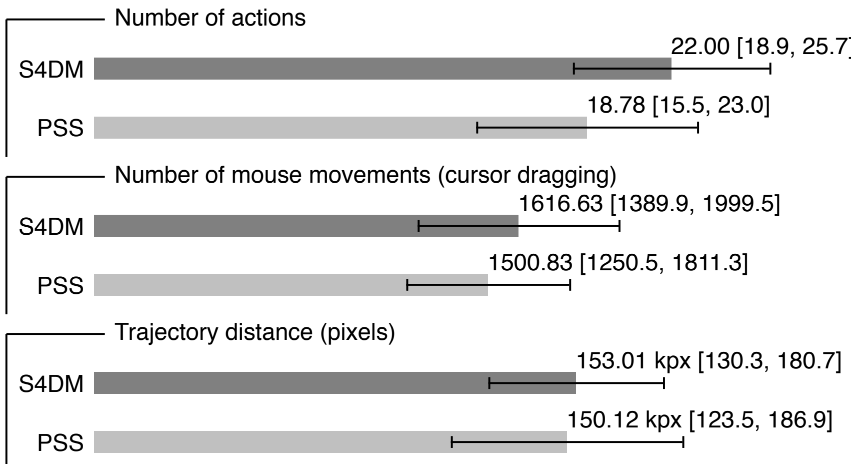


Figure 5.12. Interaction statistics

We measured the distance in pixels (1 kpx=1000 pixels) of the trajectory followed by the mouse cursor. To compute this distance, we considered a mean width (1419 pixels) computed from the logs. For S4DM, the trajectory included the mouse movements to reach and click buttons (radio buttons to select a criteria priority and the alignment button). For both groups, the distance is about 150 kpx, without significant difference.

Buttons and Restrictor Knob Use. Figure 5.14 reports how many times (horizontal axis) the buttons (S4DM) or the restrictor knobs were used, and the percentage of participants that used these widgets (vertical axis). In addition, we observe that some participants have not used one of the following widgets: 42.86% for the 'priority' radio buttons, 68.13% for the 'align' button, and 27,91% for the restrictor knob.

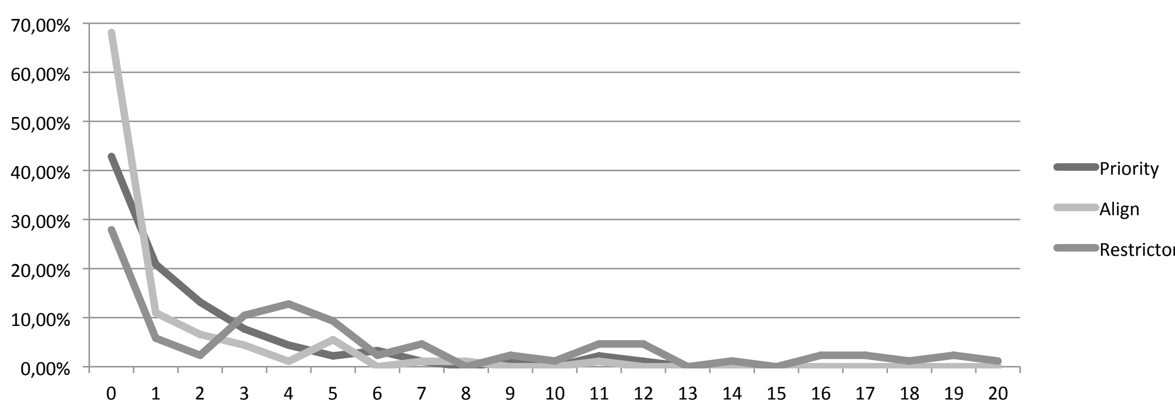


Figure 5.13. Use of Buttons (S4DM) and restrictor knob (PSS)

Most of the S4DM participants used the priority buttons once (20.88%) or twice (13.19%) while the remaining 23% used the buttons from three to twelve times. Similarly, most of the participants used the 'align' button once (10.99%) or twice (6.59%). The remaining 14% used the buttons from three to eleven times.

As for PSS, the restrictor knob was used from once to seven times by 47.67% of the participants. The remaining 24.42% used it from eight to thirty-eight times (not shown on the graph).

5.6.8. Analysis

In this section, we analyze and interpret the results according to the criteria specified in Section 5.6.6.

C1 - Accuracy and Satisfaction. Using the financial cost to measure decision accuracy (see justification in Section 5.6.6), we observe a significant difference between the two interaction techniques: Sliders4DM leads to a more optimal decision than PSS (see section 5.6.7 *Decision Task*) as the users of S4DM save 16.76 €/month (19.26 $/month). PSS users chose a more expensive option by ~36%. For Sliders4DM, these results are consistent with the preferences provided by the students involved in the qualitative experiment (i.e., low financial cost priming over thermal comfort).

In terms of satisfaction, we may consider that Sliders4DM helps users to reach a suitable compromise faster than PSS. As reported in 5.6.7 for the three first uses of sliders, the PSS group changed the value of the financial cost twice while the S4DM group did so only once. Furthermore, 2/3 of the PSS group needed to manipulate the restrictor knob (see section 5.6.7 *Interaction Workload*). We interpret this as an initial unsatisfactory choice for financial cost.
More specifically, Sliders4DM may help users to reach a satisfactory choice in an efficient manner as (1) each slider is used once at the beginning (i.e., top-middle-bottom pattern reported in 5.6.7 *The first three used sliders*) and (2) only 1/3 of the S4DM participants used the '*align*' button (see Section 5.6.7 *Interaction workload*) meaning that often the cursors were already set at a suitable position.

C2 - Time-on-Task. Although both groups spent a similar amount of time to achieve the decision task (~150 seconds, see 5.6.7 *Completion time and duration*), we observe differences at the action level: with Sliders4DM, participants' actions are clearly shorter than with PSS. This is correlated with a significant smaller ratio (total active time) / (total duration) for Sliders4DM. We hypothesize that Sliders4DM allows users to find a suitable compromise more quickly.

C3 - Incentive to Explore. In terms of exploration, the “first three uses” patterns show differences between the two interaction techniques. Correlated to our previous observation, although the PSS group achieved a corrective pattern cost-cost-air (see 5.6.7 *The first three used sliders*), the S4DM group used each slider once in a cost-air-thermal comfort sequence. We suspect that the tight coupling between the cursor’s positions enforced in PSS leads to corrective patterns.

C4 - Interaction Workload. We expected that interaction workload would be higher for Sliders4DM given that Sliders4DM includes three radio buttons and one contextual '*align*' button 'outside' the sliders. In fact, both interaction techniques show very similar results. The presence of the radio buttons and the '*align*' button did not increase trajectory lengths significantly (see 5.6.7 *Interaction Workload*). The total number of mouse movements to drag a slider cursor or to drag a restrictor knob is also similar for the two techniques. Consequently, both interaction techniques seem to impose a similar interaction workload.

Summary: A quantitative experimental study with 177 participants had been conducted to compare the Sliders4DM with PSS. The experiment underlines some interesting results.

- *Accuracy and Satisfaction*. Sliders4DM leads to a more optimal decision than PSS. Sliders4DM also helps users to reach a suitable compromise faster and in a more efficient manner than PSS;
- *Time-on-Task*. With Sliders4DM, participants' actions are shorter than with PSS. It leads to the hypothesis that Sliders4DM allows users to find a suitable compromise more quickly;
- *Incentive to Explore*. While the PSS group achieved a corrective pattern cost-cost-air, the Sliders4DM group used each slider once in a cost-air-thermal comfort sequence.
- *Interaction Workload*. Both interaction techniques show very similar results and seem to impose a similar interaction workload.

5.7. Discussion

With the notable exception of the Pareto Slider designed for planning surgery (PSS), to the best of our knowledge, no slider widget has been designed to explore Pareto fronts. In fact, most revisited sliders focus on data base query and data base exploration [2, 3, 100, 105, 164, 171, 181]. The Pareto slider approach (i.e., PSS and our Sliders4DM) complements these interaction techniques by addressing decision tasks explicitly with some similarities with Influence Explorer [173]. As in Influence Explorer, the sliders of the Pareto approach are tightly dependent, and they both use color-coding to differentiate parameter ranges.

Influence Explorer [173] and WeightLifter [129] both target experts in engineering design. By contrast, we target layman users that need to find a suitable compromise without needing to know the underlying optimization mathematical model to perform their decision task. Similar to Influence Explorer, Pareto Slider for Surgery [156] allows users to define the domain of values for any criteria, using restrictor cursors. This is a limitation of our Sliders4DM that has been pointed out in the first experiment. Improvements have been made and tested in the second experiment. Interestingly, WeightLifter allows users to specify relative weights between the criteria. From this perspective, our Sliders4DM as well as the PSS are less powerful, as users can specify only one criterion as the most important.

The two experimental studies seem to favor Sliders4DM in terms of decision task accuracy and satisfaction, time-on-task, and incentive to explore alternative solutions. Decoupling cursors placement facilitates exploration provided that visual feedback shows the impact of cursor movements over the full range of values in a strongly- coupled manner. With this approach, the user retains the liberty to position a cursor in non-optimal or impossible areas. In such cases, Sliders4DM proposes corrective actions that users are not forced to accept. Thus, the system accommodates situations in which users may not be looking for optimality, but for "good enough" optimality. By contrast, the PSS cursors, which are tightly coupled based on a "black box" algorithm, may lead to unsatisfying solutions for the user. However, as the surgery system has been evaluated with two surgeons only, we cannot assert whether this lack of freedom is a strong restriction on end-user's objectives.

By contrast, with our Sliders4DM, moving one cursor does not move the other cursors. Instead, it shows impact on all the value ranges in a strongly-coupled manner. The other cursors may then find themselves in a grey area (denoting a non-optimal but reachable value) or in a red area (corresponding to a non-reachable value), or in a white Pareto optimal range. As discussed above, Sliders4DM proposes corrective actions for the red and grey areas. End- users are not forced to accept the recommendations for the grey areas. After all, in some situations, users may not be looking for optimality, but look for "good enough" optimality provided it corresponds to their needs – typically being ready to pay extra money for significant additional comfort and air quality because one has the flu.

Moreover, as recommended by Matejka et al. from their study on slider decorations for rating tasks [112]. Sliders4DM uses dynamic feedback to improve speed and precision: each slider reports the value associated with the current cursor position. According to the same study, tick marks along the sliders should be avoided as they introduce bias into the user's choice. While using two labels at the ends of sliders may reduce bias, we have adopted multiple tick marks along each slider to provide users with additional information about domain concepts. In addition, given the context of our target domain, influencing the user to choose values that favor energy savings is judged to be appropriate.

In terms of implementation, the Sliders4DM is model agnostic. For the e-coach application, the Pareto sliders are implemented to support exploration of a mathematical model of a Pareto front obtained by interpolating a set of measures that characterize the actual physical conditions of the habitat.

5.8. Limitations and caveats

All the participants involved in the comparative experiment were students, and this may have affected the results. In addition, the mapping we used between the objective logged data and the subjective metrics may have also influenced the result. In particular, we have assumed that financial cost was a primary criterion and thus used the choices made by the participants for financial cost to measure decision accuracy. While this assumption is backed by strong evidence, it may not be valid when applied to participants with very different cultural backgrounds.

Although Sliders4DM can be instantiated with more than three criteria, scalability has not been addressed. Some of our visual cues, such as the dynamic dashed lines, which worked well for three criteria, may lead to visual cluttering, impeding the decision process. In addition, decision making with more than three criteria is indeed cognitively demanding, possibly requiring additional assistance. However, as demonstrated in [1, 115], one can draw on mathematical methods, such as dimension reduction, to address the problem of visualizing Pareto solutions for more than three objectives. Alternatively, a locking mechanism, similar to that developed by Monz et al. for surgeons [115], may be used to select the three dependent criteria and thus reduce the dimension to three objectives.

5.9. Summary

In this chapter, we propose Sliders4DM, a novel combination of tightly coupled sliders that employ "What-if" approach to allow novice users to find optimal trade-offs between interdependent, possibly conflicting, criteria especially in household context.

The Sliders4DM was designed (1) to make observable the solution space through a set of colored ranges (i.e., explain), (2) to support the exploration of the solution space using sliders, a familiar interaction technique (i.e., high ability), (3) to facilitate the understanding of the mutual influence between the criteria of the optimization problem using dynamic visual features such as the pop up pairs of linking lines coupled with the dynamic update of the values ranges (i.e., supporting decision through simulation), (4) to hide the complexity of the underlying mathematical model, while providing users with explanations using, when appropriate, dynamic textual labels and icons, as well as suggestions for corrective actions as speed-up buttons (i.e., explain and high ability).

A first experimental study with 16 participants has confirmed the usability of the Sliders4DM as well as the intelligibility of the visual design. This positive result leads to a second version of the Sliders4DM, a quantitative objective comparative study with 177 participants where we compare our Sliders4DM with an alternative approach in the domain of medical (PSS).

We believe that Sliders4DM widget could be an appropriate design element for not only supporting the decision-making process but also introducing ways to understand and explore the current problem tackled by persuasion. Besides, it achieved its original aims of assisting occupants express their preferences. Through what-if process, Sliders4DM simulates situation, suggesting appropriate compromises in a way that balances the user requirements and the system capacities. According to the four roles of persuasive interactive system introduced in UP+, we argue that Sliders4DM widget is an interactional brick that could be useful for both *recommender* and *facilitator* roles.

The next step, discussed in chapter 6, is the interoperation of the Sliders4DM widget with our Plan4Action user interface. Indeed, the e-coach engine generates Pareto-optimal solutions to suggests action plans (e.g., opening and closing doors and windows) to save energy in compliance with the trade-off specified by the inhabitant with Sliders4DM. Consequently, we will present a combination of the Sliders4DM widget with our third contribution, the Plan4Action user interface.

6. Plan4actions

6.1. Introduction

Our third contribution and second interactional brick is Plan4actions, an interactive tool allowing users to edit and adapt a contextual plan of actions (of the day, such as opening a window) in order to optimally manage energy consumption according to one's preferences specified with Sliders4DM. It aims at helping inhabitants to act for a behavior change (requirement R1) through a cooperative approach with a smart energy manager for the home: it is designed to involve users in the decision and action loop (requirement R2).

We implement functionalities that aim at generating contextual ***recommendations*** for actions along with ***explanations***. Moreover, inhabitants can ***explore*** the technical solution space in a "*what-if*" manner. It also aims at helping inhabitants to understand the functioning and rationale of their home and energy management system, and thus be incited to act in a more virtuous manner. To do so, we propose a novel concept of user interface in order to plan an appropriate sequence of actions in order to manage energy consumption. It aims at satisfying a requested level of comfort and depending on the availability of inhabitants at home to achieve actions, thanks to explanations provided by the smart energy manager. Regarding UP+, it specifically targets the ***recommender*** classes of functionalities as well as the aspects related to ***causality*** in terms of ***explain***, ***simulate*** and ***manage*** persuasive functions.

The chapter is organized as follow. Next section motivates the need for cooperative systems in the context of home management systems, highlighting issues with existing systems. Section 6.2 uncovers approaches aiming at overcoming these issues. The remaining sections details our Plan4actions user interface as well as its experimental evaluation.

6.1.1. Motivation

Advances in sensing technology and computing devices make modern home become more connected, automated, and intelligent. Home management systems are currently designed in different ways to help inhabitants in decision-making process. For this purpose, information about the household are often presented under the form of feedbacks to inform inhabitants about the home situation. This technique aims at empowering and motivating them to make better decisions. However, feedback-based systems are often limited at revealing usage information and does not seems to be effective in the long run (see chapter 2).

Among these approaches, applying automation features seems to be a necessary solution, it makes the sustainable changes "*more effortless or convenient*" [85]. In this line of works, the home management system often take control over the home. The system acts on behalf of the inhabitants for doing the household practices autonomously (e.g., heating, laundry). The lack of control results in many concerns for the inhabitants. For instance, inhabitants may encounter situations for which the system would make unappropriated decisions. In some cases, without the throughout understanding of how the system works, inhabitants might be confused and even annoyed with the management system. In addition, the complexity of inhabitants' daily life often leads to conflicts between system decisions and inhabitants' interests, even when the system generates an appropriate decision. For example, a system might detect a too high level of CO2 inside then asks for opening the window although the air is too polluted outside.

By contrast, in our approach, we consider inhabitants being in a control position, cooperating with the system to be actively involved in decision-making and actions (requirement R2). However, in order to help inhabitants to make appropriate decisions and actions, we consider tools that assist inhabitants to better understand the functioning of their home, and thus in decision-making tasks. As highlighted in next sections, current studies show that the cooperation between inhabitants and a home management system could be a promising solution to solve the current issues.

6.1.2. Automation in home management systems

Automation is more and more used in home management systems in order to reduce the workload of inhabitants in controlling their home. In this line of works, home management systems have been explored in different ways for "automated" functionalities that can support inhabitants. In this endeavor, many systems make decisions on behalf of the user to effectively save energy. For instance, a system can optimize energy usage [93, 149] based on the prediction of available renewable energy. Indeed, a notable number of studies have investigated how smart features utilizing automatic functionalities can assist inhabitants in their energy-consuming practices such as heating, lighting, scheduling thermostats or washing clothes [17, 93, 184]. In addition, smart systems are also designed to detect and/or predict home occupancy in order to save energy when no one is at home [97, 108]. In this line of works, a prediction engine would allow the system to reduce energy usage without compromising inhabitants' preferred comfort level. Moreover, because of the complexities of the home, it makes user-done scheduling tasks difficult and time-consuming tasks, especially for non-expert users. Therefore, auto-schedule is another targeted feature. By this means, the system has full power to control the home parameters (e.g., temperature, air quality) to optimize energy usage and occupant's comfort. For example, the Nest (a commercial smart thermostat) employs a learning-based approach to adjust the thermal comfort and automatically generates heating schedules for inhabitants. Figure 6.1 shows the three interfaces of the Nest: (left) interface of the thermostat device mounted on the wall, (middle) the mobile interface and (right) the web interface which allows the auto-schedule.

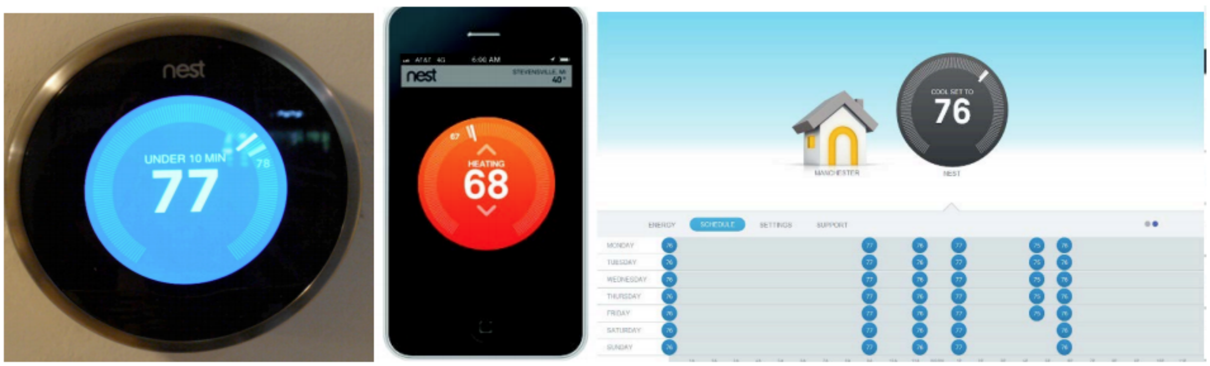


Figure 6.1. (left) interface of the thermostat device mounted on the wall, (middle) the mobile interface and (right) the web interface which allows the auto-schedule

6.1.3. Pitfalls of fully-autonomous systems

Against this background, researchers have indicated that fully-autonomous systems do not work as expected and often fall short in real-world environment practices [104, 158, 184]. To explain this failure, some considers that unreliability in learning and predicting inhabitants' behaviors are the main factors. It results in false or misleading decisions from the management systems, thus making inhabitants to be frustrated and annoyed [20, 141, 184]. Others suggest that inhabitants might abandon these smart devices when they cannot understand their functioning or why they did not function as expected [141]. Even in some situations for which the automatic system succeeds in optimizing energy usage and user comfort (e.g., open the blinds for increasing the lighting condition), yet fails in "*doing the right thing*" [81] (e.g., it throws glare on the television screen, when everyone is watching a movie). In [20], Brush et al. consider the "*the structural changes needed to install home automation*" as a challenge for the broad adoption of this technology. Additionally, the complex UI often prevents inhabitants from effectively taking advantage of automation functionalities.

In summary, we believe there are two main reasons explaining the failure of fully-autonomous systems.

Predicting everyday life is complex

People's routines and habits drive their behaviors [4]. The capacity to learn, understand and predict inhabitant's routines offers opportunities for optimizing home energy resource. Therefore, many autonomous systems try to model the routines of inhabitants. However, the complexity of everyday life causes problems for modeling. Firstly, it requires a large training set containing appropriate decisions for all possible contextual situations [81], which is not always possible.

Even when we remove the dataset and training barrier, the nuanced daily routines also make it difficult to effectively set an appropriate and relevant schedule [5]. In fact, inflexible scheduling options and difficult scheduling process prevent users from frequently changing their current schedules and preferences. Additionally, the daily basis always produces exceptions, making it even more difficult to anticipate.

Moreover, autonomous systems require inhabitants to learn how to control and make use of their features. Sometimes it takes time and efforts to be fully in control of the appliance. According to Lazar et al. [104], the incapability in integrating new routines leads inhabitants to abandon the home management systems.

Taking over the control

Secondly, autonomous systems leave inhabitants out of control of the household. Inhabitants' desire to stay in control is thus another way to explain the pitfall. Yang and Newman examined the *living with the smart thermostat* in two consecutive studies [141, 184]. Within these studies, it is reported that such a thermostat could cause frustration, or even lead users to the abandon the technology because of the actions it acted on behalf of the user. Besides, Yang and Newman confirm that the lack of control is one of the reasons for the decrease of user's effort and engagement overtime towards the system. Additionally, Brush [20] confirmed that users expressed resistance when they cannot interfere with the system and emphasized the importance of having centralized control of the home. Moreover, for S. Intille [81], stripping people of their sense of control have been shown to be "*psychologically and physically debilitating*".

6.2. Balancing user control & system autonomy

6.2.1. Related works

To overcome these issues of fully-automated home management systems, researchers have proposed to *balance system autonomy and user control*. In other words, this approach aims at involving users in the process of decision-making while providing autonomous functionalities that assist inhabitants in certain tasks. Next section summarizes some of the studies that consider such an approach.

TariffAgent

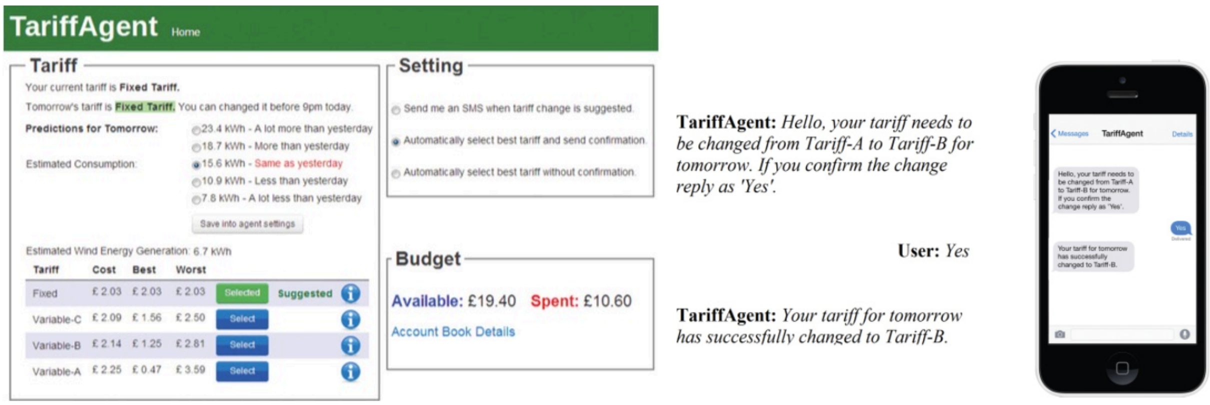


Figure 6.2. Two ways TariffAgent interact with inhabitants: a web page (left) and a dialog with inhabitants via SMS (right)

TariffAgent [6] is an agent that calculates the best electricity tariff according to the household consumption (estimated thanks to monitoring devices). It allows inhabitants to select from these tariffs. The authors evaluated three different versions of the Tariff Agent corresponding to three levels of autonomy: suggestions only (the system recommends a tariff switch that it is only achieved upon user's approval), semi-autonomous (the system automatically switches to the best tariff and informs the user), fully autonomous (the system automatically switches to the best tariff, but doesn't inform the user). Figure 6.2 shows two ways for TariffAgent to interact with inhabitants: a web site (left, home page) and a dialog with inhabitants via SMS (right). In the home page, the system shows the prediction for tomorrow's tariff (top-right) and proposes suggestions (bottom-right). Besides, the option to select among the three levels of autonomy is also available (top-left). In the right-hand side, the system suggests a tariff-change situation and then lets the user making the decision.

Results show that people are in needs for staying in control of their home, however, at certain level of autonomy, they are willing to delegate some decisions to the system. As results, Alan et al. suggest that "*flexible autonomy is a promising way to sustain users' engagement with smart systems, despite their occasional mistakes*". The authors also remark that users take responsibility for the undesired outcomes of automated actions when the autonomy level can be flexibly adjusted.

It is too hot

A recent study by Costanza et al. [5] highlight interesting aspects on how users interact with a smart thermostat and its impact on the level of comfort. Indeed, three different smart systems were implemented and deployed. It includes a *manual* one through which users specify by themselves the temperature setpoint, and two *learning-based* ones (direct and indirect learning) that utilize an artificial intelligence (AI) algorithm to automate the temperature settings based on learned households' preferences. All the three options required users to keep interacting and expressing their preferences.

Results show that users make use of different modes of the system in various ways in order to effectively save money while maintaining their desired level of comfort. Importantly, the study indicates a positive attitude towards the system when the users feel that they are in control over the system. Constanza et al. believe this finding enhances what have been concluded from previous studies about the amount of control given to inhabitants. Moreover, Constanza highly appreciate the potential of smart energy systems which assist inhabitants in controlling their home.

ThermoCoach

Figure 6.3. (left) Four schedule propositions from ThermoCoach, (right) Inhabitants can review/modify and activate the schedule that they found suitable

Close to our work, ThermoCoach [141] employs the mixed-initiative eco-coaching approach. It is able to generate suggestions for specific actions in order to reduce wasted energy and keeping inhabitants in control of these actions. It relies on wireless tags attached to members of the household, and different motion sensors to model occupancy patterns. It then generates schedules and informs the user about the different schedule options along with the related impacts in terms of comfort (i.e., temperature) and energy saving. For instance, as shown in Figure 6.3-left, ThermoCoach provides multiple personalized and actionable suggestions based on the current situation of the home for thermostat scheduling. It then lets the user to review/edit the schedules and decide which one to activate (Figure 6.3-right).

Results show that actionable recommendations facilitate the action taking. Yang et al. indicate that inhabitants appreciate the concrete plan of actions for saving energy. Personalization is also a well-received design element, personalized recommendation are found to effectively increase system's credibility and reduce uncertainty [141]. Besides, the possibility to explore the solution space (i.e., view/edit/activate different scheduling options) provides the sense of control and support decision-making.

Reef

Extending the eco-coaching approach proposed in ThermoCoach, Huang et al. [78] combine this technique with comfort awareness and adaptive thermal comfort models to thermostat control. According to the authors, it offers a bright solution for improving possible savings by offering both schedule and setpoint recommendations and action plan. Developed as a non-functional proof-of-concept, Reef employs the eco-coaching technique to help the decision-making while keeping inhabitants in control. Figure 6.4 illustrates some usage scenarios of the prototype. For instance, Reef also requires users to manually create their temperature schedules with feedback on energy usage for each preference (Figure 6.4-c, d). By contrast, the system can promote proactive decisions including lowering the temperature or applying eco-energy plans without asking permission (Figure 6.4-a, b). However, it informs users about the benefit of the action and gives users the possibility to switch back to their previous settings.

Results show that inhabitants valued their notion of control over the household. In fact, inhabitants seem to favor a more "*advisory and informative approach*" for short-term saving opportunities [78]. However, in the scenarios that required user-scheduling for longer planning, inhabitants expressed their interests in a more proactive actions from the management system. Interestingly, differing from other mixed initiative approaches [6, 141], Huang et al. view their eco-coaching technique as a negotiation process where the system and inhabitants cooperate to reach a shared goal.

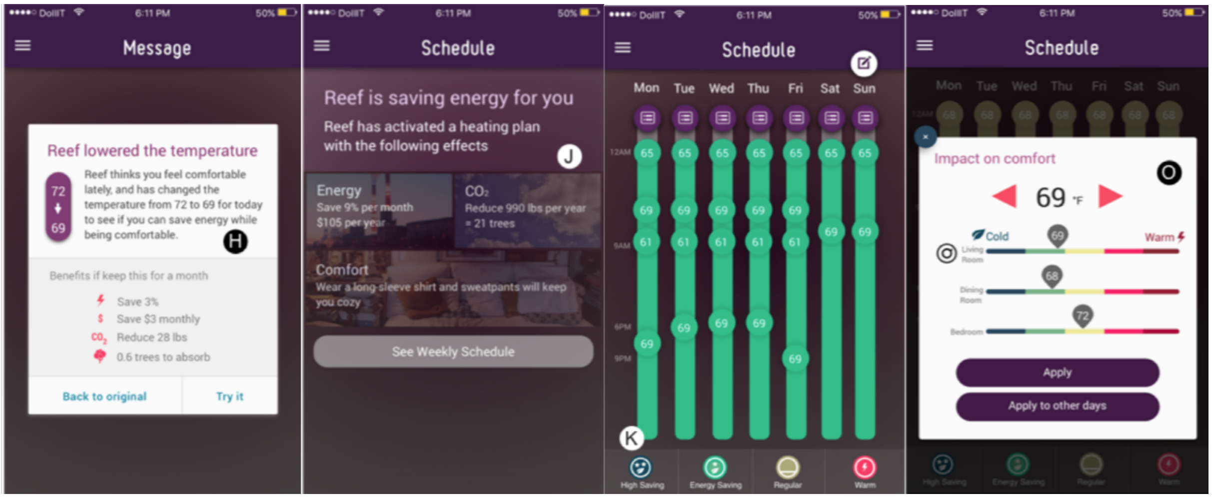


Figure 6.4 a) Reef lowers the home temperature on behalf of the inhabitants b) it activates heating plan for saving energy c) and d) it allows inhabitants to make their own schedule and provides information about the impact on comfort for the selected schedule

Intille's vision of future home management system

Sixteen years ago, S. Intille [81] shared an interesting view of future home design. Within this work, he envisioned an automated home that uses subtle reminders rather than proactive control. In this way, the home offers unobtrusive suggestion and leaves the task of interpreting the suggestion in contexts to inhabitants. For instance, the system could recommend to open a window and turn on/off an air-conditioner in order to save energy. The user might realize that it is too noisy outside, then s/he could simply decide not to open the window but turn off the air-conditioner anyway.

Besides, S. Intille [81] also consider the importance of educational aspects in smart home. The author argues that a future home should not only motivate towards behavior change but also to teach inhabitants about how to achieve a desired one. For instance, besides proposing contextual recommendations (e.g., open the window), the home could also try to explain it (e.g., a reason to open the window and its benefits) so that they could "*learn how to control the environment on their own*". The advantage is threefold: first, it teaches inhabitants about the system functioning as well as how to control their home environment; second, it increases trustworthy and user's confidence when using the system; and third, the information learned by inhabitants could be transferable to other environments where there is no automatic means.

6.2.2. Analysis

We reviewed five studies which proposed to *balance system autonomy and user control*. From these works, we underline the following salient aspects:

Suggestions

All of the reviewed studies provide this feature. It could be advice for better temperature settings (Reef), or suggestions in case of tariff changes (TariffAgent). ThermoCoach sends inhabitants four scheduling options via email. Meanwhile, S. Intille proposes unobtrusive suggestion and leaves the task of interpreting the suggestion in contexts to inhabitants.

Action Plan

These works provide access to the action plan with different level of autonomy. For instance, ThermoCoach allows inhabitants to be fully in control of editing/modifying/activating the actionable plan; Reef allows inhabitants to modify the temperature settings and schedule it on their own. The *manual* mode of TariffAgent offers inhabitants with possibility to adjust the tariff by themselves. However, in all these studies except for the imaginary view of S. Intille, the home system is responsible for taking actions autonomously according to the proposed plan.

Cooperation

The cooperation process between inhabitants and the system is demonstrated clearly in ThermoCoach (i.e., the system proposes, the user can view/modify/activate, then the system accomplish the plan) and Intille's vision (i.e., the system proposes, the user can decide to follow or not). Besides, it does not appear to be obvious in It is too hot and TariffAgent (the system acts autonomously and only asks for approval to take actions in certain situations). Meanwhile, in Reef, Huang et al. view their eco-coaching technique as a negotiation process where the system and inhabitants cooperate to reach a shared goal.

Adaptation

The reviewed studies show that people find ways to adapt to the system's capacities and functioning in order to achieve their objectives either in terms of financial cost or comfort level. In TariffAgent, inhabitants show their willingness to delegate some decisions to the system. In It is too hot, the participants developed strategies for different modes of the system to reach their goals.

Flexibility

Being flexible to act upon their will is an important need for the participants of these reviewed studies. Alan et al. (TariffAgent) consider flexibility as *a promising way to sustain users' engagement with smart systems*. Being flexible to act can also promote positive attitude from users (It is too hot), provides the sense of control and support decision-making (ThermoCoach).

Summary: The literature review shows that fully automated systems are often fail in addressing home management tasks. Balancing system control and user autonomy seems to be a promising solution. Our intention is to target the human-computer cooperation in home management system rather than automation home. The Plan4actions is intended to provide inhabitants with explanation for each recommended action and its direct impacts on home comfort.

6.3. Plan4actions Design

Plan4Actions builds on this literature but aims at extending it in four main keys. First, instead of focusing on the thermal comfort, we explore other criteria related to the home such as air quality and financial cost. Second, as all the systems presented previously embed components to automate the prediction of inhabitants' routines whether it is related to the occupancy or the home level of comfort, we take a different approach by giving full control to the user over the scheduling process. Third, we propose to explore the human-machine cooperation process via *what-if* approach. Indeed, while the notion of recommending systems has been explored, the approach is studied in a passive manner rather than an interactive simulative process. Lastly, motivated by the notion of "teaching" home, we employ educational-oriented approach into our design, supposing that contextual explanations associated with recommended action in an interactive manner would promote better understanding of the home functioning. Besides, we believe the explanation aspect could increase inhabitant's motivation in the long-term.

We identify the following requirements in the design of Plan4Actions:

(1) To provide interactive concrete plans and explanations based on user's preferences,
(2) To help inhabitants understanding the functioning and rationale of their home,
(3) To allow inhabitants to explore alternatives, and
(4) To facilitate cooperation between inhabitants and the system.

Moreover, to better understand the impacts of direct feedback on users, any change either from action plan or the preferences would affect other elements automatically: we called it the "**equal-opportunity**" approach. Next subsections present our design solution, how it targets these four requirements and how "equal-opportunity" is implemented. Also, we detail the results of an experimental qualitative study conducted with 13 participants.

6.3.1. Plan4Actions at a glance

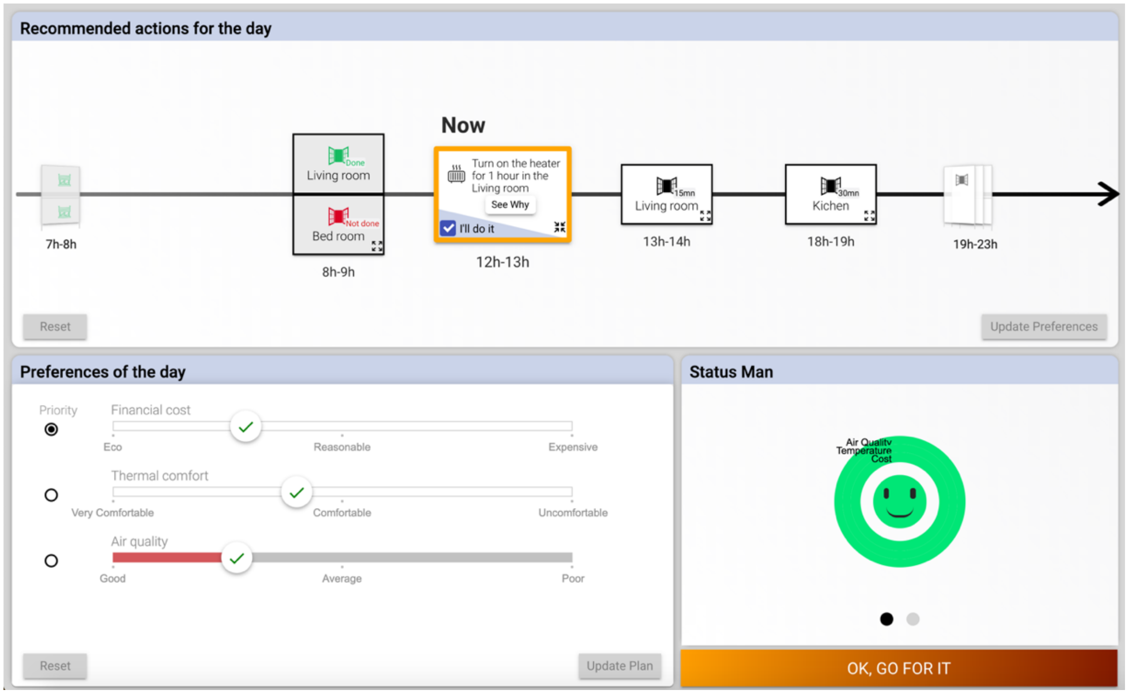


Figure 6.5. Main design of Plan4actions

Figure 6.5 illustrates the Plan4actions user interface: three main design elements are shown. At the top of the interface, a concrete plan which consists of recommended actions generated by the e-coach engine is displayed: The *Recommended actions for the day* are provided based on the inhabitant's preferences (bottom-left area of the interface). The *Preferences of the day* are defined by the Sliders4DM widget, which is previously discussed in chapter 5. Moreover, a *Status man* representation is situated at the bottom-right of the interface. Its objective is to indicate the overall household situation in terms of financial cost, thermal comfort and air quality. Finally, a button labeled "Ok, go for it" allows the user to indicate to the system that s/he is satisfied with the current choices. Before detailing these three features and the underlying design rationale, we illustrate here a Scenario showing the sequence of user actions and the system interventions in the interaction process.

#1. **(User)** As shown in Figure 6.5, the Sliders4DM widget shows that the user has defined their preferences in terms of financial cost, air quality and thermal comfort. In this scenario, we assume that the system knows the overall preferences of inhabitants: regular periods of presence at home (e.g., leaving home at 8am, being back for lunch at 12:30pm and at 6pm at the end of the day) → **(System)** The e-coach engine thus generates the recommended action plan in order to achieve the defined preferences, and display it on top of the screen.

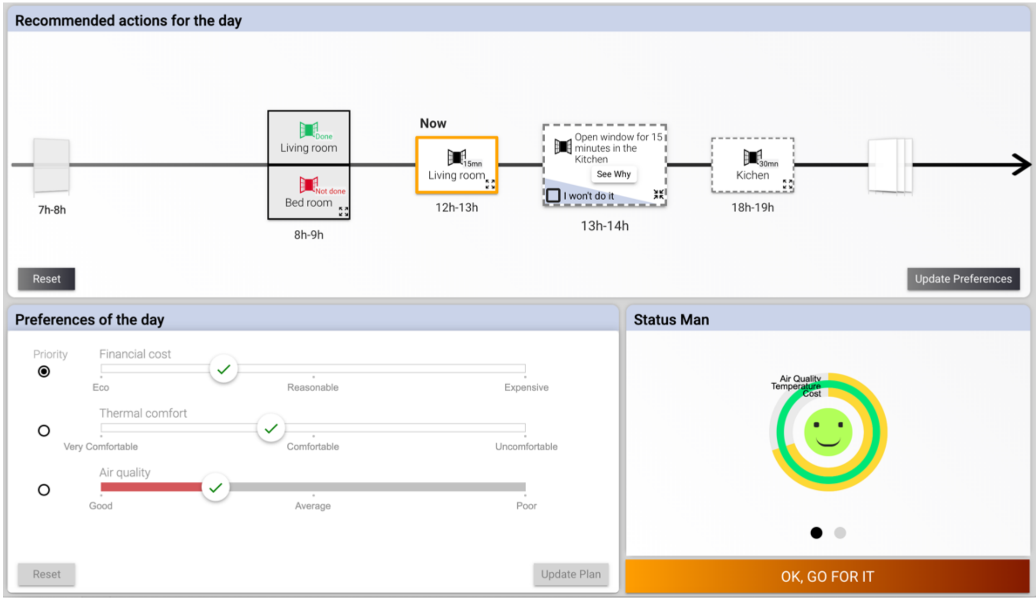


Figure 6.6. The user declares to not do the actions at 13-14h and 18-19h, the system shows direct impacts on Status Man

#2 **(User)** The user visualizes the proposed action plan, for some reasons, the user might declare that he/she cannot do the actions at 13-14h and 18-19h timeslots by unchecking the checkbox labeled "I'll do it" (Figure 6.6) → **(System)** The system acknowledges the modification(s) via visual feedbacks on the action plan and shows direct impact of the missing action(s) on the Status Man.

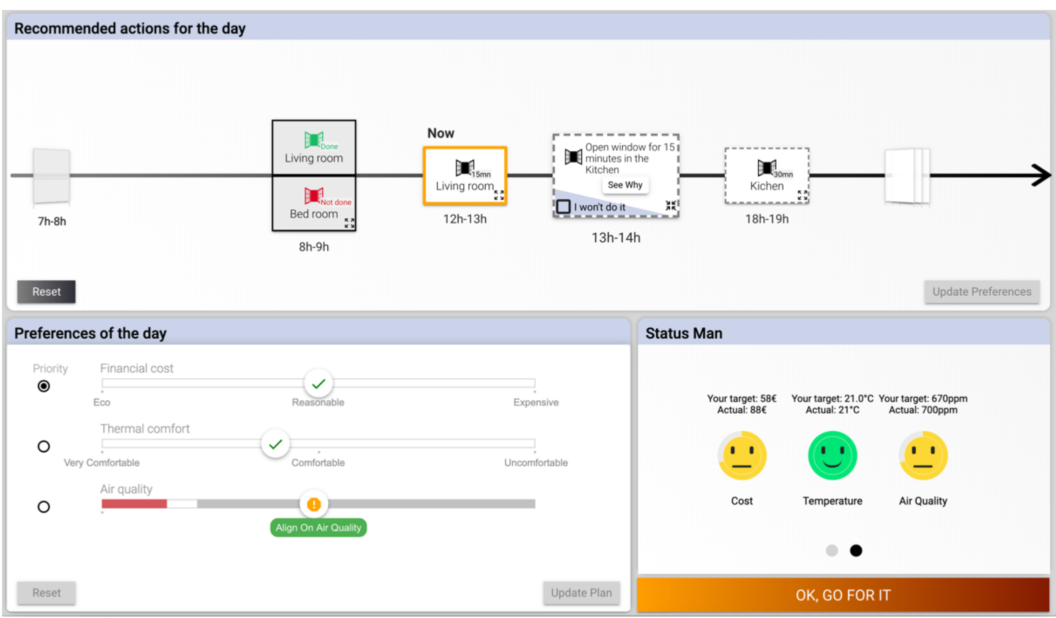


Figure 6.7. The user updates their preferences, Sliders4DM moved the cursors to positions corresponded with current action plan

#3 **(System)** As shown in Figure 6.7, the detailed view of the Status Man presents each criterion separately. The view shows the impacts of missing actions via its color-coded and progress bar values (both visual and numeric). The button "Update preferences" is enabled, indicating that the user can update his/her preferences based on this current plan → **(User)** The user updates his/her preferences, the sliders are automatically moved to the values which associated to current action plan. The user can either accept this plan/preference or continue to explore more the solution space.

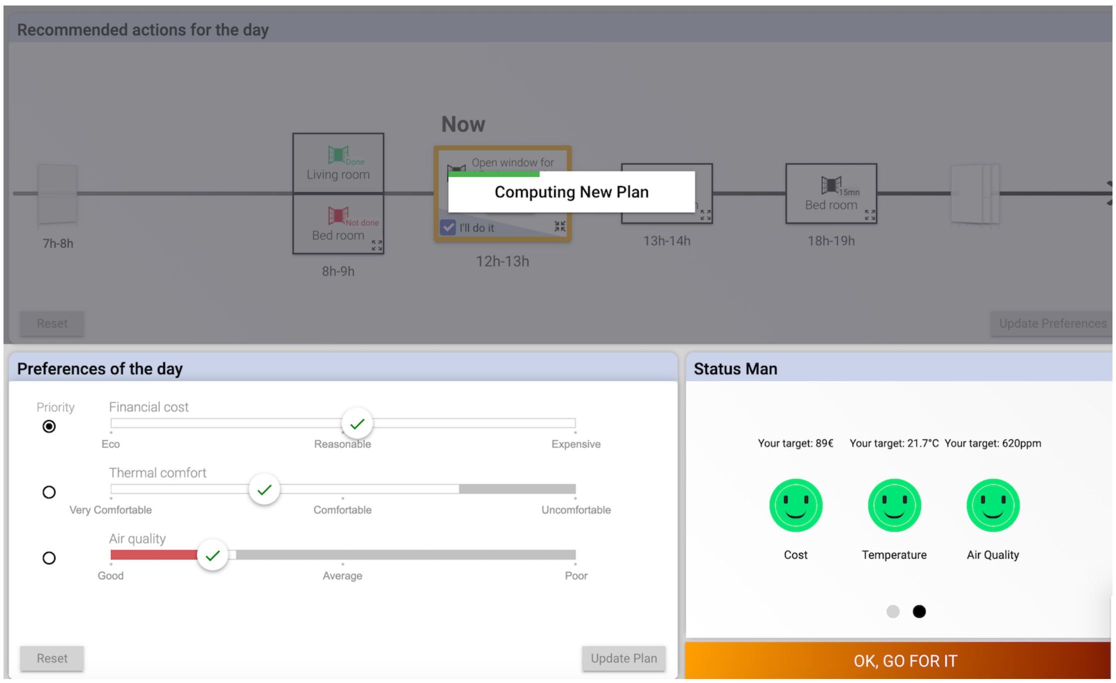


Figure 6.8. The user found a new set of preferences, the system updates it with a new plan

#4. **(User)** In the scenario presented in Figure 6.8, the user is not satisfied with current preferences. Using the Sliders4DM, the user finds another compromise in terms of cost, thermal comfort and air quality. S/He then updates the actual plan to get the new set of recommended actions associated with the preference s/he has just set → **(System)** The e-coach engine generates a new plan, Plan4actions replaces the last one with this new action plan. Section 8.2 of the Annexes describes in detail the interaction and functioning of the Prototype utilized for experiment.

The computation of the action plan and of the textual explanations is implemented in the e-coach engine, developed by the G-SCOP laboratory in the context the INVOLVED project. The implementation details are out of the scope of this thesis but the main principles may be found in [7]. In a nutshell, this engine takes into account the input parameters and overall preferences defined by the end-users as well as the contextual variables related to the household. These variables could be the outside temperature, the solar intensity or the number of inhabitants etc. This engine is able to predict the consequences of one action in a near future. Therefore, an action that belongs to the calculated plan would have different impacts on the home comfort. For example, opening the living room's window for 15 minutes at certain period of the day may help to increase the air quality, but also affect the home temperature accordingly to the outside temperature. Overall, the engine balances all these variables in order to satisfy the desired home comfort with a concrete plan for the day.

6.3.2. Main features and design rationale

Action plan: recommendations to help planning the change

The Action plan feature aims at accompanying inhabitants in their behavior change on a daily basis. As highlighted in introduction, we consider the recommender persuasive functions through the generation of recommended daily actions to minimize energy consumption while reaching inhabitants' preferences.

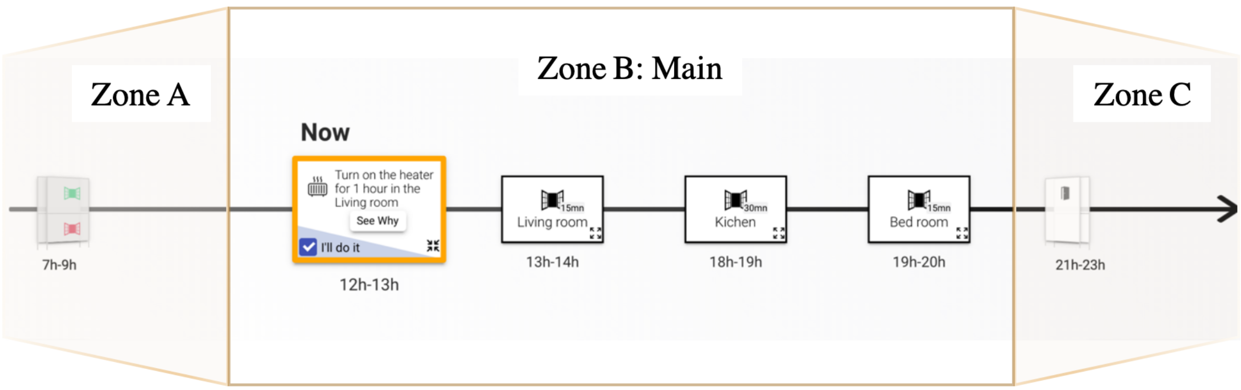


Figure 6.9. Three navigation zones inspired from Perspective Wall concept [109]

Inspired by the Perspective Wall visualization [109], as shown in Figure 6.9, we have considered a timeline-based representation of a daily action plan. Indeed, this visualization would preserve all the actions within the plan view, providing glanceable status over the action plan, as in the Mondrian UI. Furthermore, timelines are a familiar concept with a good affordance: actions are placed from left to right based on its timeslot on a 7am-23pm time range. The granularity is of one hour. This temporal scale has been proven to make information related to current household practices (e.g., turning on/off heater, opening/closing doors) understandable and relevant Consequently, we present a plan as a sequence of recommended actions related to the household environment (e.g., living room, bedroom, kitchen), indicating the impacts on home comfort (e.g., increasing of air quality, changes in temperature, reduction of electricity cost). For better understanding the cause and effect relationship, explanations are coupled with the recommended actions (causality). By following all the recommended actions, the desired level of comfort will be reached. Otherwise, missing an action may lead to an unwanted counter-effect (e.g., not opening a window could lead to an increased indoor CO2 level instead of low level).

We only represent the actions related to the periods of presence of inhabitants. Indeed, as discussed in the previous section, we assume that the system knows the usual periods of absence. Figure 6.9 illustrates our scenario: we are at noon; the next recommended action will be between 12am-1pm; and no action is offered when the user is away (i.e., 9am-12pm and 2pm-6pm). To facilitate user interaction with the plan, as we consider a tablet for the interactive device, we rely on usual and simple touch gestures. Indeed, in order to navigate through this set of actions, users can 'swipe' forward to see the upcoming action(s) or backward to view the past ones. User can also 'tap' on any action to get more detailed information. In the action plan timeline, three interactive zones are defined (Figure 6.9). It consists of a *main* view (zone B), detailed subset of actions, and two *secondary* views (zone A and C), two stacks of actions. The *main* view is where currently consulted action(s) are located, other items, depending on their timeslot, are positioned either in zone A or zone C.

Similar to the Mondrian UI (i.e., combining a glanceable UI with a more detailed one), we rely on the zoomable technique for action boxes: three levels of information details related to a recommended action are presented, an action can be displayed as one of three modes: '*packed*', '*normal*' or '*focus*'. The *Focus* mode is applied for the action under focus (highlighted with an orange border), which can be the next action by default or a selected one during the interaction process. For instance, as shown in Figure 6.9, the action at timeslot 12pm-1pm is under *focus*. The user can access to detailed information about the goal of the action (e.g., control the heater), where to apply (e.g., living room) and how long (e.g., one hour). The *normal* mode is applied for other actions that are in the *main* view (zone B). For instance, the action at timeslot 1pm-2pm is under the *normal* mode. Action's information is represented in a very concise manner. Action(s) in two secondary views (zone A or C) are designed under *packed* mode.

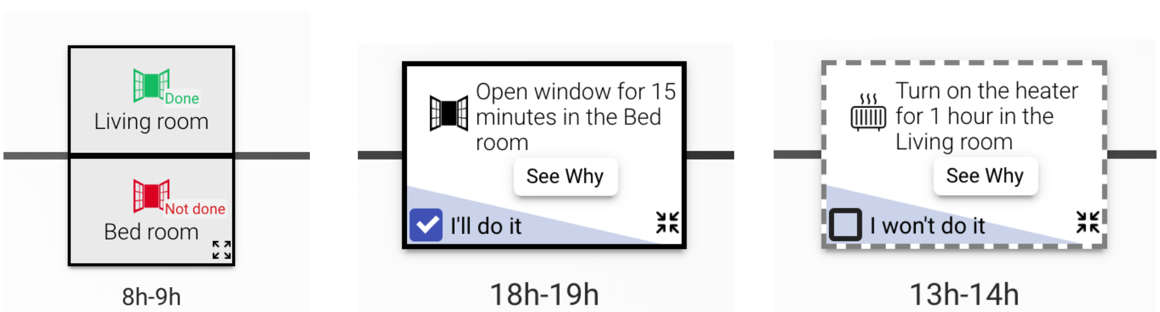


Figure 6.10. a) Done – Not Done action; b) Will do action; c) Won't do action

The plan is flexible as users are allowed to adapt the sequence of actions to take into account exceptions. Hence, a checkbox is provided in the action boxes (see Figure 6.9 and 6.10), allowing users to decide if s/he wants to take the action or not. However, modifying the plan may become incompatible with the requested level of comfort. This point is discussed in a following section.

Color encoding is used to discriminate the actions. For instance, the gray background is employed for past action(s), white background is for current and future action(s). The next action to take is highlighted with a solid orange border to attract the user's attention (Figure 6.9). In addition, for past action(s), a red or green color is used to indicate if the user has missed or achieved the recommended action. Figure 6.10a provides a detailed look at these actions. So as to differentiate the "will do" and "won't do" action, we utilized a different border design for the action box, precisely, a straight border for a "will-do" action and a dashed line for the other (Figures 6.10b and 6.10c).

Explanation: help inhabitants understand their home.

In order to go one step further compared to existing works, we couple contextual recommendations for actions along with the related explanation, with the objective of helping inhabitants to better understand their home thus to support the decision-making process. The complexities of the home settings as well as the nuanced routines lead to difficulties in understanding what is happening and how different actions may impact their own comfort. Thus, the explanations are provided with sufficient information about the current phenomena in which causality plays a central role. In addition, it contributes to establish a cooperative decision loop between the users and the system.

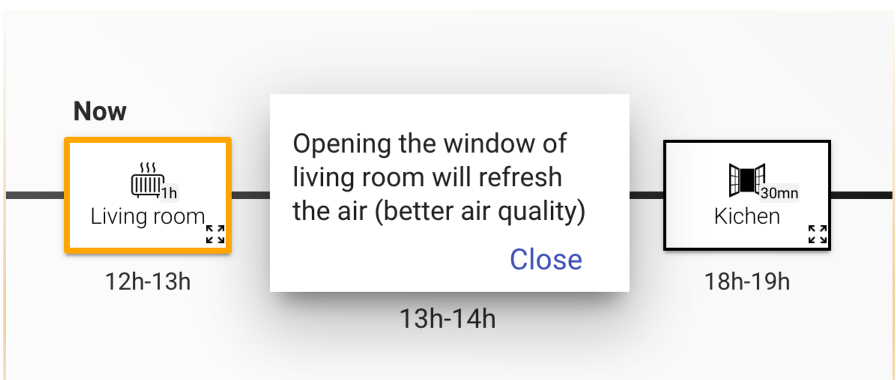


Figure 6.11. Explanation for a recommended action

The user can visualize the corresponding explanation for a recommended action by tapping on the button marked "See why". For instance, as shown in Figure 6.11, coupled with the proposition of opening the window around 1pm to 2pm, the system explains to the user that "*opening the window of living room will refresh the air (better air quality)*".

Presenting these explanations in a suitable way is very important as the actions proposed by the system do not have the same importance in terms of impact. Some of them might be skipped if necessary, some of them should be performed because of their strong influence on a particular criterion. The explanation about why to do such action, and how it will impact the home might increase the understanding and confidence of the user when using the system. Moreover, it could support the cooperation process by explaining the positive/negative effects of following/unfollowing the action plan in a simple and direct manner. Conversely, when an inhabitant becomes expert about his/her home, s/he may not need any more explanations. It is one of reasons we choose to design Plan4Actions as a multi-level user-interface.

What-if Process and equal-opportunity: allow inhabitants to explore alternatives

The action plan is connected with the Sliders4DM widget. As explained in chapter 5, Sliders4DM allows users to navigate through different set of trade-offs, based on a "what-if" way of thinking. With Plan4Actions, we take the "what-if" exploration further. As illustrated in section 6.3.1, each compromise defined by the Sliders4DM is used as input parameters so that the e-coach engine could calculate the most suitable action plan. Consequently, Plan4Actions offers two ways to explore alternatives: (1) through the Sliders4DM: modifying the sliders would lead to a new plan that would meet the new requirements; (2) through the removal of actions for the current action plan, updating the sliders. This is equal-opportunity. Therefore, users can explore the solution space through preferences/action plan compromises. With regard to exploration, inhabitants will adopt a clear "what if" approach in both the *expression of user's preferences* and *selection of action plan* tasks.

Comparing to ThermoCoach [141], our design approach offers an infinite set of solutions rather than four recommended schedules. Moreover, rather than a passive manner, we provide inhabitants a more interactive and flexible way to explore the solution space.

Status man: facilitating decision-making process

To facilitate the decision-making process, we associate the plan of actions with a "status man" that gives global information over cost, temperature, and air quality as well as information for each criterion individually according to the values defined with Sliders4DM. It also indicates how far a current action plan is optimal for current users' preferences. Figure 6.12 illustrates two different views of the "Status man". In the left-hand side, a global representation reflects the overall situation of all the three criteria. It consists of oval smiley and a circular progress bar; the background color ranged from green (best) to red (worst) to illustrate the overall status (i.e., usual traffic light metaphor). On the other side, a more detailed view shows each of the three criteria and its values in number (i.e., target and actual).

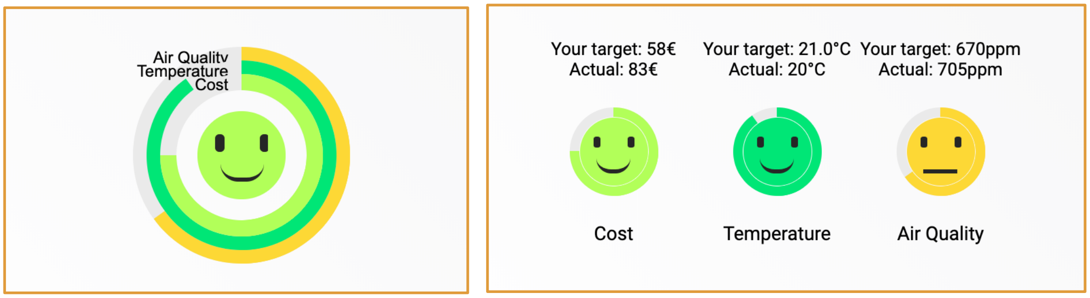


Figure 6.12. Global and detailed view of "Status man"

As an illustration, let us consider the two following scenarios: Firstly, for a recommended action plan, the user can decide if s/he want to perform the action(s) from the plan; s/he can immediately see impacts on both the 'status man' (color and radius) and the sliders (positions of cursors). Figure 6.13 (top) illustrates this scenario where the user declared to not do the action at noon, 1pm and 9pm. It is also important to note that the plan of actions and the 'status man' are updated upon changes (i.e., via button "update preferences") in the sliders (i.e., equal opportunity). This results in the new set of preferences for the current modified plan illustrated in Figure 6.13 (bottom). In this approach, the system projects future situation through simulation process (via status man and sliders) and leaves the user in control. For instance, the Figure 6.12 shows current situation where the actual thermal comfort is very close to the defined one, the financial cost criteria is slightly deviated but still not so far from optimal. By contrast, the air quality does not seem to be good. The user may understand that removing action(s) as intended might affect severely her/his comfort (e.g., the status man becomes orange) and thus s/he will have to make a compromise (e.g., remove less actions so that the status man stays at green).

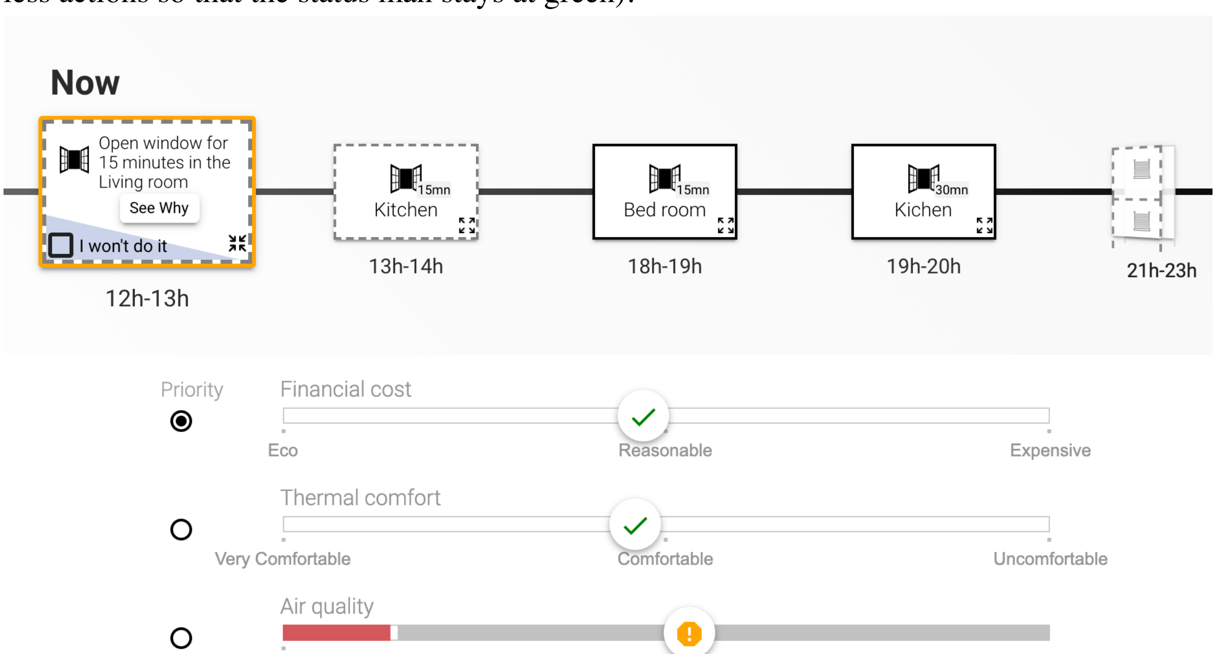


Figure 6.13. (top) The user makes modification(s) on the current action plan; (bottom) the preferences associated to the current plan

In the second scenario, in case of a compromise cannot be made (e.g., the actions proposed are not suitable for the user's lifestyle), the user can explore other sets of solutions by modifying Sliders4DM parameters. The system will take into account the user's modification so that it could offer better plan. The cooperative loop is finished when the user and the system reached a compromise satisfying the user's requirement and the system's capacity. Figure 6.14 illustrates a situation where the user found a new set of preferences and the e-coach engine is computing a new plan accordingly (i.e., via button "update plan").

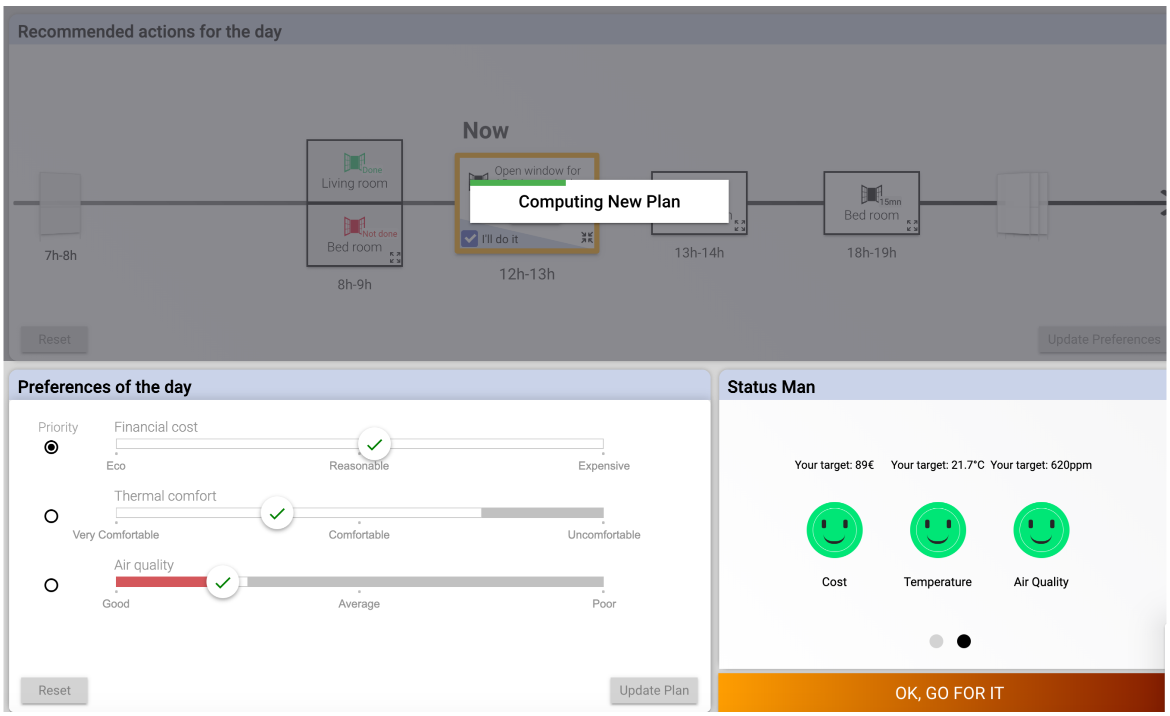


Figure 6.14. The e-coach engine is computing a new plan according to the new set of preferences

Summary. We presented the design rationale of Plan4actions prototype. In order to effectively involve inhabitants into the decision loop, the prototype is designed to (1) provide interactive concrete plans and explanations based on user's preferences, (2) help inhabitants understanding the functioning and rationale of their home, (3) allow inhabitants to explore alternatives, and (4) facilitate cooperation between inhabitants and the system. Moreover, to better understand the impacts of direct feedback on users, any change either from action plan or the preferences would affect other elements automatically; we employed in Plan4actions the "**equal-opportunity**" approach.

6.4. Experimental evaluation of Plan4Actions

The evaluation of Plan4Actions targets the following evaluation goals:

(1) Usability of Plan4Actions: significance of visual elements, affordance, user tasks;
(2) Intelligibility: do participants understand the purpose of the main features of Plan4Actions (i.e., Action plan, Sliders4DM, Status Man) separately and as a whole;
(3) Usefulness and Intelligibility of explanations;
(4) Usefulness and Willingness to use the Plan4Actions.

In order to reach these goals, we conducted a twofold evaluation composed of two sessions: the first one focuses on the action plan coupled with explanations while the second one targets the whole Plan4Actions user interface.

6.4.1. Participants and Apparatus

For this experiment, we have recruited four-teen participants by email and word of mouth (eight men and six women), but only third-teen (seven men and six women) are selected for the data analysis. The participants have ages range from 21 to 63, with the mean age of ~33,15. Of the third-teen participants: six are considered to be experts (i.e., familiar with HCI), the others are considered as novice users (i.e., not familiar with HCI). They are in different professions, containing six computer scientists (four PhD students, one Post-doc and one lecturer), three students, one IT consultant, one sales representative, one R&D engineer and one job-seeker. None of the participants are involved in the project. All of them were confident in using computers and tablets. The participants all signed the consent forms to participant in the research at the beginning of the experiment. They were not paid during their participation.

In their current households, a majority of participants live alone (7/13). Among the remaining six participants, two live as family (with their partners and children). One participant lives with his partner and two other adults (another couple). Of the three participants left, one lives with his partner, one lives with his son (adult) and the last one lives with a pet (a cat).

All of the 13 households use electricity and most of them (10/13) run only with electricity. Besides, one household uses hot water provided by the city, two utilizes heat pump system of which one participant have used additionally a solar system for boiling water. Most of the participants are following individual heating scheme (11/13) and the others (2/13) are using the heating system of the city. Last but not least, only one participant possesses a device for energy management (smart thermostat) at home.

Participants performed their tasks with a Surface 3 tablet (10,8"), running the user interface of the interface used for the two session of our experiment. The Plan4Actions widget is implemented in JavaScript as the client of a web application using the Polymer programming toolkit.

6.4.2. Tasks

During the evaluation process, participants were requested, depending on the exploration path, to complete different tasks. The objective of this phase is to observe how current UI elements and manipulation can help participants to accomplish the tasks. Tasks to be achieved for each session are:

Session 1 (Action plan alone):

- To explore the actions, to interpret them based on their concise representation only, then to expand it interpret their expanded textual description and the content behind 'See why';
- To read the explanation associated with the actions.
- To identify differences in actions' representations (i.e., current, past, and future actions)

Session 2 (Plan4actions as a whole: Action plan + Sliders4DM + Status Man)

- To focus on the action plan in order to identify changes
- To bring the participant in the (equal-opportunity) loop:
    - Skipping actions and see impact on the status man
    - Updating the preferences upon the modification(s) made in the Action plan and seeing the change(s) on Sliders4DM.
    - Changing preferences settings with Sliders4DM and seing impact on the status man
    - Computing a new plan with new set of preferences

6.4.3. Experiment design

This section describes the experiment procedure for each session. Both sessions follow a procedure made of 4 steps: *warm-up, training, interaction* and *questionnaire*. We asked the participants to do the two sessions of the experiment in separate days based on their preferences. The experiment took place either in our laboratory or in the participant's household.

Session 1: Action plan and explanations

Warm-up. the participants were progressively brought into the topic through two activities. In the first activity, the participant was provided with 7 cards depicting factors that could motivate for energy saving (i.e., the planet, global warming, water, future generations, animals, money) and requested to choose 3 cards among the 7, rank them and associate the meaning to them using own words. As shown in Figure 6.15 (top), a participant chose first the global warming, then trees for biodiversity, and animals for biodiversity. In the second activity, the participant had to represent, with stickers of different colors, the actions taken at home and related to energy management on a paper-based schedule. In Figure 6.15 (bottom), during winter, the red sticker represented heating practice while the blue one represented aerating activity. This first activity aims at making the participants aware of the needs for energy conservation. The second task aims at involving participants into the notion of action plan based on their routines and current household practices.

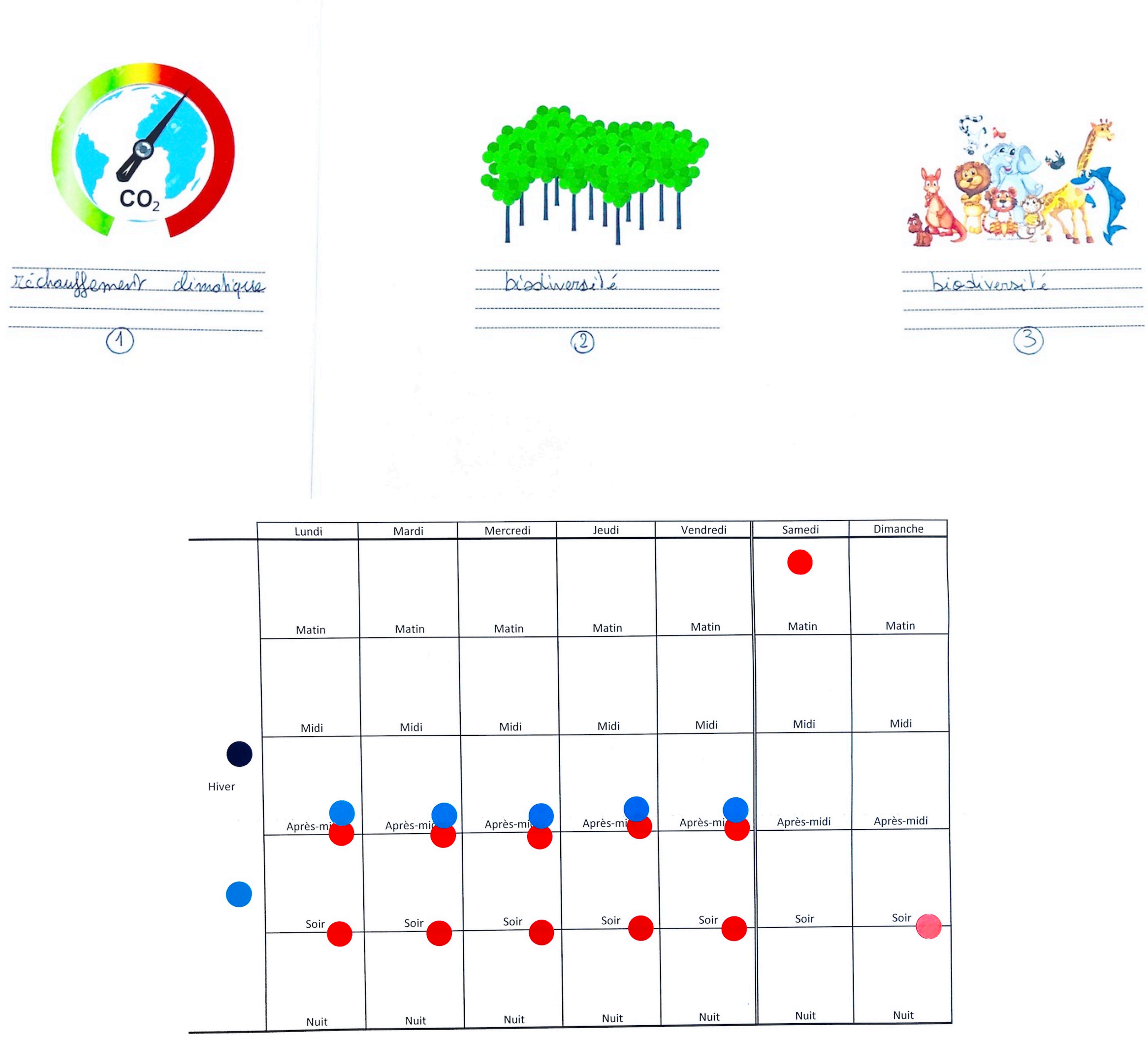


Figure 6.15. top) Participant's three motivation sources; (bottom) home scheduling

Training. In order to avoid the learning effect, we have implemented a domain-independent version of the action plan widget. As shown in Figure 6.16, from left to right, the support widget represents a list of card-based items numbered from 1 to 10. Each item consists of non-contextual design elements (i.e., colored-circle in the center, label, button, dialog). Information within these elements are presented in a neutral manner. Indeed, this step aims at making the participant familiar with the interaction concept by eliciting the affordances of the prototype. During this phase, we asked the participant to freely interact with the widget.

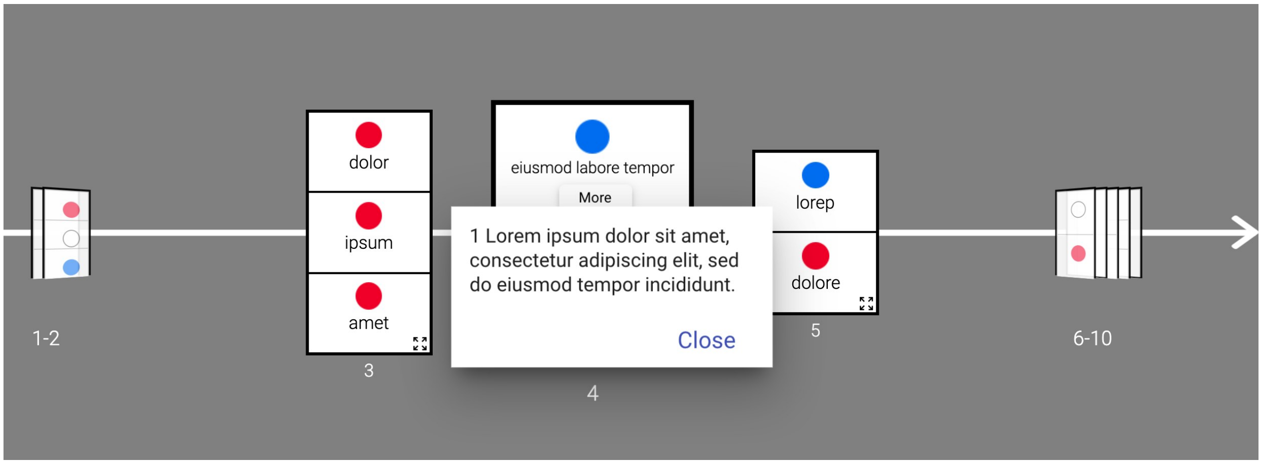


Figure 6.16. The domain-independent version of the action plan widget

Task execution. We first start with a description of the context in which the participants have to situate themselves. We ask participants to imagine that they are in a small apartment, which consists of a living-room, one bedroom and a kitchen. The apartment plan (Figure 6.17) is used for supporting the contextualization. The apartment is equipped with heater, kitchen hood etc. Besides, the location of windows and doors are specified. It is important to note that the scenario is built in winter season.

During this phase, participants have to interact with a domain-dependent and 'realistic' action plan. After a free exploration process, the participant is requested to complete specific tasks (see 6.4.2; session 1). This step aims at assessing affordance and usability of the prototype. The participant is invited to think aloud while freely exploring the UI.

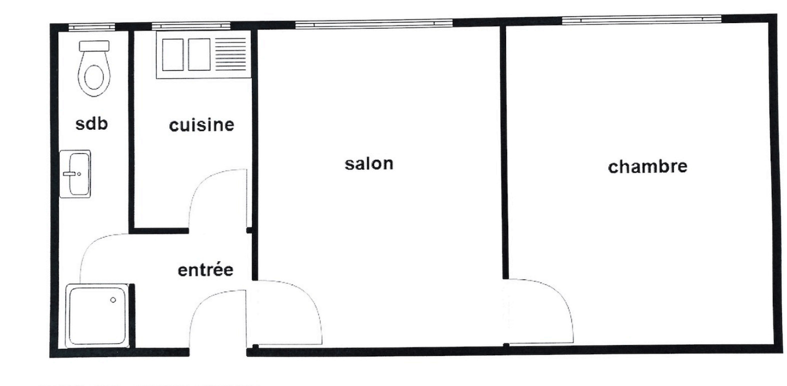


Figure 6.17. Apartment plan used in the context

Questionnaire. Before closing the session, participants had to answer two questions and fill in an online questionnaire. The two were related to the usefulness and motivation for use of the Action plan. The questionnaire was aimed to gather sociodemographic data; assess the understandability and relevance of explanations; and, once again, the usefulness and motivation for use of the Action plan.

Session 2: Plan4Actions

Warm-up. In the beginning of this session, we recalled the previous session. We asked the participant to remember about the UI of session 1 and what s/he has remarked. This section aims at getting the participant back into the context.

Training. We first ask the participant to discover the UI of the Sliders4DM widget in order to become familiar with the Sliders4DM widget in the context of the UI of Plan4Actions. At first, the participant was invited to freely interact with the Sliders4DM. To make sure the participant understood well, s/he was requested to perform a particular setting with the Sliders4DM. After, the participant could continue to freely explore the Sliders4DM. The goal of this phase is to elicit the perceivable affordance of the Sliders4DM. No time limit was imposed, the participants were told to start the next phase when they felt ready.

Task execution. the participant discovered the UI of the Plan4Actions as a whole. We first ask the participant about the differences between this UI and the previous one, how they understand the elements provided in the UI and their relation. The goal of this phase is to understand how the manipulation and visual UI elements helped users to find a suitable and satisfying combination in terms of their preferences and action plan (see 6.4.2; session 2). We are also interested in analyzing how the participants consider co-decision with the system through its recommendations. The participants were instructed to think aloud as they were executing the tasks.

Questionnaire. To conclude the experiment, we submitted a non-modified standard SUS questionnaire with a discrete scale ranging from 1 (strongly disagree) to 5 (strongly agree). Besides, participants had to answer again the two questions raised at the end of session 1 about the usefulness and the willingness to use, this time, the Plan4actions as a whole.

6.4.4. Data collection

For each participant, we made clear that the experiment data will be recorded in two ways: audio and screen capturing. Considering that participants were prompted all along the experiment sessions to think aloud, all sessions were audio-recorded. Additionally, all interactions with the Plan4actions as well with the widget support and the Sliders4DM were recorded using screen capture. Besides, for each session, we collected all the cards, paper-based schedule and questionnaires with information filled by the participants for the analysis process.

All evaluations of the first as well as the second session were fully audio-recorded, transcribed, and analyzed using content analysis. In addition, interactions with the prototype were video-recorded and subsequently analyzed, particularly with the aim to understand usability problems. For reaching the evaluation goals above, in the analysis process, we cover the following themes: **Visual Affordances** and **Interaction Paradigms** (i.e. different components of the prototype;

interaction to support the tasks-execution or free exploration)**, Intelligibility** (i.e., comprehension of each components and the prototype as a whole)**, Explanation** (i.e. understandability, relevance and usefulness)**, Usefulness** and **Willingness to use Plan4actions**. For each theme we analyzed and collected the corresponded verbatims of each participant during their interaction whether it is free exploration or task-based execution.

6.5. Results

Twenty-six experiment sessions have been conducted within two months, from the beginning of December 2018 until the end of January 2019. A total of ~1083 minutes of recording (audio and screen capturing) has been collected (601 minutes for session 1; 482 for session 2), with an average of ~83 minutes per participant. During the two sessions of the experiment, the Plan4actions prototype is called by the general term: "e-coach". Next section reveals our evaluation goals.

6.5.1. Affordance: Visual elements & Tasks

Usability of the Action plan

Timeline concept
All of the participants understood well the time-oriented aspect of the action plan. Some made it spontaneously explicit: "*So, I see a timeline on which there are events that are; let's say, periods of time that are disjointed or not necessarily disjointed, but it is represented in the same way [...]*" (P4); "*Yes. We understand that it is a chronology. This is the usual representation of a timeline*" (P8); "*So, wait, it (the line) is leaving from 7h to 14h or you can go further? Oh yes, there you have the day*" (P14).

Significance of icons
The icons utilized for visually describing the recommended actions are found to be easy to understand. All participants except one (P14) declared to have clearly understood icons representing the different actions suggested by Plan4Actions: *"You just have the pictogram with a label, let's say, the room that it concerns. That, I understand very well […] you have the duration"* (P1); *"Yes, it's (the icons) pretty easy to understand"* (P7). Nevertheless, some misinterpretations, particularly regarding the door (4/13 participants) and shutter (5) icons could be noticed: *"I do not understand this one (whether the action is to close or open the window?), just with the logo […],"* (P5). Nevertheless, the text description of the action also facilitates the understanding of icons, the participants become familiar after several trials: *"You see, for the door, at first, I said to myself: look, it's weird there's a door; in fact, now, it's good, I saw it once and it will be enough for me"* (P1); *"I do not understand this one […], So, I click on there to have more […] is that there is a*

door that separates the living room […]" (P5). Overall, the icons are meaningful enough to support the understanding of the action plan. Potential improvement could be to make some of the icons more explicit or animated.

Cluster of actions

Eight participants (8/13) referred positively on how the actions are grouped in one timeslot. They understood clearly that multiple actions must be achieved at the same period of time. Some participants can even correlate the logical relationship between the grouping actions. The following verbatim explains this point: *"No, on the contrary, I think it's better to put them together because, precisely, these two are going great together. OK, you'll need to heat the living room because you'll be there for a while, but close the door before or at the same time. The two actions are in tandem"* (P1); *"There (19h-20h), in fact, there is a compatibility between the two. When you put the heating, it's better to close the door [...] so that the temperature increases more quickly"* (P11); *"It's two advices in the same box [...] one that applies to heating and the other makes you understand that while you heat, it's still good to keep the doors closed because, otherwise, you will lose the heat"* (P13);

Action Box: Design and Interaction

This section highlights how participants understand the visual elements to distinguish different types of actions. Three categories are considered: Past/Current/Future, Done/Not Done and Will do/Won't do action.

Past/Current/Future action

Most of the participants (10/13) can clearly situate the current time of the scenario. The thick orange border and obviously "Now" label facilitate the identification of current event. Of the three participants left, one (P3) seems to be confused and cannot determine the time period under question. The other two (P2, P4) can detect the "Now" labeling, but does not mention the timeslot of the event.

On the other hand, the notion of past, current and future actions seems to be unclear for many of the participants. Less than half of the participants (6/13) can point out the different between the three type of actions: *"Well, that's before; it's a thing before 'now', So, it (Plan4Actions) was able to judge if I had done or if I had not done what it told me to do. So, after that, actually, I have not had time to do it yet (future actions)"* (P1); *So, you have two actions. So, this is in the morning, which is past; this is now; and this is next* (P6); *"I would say that, that (8h-9h) is what was done before; that is now; and, that, ... we have not come yet at that time"* (P14).

The difference in terms of background color and the labeling of the timeslot are two elements to support the distinction. However, they seem to be insufficient. Seven participants (7/13) shared this remark: *"Yes, I see it's gray, but it did not catch me at all [...] Yeah, but, I do not understand why. What is the difference? Why, there, it's gray and there, white?"* (P5); *"Not clear enough [the difference]. Yes, I saw [at the beginning], but I took a little time to understand"* (P7); *"No, no, not especially ... [that does not see] enough"* (P13); *"I did not notice the background [...] the background changes too, right? No, I did not notice"* (P11). Three participants proposed the design to be more colorful and consistent, with that, they mean to use either the background or the border for differentiating these types of actions (P9, P13, P3).

Done/Not Done action

The majority of our participants (11/13) clearly noticed the visual difference: "*I should, between 8am and 9am, aerate for an hour. Obviously, I did it on 'Living room' and I did not do it on the room*" (P1); *"An action that is performed; an action that is not performed […], it's written 'Not done'. So, it's to appeal to you, [...]"* (P5); *"It says to me, between 7am and 8am, without reading the text, I think, it is to open the shutters of the stay and the room [...] Ah, I understand. I had to do that and I did it and I did not open the bedroom windows […] and now it is 12h-13h, I have not done the tasks yet So, when I'm going to do it, it'll go green or red*" (P12). Two participants (P7, P14) had problems in understanding the design intention. For participant P7, s/he has difficulties at first translating the visual elements, at the end, s/he was be able to see it though: *"For me, either it tells me that he advised me to open the window of 'Living Room' and not open the window of 'Bedroom' or I have already opened the window of 'Living Room' [...] what I understood, I did not do; I did not open the window of 'Bedroom' [...] it takes a little while to understand"* (P7); The participant P14 seems to be confused with the nature of suggested actions: *Ah, maybe it's because there should not be an airflow between the two rooms because if you have opened here ('Living room' between 8h-9h) […] I understand, it's not an action, it's a non-action"* (P14).

Moreover, some participants commented on the color-encoding, the red color seems to be too strong as indication for a recommended action: *"it's red, as if it's not good […] the green and the red, for me, it has a connotation, there is something that is positive compared to something that is not [...]"* (P13); *"Perhaps, I would have chosen blue; red, it's still ... you see, the red light, you see if you cross ... And, then, there are many expressions; when you're really upset, you say, I see red"* (P8).

Will do/Won't do action

Eight participants (8/13) clearly understood the differences between these two types of action: *"There, you put the dashed line here, Ah because I told it (Plan4actions) I'm not going to do it"* (P2); *"The framing is different. Okay so it's to indicate that this box will be different compare to others"* (P5); *"the clipping that are in dotted"* (P9). It is not that clear for other five participants (5/13). The reasons are either because of the visual change is not enough to attract attention, or even when being remarked, it is not easy to understand: *"Ah, I did not notice, it's the dotted line, it's the detail [...], usually we do not understand"* (P7);*"there are small dots, no I do not pay attention"* (P8); *"I notice the dashed but I do not know what it is"* (P13);*"Yes, there is the type of the dotted, but I did not understand, ah ok, alright, now when I noticed it's pretty clear, but you have to explain"* (P3). Participants proposed to use color to distinguish the actions instead of the actual way: *"Maybe the color? Indeed, just put the checkbox just below, as icon, it will be good*" (P3); *"You can put a color a little transparent or the gray"* (P7).

Information grouping and Description level

Participants provided mixed opinions about the current grouping of action information (i.e., icons, description text and "see why" button) and how interaction allows access to different level of information. Eight participants (8/13) wanted to keep the grouping and interaction as the way it is: *"I prefer that (the current way), to see the stuff quickly ... I prefer that, by default, it is in expert mode, immediately quickly, efficiently, without details; and when I do not know or when I'm a novice, when I need a little reminder; I will look for myself*" (P2); *"I guess, it is good to have this one (normal mode), […], I prefer to see this one because I don't like seeing too much text but, then, if I cannot understand something, I can simply tap on it and I can see what is going on"* (P6); *"I would leave like this (as it is) because, when I get used to it, after two-three (used) times, I think I will master the icons and I will not necessarily need to read all the text"* (P12).

Five participants (5/13) thought differently. For instance, participant P2 wanted to apply the *normal mode* for every action (even the current one), then the details are on demand as it is. Participant P7 required the detailed view for all the actions. Participant P13 spoke about having the details for the all the actions in the main view. In addition, participant P11 expressed an idea about having the focus level when the plan is used for the first time, after that the normal mode will be employed. Last but not least, participant P8 proposed to have a more direct access to the "see why" button: "*Yes, maybe ... without going through the [enlargement] step. […] because there is a repetition […] I would keep the icon with the 'See Why'*'" (P8).

Status Man: design & preference

Status Man Visualization

Most of the participants spoke about the Status Man visualization, its meaning and relation with the recommended actions. According to eleven participants (11/13), this element offered a clear view about the home status. The three circle-progress, the code-color and the smiley imbedded in the design are easily understood by the participants. "*Yes, there, it seems like a diagram. If I respect nothing, it (the smiley) is less and less happy"* (P8); *"I like this series so you have the three criteria. These traits (circle-progress) must arrive and must make a complete circus. I understand, there is no problem"* (P5); "*So actually, we are in red, I think in red it's not good […], ah, the thermal comfort is not good, [...] the green in general is ok, red is not good. That one (the Status Man) is* *good"* (P14). Moreover, four participants highly enjoyed the smiley representation and expressed their sentiments about this element. *"[Do you like it when it smiles at you?] Well yeah, it's nice to me*" (P2); "*I like smileys, it's a good way to have a direct feedback with the eyes*" (P5); "*it (the smiley) is active, it even blinks at me*" (P9);"*I like it a lot, it's quite funny, I like it, if it (the system) can be a bit of that style, I like it*" (P12);

Two participants had troubles at understanding the meaning of the visualization. Among these two, one indicated that the animation of the circle progress causes misunderstandings: "*it seems to be three variables displayed the quality of the air, temperature and cost, the three on which we played just before (with Sliders4DM). However, I do not understand much. I would have understood that it was a progress bar that started from here and started in gray and not that is being emptied"* (P1). The other questioned the relationship between actions in the plan and its impact on the Status Man, s/he also encountered problem when decoding what the smiley representation means. "*Well I understand that if I do not do the things (recommended actions) that are there then probably it's not so good, three concentric circles, air quality temperature and cost, I do not know why the financial cost is getting worse, for example, if I turn on (the heater) the cost becomes the same, my cost does not drop, do not increase. Ok that's weird […]. After it makes me a little guy (the smiley) but I do not know what that means*" (P4).

Preferences over different views of Status Man

Participants seem to favor the detailed view of the Status Man over the global one. Only three participants (3/13) preferred to keep the Status Man presentation as it is (global view by default). They all consider the detailed one as necessary: "*I guess the overall is good, I can also check the overall status. By default, I prefer to see the whole view of the status first, then I can see the detail*" (P6). Except for one participant (P4), who did not find the benefits of the Status Man, nine participants (9/13) have chosen the detailed presentation to be the default view: *"Oh ok, it's better! It's clearer, yes, it's more detailed, it's better"* (P3); *"Yes, because with that (global), I know it's not good but I do not know how, the (detail) is too cool, I see immediately (the values) and three degrees it shows, it's super cool."* (P7); *"I like the whole thing but there you have the price, I think that I will go with the detail view, even if I find that the overall it is cuter. I keep the detail view at the home screen."* (P8)*; "I prefer that one (detail), the values speak to me more, I will put it by default, I do not keep the overall view."* (P11); *"I think the second view (detail), it can be better because it allows you to see the current situation with the goal that you set, see if there is a significant shift, you see it less in the first solution (global view); you have the global state, you have the state and the differential between the state and the goal that you have fixed"* (P14).

Of these nine participants, three wanted to keep both of the views in the interface (P1, P5, P14), the other six declared that the detailed view alone has provided enough information for them. Last but not least, one participant shared an interesting thought about the use of these two representations: "*This is clearer (detail view), but let's say it's the level of expertise that's different.*

This is a level of expertise that is kind of expert, I already know that my three criteria that I see and that I have to go (overall view), there when you are a novice. This is what I have to use I think (detailed view)" (P5).

Update & Reset button

The usability of update and reset buttons have received mixed opinions. Less than half of the participants (6/13) has clearly marked the appearance of these buttons, then be able to make use of them without our suggestion. The other seven participants either cannot figure out how it works or do not pay attention. Several remarks have been drawn: "*When should I update? I don't know, I can always try and if it does not work it is not the right time […] because it's too dark (the button background)"* (P8); "*Maybe that, it is less necessary to put it in discreet, because if you had not made me see, it is little in the angle [...]*" (P9). Sharing the same point of view, some participants proposed to make changes to the buttons: *"Maybe I could add some highlight here (on the button), that ok if you want you can update your preferences, so then if I am not going to do this (actions), then here it can be like popping up (the update button)"* (P6); "*The color more visible, I prefer it to be red or something, as you see that there is something that has changed*" (P11).

I'll do it/ I won't do it checkbox

The majority (11/13) of participants clearly understood the purpose of this element. Nevertheless, different formulations have been made: *"The tasks in the past I cannot do, but the on-going tasks, I can say that I will to do it or not"* (P3); *"You'll take the recommendation or you won't. That's it I guess*" (P6); *"I think it means "I'm going to do it", In fact, finally he (the system) gives me a conclusion, a list of the ones I did, and I did not, and base on that, gives me results [...]"* (P7); *"Something to do, an execution to perform, I want to do it or I do not want to do it, you give the agreement or not […], let's say it's a condition for the future, if you do it will give some consequences and if you won't, there will necessarily be consequences"* (P14). On the contrary, two participants had difficulties to identify the actor in charge of taking the actions (i.e., the system or themselves): *"It's it (Plan4actions), that it said it will do it, I said nothing, I did not valid, it's not logical"* (P9); *"as if I gave something saying that 'I will do it' or if it is it (the system), who will do it but basically, the task is taken into account"*(P13).

Most of the participants perceived positively the capacity to interact and make changes to the recommended plan. One reason might be the ability to visualize the impact of each action on the home. The following verbatim made clear this remark: *"Because right now I cannot do it but it's good to be able to also plan to say tonight I will not be there, for me it seems to me super useful"* (P1); *"Well I already see the impact of the stuff directly […], I can potentially see what (action) is important"* (P2); *"It's important to know what changes it is to do it or not to do (an action), because sometimes we can know it's true but we do not know how to measure it"* (P3); *"It makes it much* *easier to update your timeline, you see a lot more easily here*" (P5); *"Yes, it's too cool […], it gives a visual immediately, so I think it's good it's clear*" (P7); *"In fact, what is interesting is that you can test, you can see directly with the diagram (Status Man), you can test before doing it"* (P8); *"Saying I'm going to do it or not, that's fine. I see directly the impact of your actions […], it makes more sense"* (P11).

Besides, several interesting comments have been submitted. For instance, participant P4 suggests a global level of setting to schedule the home/away period: *"(global setting), for that to be taken into account because otherwise I click on I cannot do a thing to determine the fact that I am at home (but I do not want to do)"* (P4); participant P5 found that the checkbox incited him to click on, thus propose another interaction method: *"I feel that it encourages to click on (the checkbox) […], a way to correct it would be to be a click long, and you do "No, I will not do it" The long click is instinctive, a tablet is pretty much OK"* (P5).

Plan4actions: Organization of the interface

Most of the participants clearly distinguish the three separate windows displayed within the Plan4Actions interface. They all consider the importance of each element and their impact on the overall purpose of the Plan4Actions. However, seven participants (7/13) referred to their needs to reorganize the interface in a way that promote better usability for them. By contrast, six participants (6/13) wanted to keep this way of organizing the UI elements. From those who wanted to change the interface organization, different suggestions have been proposed. The following section describes this point.

Two participants spoke about putting together the plan view and the Status Man view as a group: *"Recommendations and Status Man go together, and the references are apart"* (P1); *"Status Man on top or beside the actions (plan) to easily see the impacts"* (P11). Others suggested to emphasize more the action plan by allowing this element to take more space: *"This part (the preferences) takes too much space, we do not really need so much surface for them, increase this part (Action plan) because it is more important, enlarge a little because there is also "see why", "I will do it" […], for me there is a lot of information, you really need at least two thirds (of the surface)"* (P7); "*Yes, put a little more space on the actions*" (P12). Some participants proposed changes in terms of positioning for the current elements: *"I will perhaps first put the Status Man to see the continuing status of the house (instead of the actions), the actions in second (instead of preferences) and then the preferences (instead of Status Man)"* (P14); *"Maybe I would put the preferences on top to have a sense of reading […] the preferences is up with the Status Man and the recommendations on the bottom, to respect the traditional way of reading in Europe*" (P8).

Summary. We examined the usability of each components and the entirety of Plan4actions. It is reported that participants understood well the time-oriented aspect of the action plan and the meaning of the icons utilized for describing the action. They also referred positively on the cluster of actions and how related information are grouped. However, the difference between past/current/future; done/not done actions seems to be unclear for many. In the other hand, Status Man offered a clear view about the home status, among the two views which SM provides (global and detailed), participants seem to favor the detailed view. Moreover, most of the participants perceived positively the capacity to interact and make changes to the recommended plan. Last but not least, participants appreciate the importance of all the three elements and their impact on the overall purpose of the Plan4Actions.

6.5.2. Intelligibility of Plan4Actions

Role and purpose of the Action plan widget

All the participants (13/13) understood well the purpose of the action plan. Towards this end, the participants use different terms to describe the recommendations:

- Advice (P1, P7, P8, P11, P13)
- Actions (P1, P14)
- Propositions (P2, P3)
- State of things (P4)
- Tasks (P5, P12)
- Suggestions (P9, P12)
- Recommendations (P9)
- Directives (P13)

Although participants understood well the nature of recommended actions as well as the purpose of the action plan, the role of the system did not appear to be clear to all of them. For instance, seven participants (7/13) understood that they would be responsible of performing themselves the actions (P1, P2, P6, P7, P9, P12). Two participants (2/13) understood, at first hand, that the system is performing the actions (P4, P11). Three participants (3/13) were confused and could not point it whether they or the system would be responsible of performing the suggested actions (P3, P8, P13). Last but not least, one participant (1/13) imagined a shared responsibility: the system sets temperatures and, possibly, open/close the shutters while the user has to be in charge of opening/closing doors and windows (P5).

Nature of Suggested Action

Participants could understand well the suggested actions (e.g., temperature setting, doors/windows opening) either thanks to the graphical representation or the textual one (after expanding the action box). However, participants had several comments related to relevance and realism of the recommendations: *"Something is missing here just when you cook, you close the kitchen door [...] but that action, it implies that you have isolated the kitchen before. So maybe an action is missing here"* (P1). Besides, some participants considered the duration of the actions as inappropriate: *"It (Plan4Actions) asks you to air the kitchen […] 30 minutes is a lot, 30 minutes [...] When it's cold like that in Grenoble, it cools everything. It takes 10 minutes, no more; open the door of the room (between 22h and 23h). Oh yes, it does not want me to have intimacy, it wants me to open the door of my room"* (P9); Last but not least, one participant declared that the action demanded an out-of-dated mechanisms: *"Opening the windows, then, I'll tell you, it's a bit of an old system to cool your house. Now, to save a lot more energy, it's better to invest in double-flow ventilation […]"* (P14).

Role and Purpose of Status man

All the participants (13/13) understood well the purpose of the Status Man. For expressing their understanding, many participants link with the impact of an action to the home comfort. "*I understand that if I do not make efforts, it reduces the quality of my air, temperature and my cost, I guess compared to those I put in my preferences… Well I already see the impact of the stuff (the actions) directly, I have a direct return, I see the direct impact in a unit that I can understand. So, I can potentially see which is important*." (P2); "*Depending on what I will do, what I will not do, it (the system) gives me a result about my temperature, air quality and how much it will cost*" (P7); Meanwhile, some participants consider the Status Man representation as the overall status of the household. "*It's a kind of red light, green light indicator depending on whether it (the household) is okay or not*." (P1); "*It's like a dashboard, you have defined your target, it shows you that if you are doing good, it'll be happy, and then here you see the overall status* » (P6) ; Additionally, it shows how they are far from reaching their targets defined with the Sliders4DM: *"It is not bad because it says that […] seeing that we have defined some preferences, it allows you to know if you are reaching or if you are far from (the optimal) or [...] it gives it the status of your preferences"*(P13).

In general, our participants found this widget useful (12/13). Only one participant (P4), even though s/he understands the purpose of the Status Man, did not think it can be really useful: "*In fact for me it (the Status Man) does not serve me well, it rather disturbs other things. Since the information is partially redundant"* (P4).

Relation between the three features of Plan4Actions

The majority of participants (11/13) clearly understood the relationship between the three main features, how they are linked with each other via interactions. They explicitly comprehend the role as well as the purpose of Plan4Actions as a whole. Within this line, participants have different ways to explain this point: "*In fact, it is a dialogue, here I give it my preferences, what I like, what I would like to have as a result and it (the system) adapts it, it translates into technical specifications and adapted to my home, you have two ways to have feedback here, preferences are much more technical. If you want to change then that is really depending on what you want to do*" (P5); "*So, I can change either according to plan, I change my preferences, or according to my preferences, I change my plan [...]. Depending on the preferences that you have fixed, it has the plan and if you want to do actions or not, it will judge what you want, if you do not want to do certain things it will adapt your preferences according to that on everything else [...]*" (P12); "*First, I define my own preferences, but then I have some criteria, some limitations doing this actions, so I tell the system that I'm not going to do this, I'm not going to do that, and then I update the preferences and then the system suggests me ' Okay, if you're not going to do this, your preferences are like this', then if you are okay with this, you can Go for it. So here when you update your preferences and limitations you can see the overall status […]*" (P6).

Among these eleven, two participants (P2, P8) established a clear view about how these three features work, but encounter problems finding a compromise: *"I give my preferences, it (Plan4Actions) makes me a plan, I told it, It's nice but in fact that I cannot do it […], I understand we're really in a dialogue with the machine, I tell (the system) that I will not be able to do it and I send a message: here I cannot do it; it answers me ok but in this case what I do not understand is why we go here?, How are we just like before (before updating the preferences)?"* (P8). Nevertheless, P2 struggled with update functions of Plan4Actions. In fact, after making changes either to the action plan nor the preferences, the interface need to be updated (via the update buttons): "*On the updates, not really, because there are times this visualization is not up to date, if I click here, I must do an update, suddenly, I see things that are not compatible. It does not fit me! It should either be that when I make a change, it updates me automatically, or being hidden [...]. For me it's always confusing all these updates".*

Two participants (2/13) had difficulties (P4, P13) at understanding the whole Plan4Actions UI. For instance, the participant P4 cannot understand the relation between the Sliders4DM widget and Status Man. For that participant, these two are not only redundant but also disturbs the other one. The participant P13 midjudges the function of the Sldiers4DM and Action plan widget: "*Well, the e-coach gives you advice, from this advice you can define your preferences, and by following these tips, it allows you to reach your preferences and you can view the status via Status Man*" (P13).

Summary. We evaluated the understandability of each components of Plan4actions and their relationships. Participants clearly understood the purpose of the plan and its recommended actions. However, the role of the plan and the relevance and realism of the actions did not appear to be clear to all of them. Besides, Status Man received a positive assessment from participants in terms of its purpose and utility. Last but not least, the majority of participants clearly understood the relationship between the three main features, how they are linked with each other via interactions.

6.5.3. Explanation: understandability, relevance and usefulness

a. Understandability

All participants (13/13) understood well the provided explanations and most of them found the explanations well formulated. Only two participants declared they would formulate explanations differently. For instance, P1 suggested to enrich explanations with some contextual information: *"Enrich explanations with contextual information that also make you want to look at the system; it will give something that, day by day, is different; while I have the impression that if a tool does not change overtime, I will get bored"*(P1); Nevertheless, they used different terms to express their understanding of the purpose of explanations such as: 'reasons' (P1), 'explain (actions)' (P2, P5, P7, P11, P12, P14), the 'why' (P3), 'consequences' (P4, P14), 'motivator' (P6), 'utility' (P8).

Relevance

Only few participants commented about the relevancy of explanations. For instance, participant P4 said the 'why' is confusing since it might let the user think that the system detects reasons for performing actions. On the other hand, participant P13 insisted on the veracity of explanations accordingly to suggested actions. Last but not least, Participant P14 found some explanations intuitive: "*well, open the window, in the kitchen will cool the air ... It's intuitive ... [I give other types of explanation] more related to comfort and consumption of electricity: be careful, the little dollars, they go away ... Something more playful!"* (P14).

Usefulness

All participants declared to find the explanations useful and a majority (8/13) found them necessary in order to understand how the Plan4Actions works. In addition to usefulness, explanations appeared to contribute globally in positive way: « *That is exactly it, you're asked to do things. So, by default, it annoys me because I do not want to do things; but it (the system) explains to me; So, that's good, when it explains me like that; I understand and I say ok [...], well, it's directly related to my motivations. So, if I am motivated by reason why, if I don't care [...], That's why I would* *imagine the possibility of telling it (the system) what motives me, if it knows exactly the temperature that I prefer, that's perfect»* (P2); « *Yes, because the first time, you want to know why. Is it what you think; does that confirm your expectations? Sometimes, that's another reason. That's it to comfort the user* » (P5); « *This is, I guess, some information that makes you motivated. Why should I do this now? You will have your answer* » (P6); « *In fact, it gives you an explanation [...], the explanation behind the action, behind its advice [...] because in fact, it tell you: close the window, open the window, but if you do not know why you have to do it, [...] at a certain moment, you can say to yourself: why I have to do it; you can stop, but when you see an explanation, which is reasonable, which makes sense, you will say to yourself: I'll do it* » (P11).

6.5.4. Usefulness and willingness to use the Plan4Actions

Usefulness

Session 1

After the first part of the experiment, seven participants (7/13) found the action plan useful for helping them in managing energy tasks, there are some interesting quotes from these participants: *"Yes, for example, there are things I do not do"* (P5); *"Yes, especially if we read the explanations, we know, we understand better"* (P3); *"Because we do not have enough knowledge about how to manage electricity and all that more efficiently and we do not really have that kind of awareness. So, I think it's still going to attract the attention of people 4to make the economy especially that today, we talk a lot about global warming and all that"* (P7);

By contrast, four (4/13) participants, even though are not convinced by the utility of this action plan, they still appreciated some facilities provided by Plan4actions prototype. Otherwise, it seems that they were interested in the coupling of the action plan with other functionalities such as alarm or having more parameters to control. The following verbatim uncover this remark: *"I do not really like being guided […] But, if I can parameterize myself as I want [...] For example, tell him (the system), that, I do not want to do, so stop offering me […] If the assistant, it could solve it all […] it would be nice"* (P2); "*there should be alarms to tell you: be careful, you did not do that, […], because you're not going to see your e-coach every week to find out what you have to do*" (P9); *"I do not think it will help me to better manage my consumption, but I think it help me not to forget. For example, […] I can see if I forgot to do something. Otherwise, these are things I usually do, So, it does not teach me anything new, but it allows me to not forget"* (P12); *"[…] it's worth trying and see at that point, at the billing level to see if it goes down"* (P13).

Two participants (2/13) did not find the action plan usable. Among these two, one does not consider the suggested actions as novel and helpful as s/he already done it: *"There, apart from the shutters that allow you to be safer and to which I had not thought; otherwise, yes, I do not like to put the hood"* (P9); the other finds the suggested scenario and how the actionable works not suitable for his/her regular routine: *"I do not think [...] it comes from the fact that in my house […] it's quite* *regular there what we do. In addition, we do not return between noon and two. I do not really know what it could do, if it does not pilot itself ... Otherwise, you could say, well, I cut the heating when I'm not there but, at the same time, it is necessary that you go home to cut the heat and you do not have time"* (P4).

Session 2

After the second session of the experiment, all the participant referred to the utility of Plan4Actions, and they all clearly found it usable. All the thirteen participants declared that Plan4Actions would help them better manage energy consumption in their households. However, the expected efficiency varies in different degrees: *"I think it's not bad, maybe it can just take a little time to fully understand the system, but after we understand it, it's done right"* (P13); *"I like it, It's dynamic. You have a dialogue that's what I like"* (P5); *"Yes, it is really convenient for standard apartment"* (P7). Some participants expected Plan4Actions to help them in more specific tasks: *"It could remind me to lower my heating for the night"* (P1); *"I'd like to know about how much I'm consuming, [...], whenever I turn on my radiator I tell myself the bill will arrive [...] whereas with a tool like this, you can heat without the feeling of surprise"* (P8). Moreover, two participants (P1, P3) suggested that Plan4Actions could help them learning some new things.

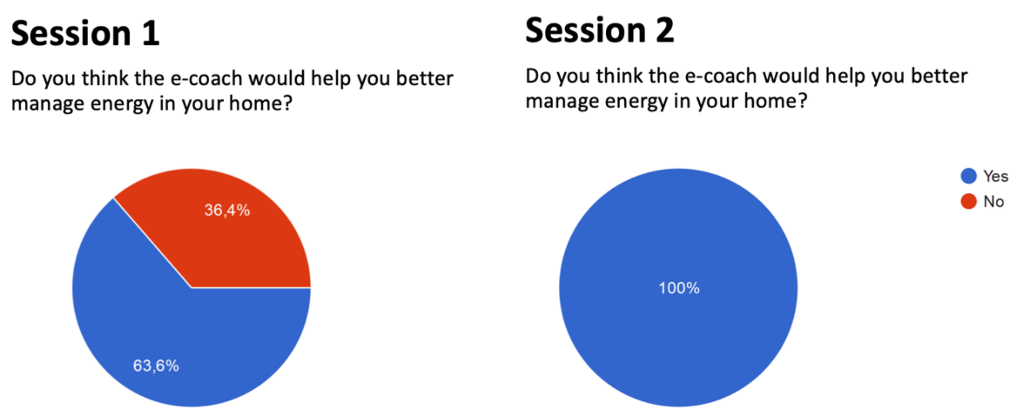


Figure 6.18. Usefulness assessment of the two session

Five participants have changed their opinion after interacting with Plan4Actions as a whole. Figure 6.18 illustrates this finding. Different reasons have been pinpointed: "*It is fixed the goal, we see if we reached them, if we reached them, it is good, otherwise we have margins of improvements to make and the e -coach will allow you to do it. I think that's not bad"* (P14); *"Today, yes because I can see where I am in relation with my preferences, it (Plan4Actions) will put the temperature to which I want [...]"* (P12); *"It's interesting to know that your actions, what results your actions can have on air quality, temperature and cost. It's good; [...], If he (Plan4Actions), it quantifies it, you see it right away, you cannot imagine it when you do things [...] and see your consequences directly on these three preferences; that's not bad"* (P9).

Nevertheless, for some participants who already acknowledge the benefits of the action plan, experiencing the whole system enhances their beliefs: *"Yes. In fact, with that (the whole system) it's even more, yesterday I see the actions to be done. […] but with this, it's more detailed, you say yeah, I do not reach my objectives because I change it (the plan) […], and I see the impact directly comparing with the other (Action plan alone)"* (P11); "*very well actually, I don't have any problem (using Plan4Actions), not at all, more on the contrary, it motives me. The measure of impact is a plus, I can really choose the ones I want, it's quite flexible, suitable for those I want. It's not the system that tells me no I have to do that but more according to your preferences"* (P3). These remarks seem to reinforce our opinion about how the separate elements of Plan4actions complement each other. More importantly, the integration of Status Man, Action plan and Sliders4DM seems to promote better understanding about the whole system, thus reveals practical use-scenarios.

Summary. We examined the usefulness of Plan4actions. The first session provided a mixed opinion about the usefulness of the action plan. While the overall assessment is somehow positive, some participants are not convinced by the utility of the action plan, and did not find the action plan usable. The possible reasons are 1) actions have to be done manually 2) they already know the actions 3) they need more features. Nevertheless, After the second session, all the participant referred to the utility of Plan4Actions, and they all clearly found it usable. <u>Five participants have changed their opinion after interacting with Plan4Actions as a whole</u>. The direct impacts on the home comfort and the capacity to set their own preferences are potential rationales for explaining the change.

Willingness to use

Session 1

The first session resulted in mixed reactions from participants in terms of willingness and motivation to use the prototype at home. Seven participants (7/13) shown their willingness to use the action plan. The motivation to reduce energy consumption seems to be the primary factor which interests these participants: *"I think it's a good motivation to reduce energy consumption because it reduces my bill at the same time; and, at the same time, I imagine that, if we consume less, we need to produce less energy, we waste less. So, it's a bit of a double objective too. So, having an app that allows me to optimize that easily is good; it could interest me"* (P2); *"I like, I'm a little curious about these things […] there, I do not see; I do not really have any ideas of how it could make things better. I would give it a chance"* (P4); *"This kind of things, it makes people aware of their energy consumption, and it is very important for the future that everyone be sensitive and bring a small share"* (P14).

On the contrary, two (2/13) participants did not want to integrate the Plan4Actions at home at all. The fact that users have to make the action by their own is the main reason: *"If it is me do the actions every time, no!"* (P3); *"No. it (Plan4Actions) taught me how to do it, but I already do it […]"* (P9). The others declared that they might consider using it if more functions are included: *"It depends on the information it gives me because of course, today, we have a billion applications […] I hope you go a little further than that but, if not that, it attracts me really not*" (P7); *"Well, maybe I would use it if it allowed me to roughly estimate the cost […], if it was something that could make comparisons […]"* (P8).

Session 2

After the session2, all the participants (13/13) confirmed that they are willing to use Plan4Actions if they had it at home. Some are very excited about its potential utility: "*I want to buy it right away. How much does it cost? […] Yes, I would use it from time to time*" (P9). By contrast, five participants declared that they would only use Plan4Actions if some extra conditions are met.

For instance, for participant P4, s/he requires some changes in terms of system design and functions: "*It (the system) would, after saying I will or I will not (do an action), propose if I want to have an alternative plan. […]*; *I will also suggest to see during the day how the costs are varying. For example, if the cost increases, there may be a peak of heating […] the peak heating will not occur all the time but it will be here, it starts to cost money. Like that I can see the periods of time for which there is a concern for air quality* […]" (P4). For participant P2, it is related to the preferences that Plan4Actions allows defining: *"with more preferences! […] it is the most important. You've already some preferences that says you're not at home between […] Yes, there are hours that I'm not at home or there are hours when I'm at home but I do not want to be bothered […] And even further, I can tell it (the system) the hours that I am in the living-room etc. It's in the same system but with more preferences"* (P2). Alert is an additional feature required by participant P11. Last but not least, other two participants (P13, P14) demand for more automation functions making Plan4Actions easier to integrate into their daily routines. This aspect will be further discussed.

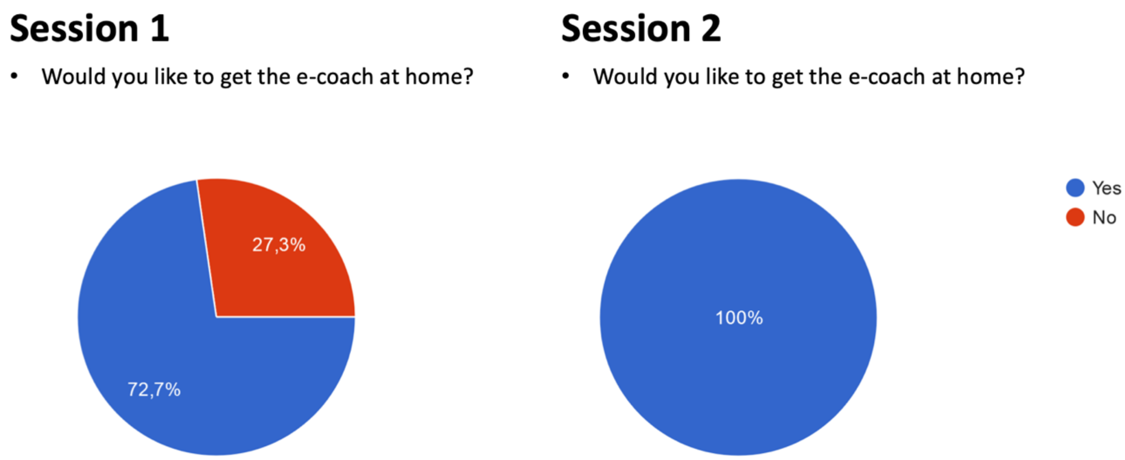


Figure 6.19. Utility assessment of the two session

On the other hand, participants seem to appreciate more the potential utility of Plan4Actions as a whole than the action plan alone. In fact, three participants have changed their mind about having the system at home. Figure 6.19 shows this finding in a more visual manner. Here is some interesting verbatim highlighting the change: *"Yesterday I did not test that (other elements of the interface), and I said no, I will not use, but against it, it seems to me with the details, [Is it possible to measure the impact that motivates you the most?] Not just the impact, but the three aspects, I like it in fact, I like it a lot"* (P3); *"I said no but after the next question […], I said yes ok actually now I see it Pplan4Actions) a little clearer and all that can allow you to understand your way of living in your apartment. I think I could use it."* (P8); *"The values (in the Status Man representation) are not bad, according to my experiences in this building, it's better a coach that an automated thing. Because with automation, we have seen that it does not work all the time, this application is good because I learn stuff too, the stuff you do not necessarily know with explanations and everything. Yeah that's cool!"* (P2). Overall, it is consistent with the assessment of Plan4Actions usefulness discussed in the section above. Figure 6.20 also shows that the novel functionalities from Plan4Actions convinced the participants to be willing to use it more frequently on a daily basis.

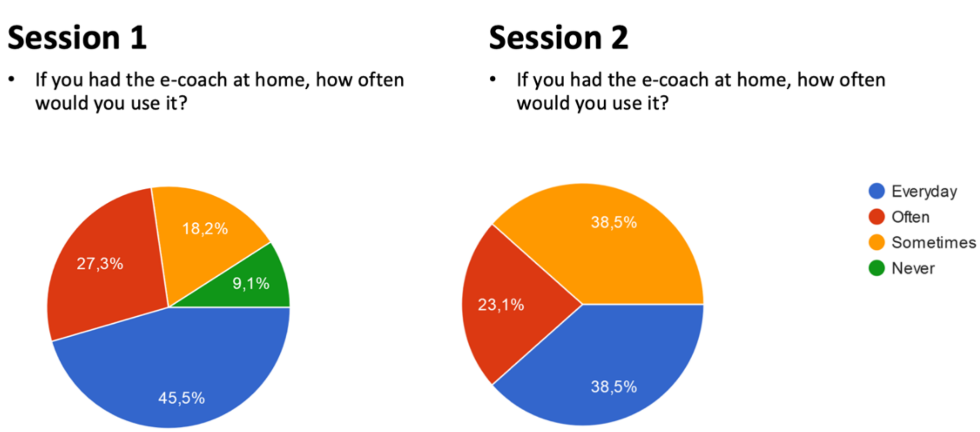


Figure 6.20. Usage frequency assessment of the two session

Summary. We examined the motivation to use the Plan4actions. The first session resulted in mixed reactions from participants in terms of willingness and motivation to use the prototype at home. The motivation to reduce energy consumption seems to be the primary factor that interests these participants. However, after the second session, all the participants confirmed that they are willing to use Plan4Actions if they had it at home. Nevertheless, the participants required some changes in terms of system design and functions including alert engine and automation functionalities. The results of this section are consistent with the assessment of Plan4Actions usefulness. Overall, Plan4Actions convinced the participants to be willing to use it for dealing with energy management tasks in their households.

6.5.5. Suggestions & remarks

This section summarizes the suggestions and propositions from the participants. We group these remarks into three categories: Notification, Action, Plan and Automation.

Notification

Three participants spoke about their requirements for a notification function: *"Yes, but I could not remember that (the actions) […] So I thought I should use something that could remind me, but I would not like the thing that beeps and told me: it's time to do that. No"* (P1); *"If I comeback home in the evening I can have lots stuff to do, so with a possible vocal system it would be easier if said hello, […], I will have the thought of opening the window for 15 minutes and do this do that"* (P4). Interestingly, participant P11 declared that s/he would use Plan4Actions only if it comes with alert functions.

Different types of Action

Four participants referred to changes in the action plan. The suggestions are either related to different type of actions to be taken into account by the system or functionalities to facilitate the use of the action plan. For instance, two participants proposed to make visible the changes in the plan each time it is updated: *"It bothers me that it (the system) does not tell me what has changed, a little thicker or a colour that changes a little bit for (attract) my intention, so that I learn them again"* (P1); *"I have not seen what has changed (the actions)[…], (for example) the shifting of an action, instead of opening the window at noon, now at 14h, put here something to indicate that the actions have changed"* (P11); In terms of action design and interaction, two participants wanted to display the checkbox (I'll do it/ I won't do it) permanently even when the action is in normal state: *"if at the end of the day I want to read what I did, what I did not, I have to click on all the stuffs so the checkbox must be visible all the time"* (P2); *"Indeed, just put the little check just below, as icon, it will be good"* (P3).

Moreover, participants also declared the need for different types of interaction over the recommended actions. For instance, it could be the action which inhabitants always do or never do in their daily basis: "*In addition to being able to say I want to do it, I can do it. It may well be actions that it is in your daily life that you could say I do it all the time*" (P1); "*I guess it can have actions that you say that I do not want to do it, never propose me that, I do not want to open the window of my room because […], there are construction works outside*" (P2).

Likewise, participants expressed their desires to add more types of action in order to better fit their daily life: "*I also like the fact of being able to add an action (which I did but not recommended), I turned on the heating for reason X and Y, because I have people at home, so does the window because there is one who smokes […] I think there are a lot of cases where you will change your process for a reason X or Y, […] it can change all the other actions so I have the impression that there really is a needs here*" (P1); *"Only one thing, I think it's depending on the work progress ... there are not too many types of actions, maybe there are other things, several possibilities, options"* (P7).

Cooperation process

Two participants wanted Plan4Actions to be more active over the cooperation process. A more direct way to reach a compromise, rather than a cooperative process where the system proposes and the participant adjust manually. For instance, the participant P2 prefers that when s/he clicks on "update preference", it will automatically find a solution that is closest to his/her preference: "*But why it (the system) does not put a combo that works direct (action plan and preferences), I would like it puts the preferences that are closest to those I had initially"* (P2). In the same vein, participant P4 wanted the system to explain more how it works: "*Maybe it offers me another plan if it exists or if there is no other plan, it says that the only way is to agree to just do these actions"* (P4).

Automation features

Five participants (5/13) spoke about the integration of the system with more automated functionalities. Two opposite sources of opinions are expressed by these participants. Firstly, as previously mentioned in a previous section, automation is the "must" condition to convince some participants to use it: "*Yes, (I will use) if I had home automation yes, it's that my current life will not be able to do it all the time, It's not that I do not want, it's just that there is chances that at such a place, such time we must think to open 15 minutes, it is a limit as a protocol to follow and it's something that I cannot include in my daily life"* (P13); *"I think the automatic side now is indispensable, more automated [...] It is the setting of the heating, ventilation, too, it is necessarily for the quality of the air […] there is also a moment that we take control, well I can open the* *window, and if I'm stupid, if I leave the window open all day, it's good that the Status Man do see and say "yeah, your target was 82 euro, you've completely exceeded because there's something that happens [...]"* (P14).

By contrast, some participants are against the automated home. For them, automation features are currently not "smart" enough to be included in the home management system. The pitfalls of the functions might affect negatively the overall user experience with Plan4Actions: "*According to my experiences in this building, it's better a coach that an automated thing. Because you has seen that, automation does not work all the time"* (P2)*; "I think the gain to automate something should not be balanced by the annoyance you have when you're doing something and that the machine decides no, […] it will be difficult to automate everything [...], it would cost a lot more expensive for a gain that is not necessarily […], the money put into this automation, I would prefer to put it in better materials typically better heating, isolation"* (P1).

6.6. Discussion

Overall, the experiment went well for most of the participants. The experiment results are consistent with the SUS score of Plan4Actions (75.19). For this first part of this section, we discuss how the participants assessed Plan4Actions. In addition, we will discuss some interesting remarks uncovered during the sessions.

Action plan

The concept of an action plan for the day is well perceived by the participants and most of the majority of participants understood its purpose. In general, the actions are mostly considered to be realistic, easy to understand and doable. Notably, participants even find ways to correlate different actions in the home context. The explanation within each action also reinforces the comprehension and credibility of the suggested plan. The results are, in general, quite positive with more than 70% of the participants declared their interests in using the action plan at the end of the first session.

In terms of usability, as the participants are confident using smartphone and tablet, our gesture-based interaction does not provide any problem for both sessions. The participants are able to navigate through the list of action, understand the semantic zoom to obtain more detailed information. In addition, the visual elements are found intelligible. This is reflected in the general understanding of the timeline concept, chronological order of the recommended actions and the timeslot labelling.

Besides, allowing multiple levels of description for an action (i.e., an action box of the timeline) based on a multilevel user interaction received many noteworthy reactions. At the meantime, we observed some misunderstandings. For instance, participants had difficulties to understand the meaning of the shutter icon. Additionally, the distinction between past/current/future actions as well as will do/won't do actions is not quite evident in the current design. One reason is because of the visual difference is not sufficient to attract participants attention. However, in the end, participants were able to overcome this misunderstanding thanks to supporting elements (i.e., text description, explanation). We believe the combination of icon, textual description and simple user interaction enhances the intelligibility of one action and of the plan in general.

However, although most of the participants understood the purpose of the action plan, many are still confused about the roles and responsibilities of the system. For instance, whether the actions would be done by the system or by the user? Likewise, if the task is accomplished, is the system detecting it automatically or has the user to inform the system? We believed that the notion of recommender is not clear for many people, especially when automation systems are becoming more and more familiar nowadays. Furthermore, some actions are found to be unsuitable for the daily routine of certain participants. For instance, participants commented on the duration of heating practice, the opening of the window during winter or night-time, etc. The inappropriate actions also resulted in the assessment of utility and potential usage of the action plan.

Explanations

All the participants were able to easily access to the explanations related to recommended actions. Besides, the button incited participants to click on it to have more tailored information about the action. In terms of intelligibility, all participants declared to have well understood the provided explanations. The majority of them were satisfied with the way explanations are formulated. More importantly, the explanations appeared to be very useful as the majority of participants (8/13) find them necessary in order to understand how the system works. Some participants considered the explanations as means to motivate them to further explore the recommended action plan. Likewise, explanations also helped participants to learn new things for better managing their household. These results confirm one of our hypotheses that explanations are interesting for home management systems and to motivate inhabitants in the long run.

Status Man

Participants highly appreciated the Status Man representation. The participants positively perceived both the global and detailed views of the Status Man. This is reflected in the favourable assessment in terms of its comprehension, usability and utility. Besides, from our analysis, the role and purpose of Status Man were well understood during the experiment.

For the two views, progress circles, all the participants properly understood their colour-encoding, and smiley faces. Additionally, besides the primary task of delivering the overall home status in an interactive manner, the Status Man had also shown its usefulness in other practices. For instance, it served as supporting tool (i.e., through visual feedback) for helping the users to set their preference settings. Likewise, the fun and playful experience provided by the smiley incited the participant to interact, thus increasing their motivation for using Plan4Actions.

Moreover, the participants favoured the detailed view over the global one. The reason seems to be that most of the participants prefer to have both the visual and numerical representations but with units (e.g., temperature) that they can understand. In addition, both representations are complementary as they support different situations. For instance, the participants relied on the colour (i.e., smiley and progress) to determine whether the air quality is good enough as the value in “ppm” does not seem to be familiar for many. By contrast, the numerical values make more sense in terms of financial cost and thermal comfort. This remark is consistent with the finding from our literature review in Chapter 4, about how people perceive informative presentation and the quantitative values.

Sliders4DM

The sliders widget is mostly used as a support widget that facilitate preferences setting and for co-decision with the system. We have received some noteworthy remarks about its usability and utility. In overall, participants understood well the purpose of the widget. It allows participants to explore the solution space in an interactive manner, helps them to effectively set their preferences. Besides, it served as an important element in the decision-making loop in which the participants have shown throughout understanding. During the experiment, Slides4DM had provided participants means to explore and find suitable compromises between their preferences over the home comfort (i.e., thermal comfort, cost, air quality), and over their lifestyle (i.e., schedule, routine and usual practices). Additionally, we also received suggestions for better integrating the Sliders4DM widget into Plan4Actions. For instance, by being more active and autonomous, the widget could automatically adjust user preferences and offer more suitable set of compromises for the user.

Plan4Actions as a whole

The favourable assessment of each element (i.e., Action plan, Status Man, Sliders4DM) created conditions for a positive impression of the whole interface. Indeed, a large number of participants understood well the relationships between the three elements of Plan4Actions. They can clearly see how they are related through user interaction. In all, the participants clearly understood the role as well as the purpose of Plan4Actions. Besides, Plan4Actions offers possibilities to explore the solution space in an interactive manner. Most of the participants felt confident in interacting with the interface. For instance, all participants were able to set their preferences, visualize the impacts while adjusting their action plan accordingly. Many considered the interaction process as a "dialog" with the system, they all understood the purpose of finding a satisfactory trade-off between home comfort and a doable action plan. This is reflected in the evaluation of Plan4Actions: 100% of participants found Plan4Actions usable and expressed strong willingness in its usage in their daily life.

Other remarks

Interestingly, we reported some significant changes in participants about the utility and usage of Plan4Actions after the second session of the experiment. We argue that one reason for the change is the capacity to flexibly set the preferences to fit participant lifestyles. Besides, the fact that participants can decide whether they want to take a recommendation or not contributed effectively to the empowerment of the change. Moreover, the ability to visualize immediately the home status and the impact of each action reinforces it. Indeed, for some participants who already acknowledged the benefits of the action plan alone, the fact of experiencing the whole system seems to enhance their beliefs. Towards this end, we believe that the three elements of Plan4actions support each other in a way that promotes better understanding about the whole system, thus, reveal practical use-scenarios. Overall, it is shown that each feature of Plan4Actions plays an important role in the overall experience of the participants. The analysis also indicates that the functionalities provided by Plan4Actions convinced the participants to be willing to use it more frequently in the daily basis.

6.7. Lessons learned

The design and the evaluation of Plan4Actions user interface uncover interesting lessons, premises of guidelines, to implement UIs smart home management systems embedding incentive recommendation features. A major lesson is that an action plan (or a schedule) is insufficient: it does not give enough flexibility to the user to establish a full co-decision loop between users and the system. The second major lesson, it must be complemented with explanations and features that allow users to explore possibilities and that accompany them in their decision-making process. In Plan4Actions, our second interactional brick, this is achieved with the combination of the Action Plan, the Sliders4DM widget and the Status Man. The Action Plan is the system view as it provides an interactive way to explore recommendations and to understand both the reasons of doing these actions (credibility) and the system's logic (observability). Complementarily, the Slider4DM widget allows users to express their preferences and helps to find a suitable tradeoff. This permits users to express their needs to the system. Finally, the Status Man serves to reveal the nature of the compromise in an intelligible manner: it acts as a gauge between user's preferences and system's optimal recommendations. Consequently, Plan4Actions seems to satisfy the requirements: (1) to provide contextual recommended actions for the day based on user preferences, (2) through contextual explanations coupled with recommended action, it helps inhabitants understand the functioning and rationale of their home and of the management system, (3) allow inhabitants to explore the solution space via what-if process, and (4) support the cooperation between inhabitants and the system, keep inhabitants in the control, involve them in the decision-making and action-taking loop.

We consider some potential improvements for Plan4Actions. First of all, it seems necessary a re-design of some visual elements, which confused many participants during the experiment (e.g., door and shutter icons, buttons update). Besides, more contextualized and sophisticated explanations are considered for future version of Plan4actions. Also based on the participants' remarks, we examine a reorganization of the interface. For instance, we choose by default the detailed view of the Status Man for better illustrating the home status. Moreover, guidance and help for first-handed user are under investigation. Like in many applications, Plan4actions could provide onboarding pages for briefly presenting each components of the interface, or an overview of actions to be performed for the first time. To conclude, a second version of Plan4Actions is under implementation.

However, the experimental evaluation of Plan4Actions raises two important issues. First, although most of the participants state they want to keep control while using a smart home management system, designing a very flexible user interface is subtle, as it must balance with precision the right level of flexibility and the necessary level of automation. Adaptation could be investigated to address this issue. We believe that is related to the level of expertise between novice and experts for smart home management system. However, we think that zoomable user interfaces are a first step to address this point. Second, a related issue is who is in charge of taking the actions: the user or the system. Indeed, some of the participants requested more automated actions. Therefore, the user interface (and the underlying system) should also provide means that allow users to choose an appropriate level of automation. Another crucial point is the effectiveness of Plan4Actions over time. An evaluation in the wild will be considered with the integration of the new version of Plan4Actions in a real domestic context, including the integration of the e-coach engine. This is mandatory to assess the incentive effect of Plan4Actions in a behavior change process in the context of energy management.

7. Conclusion, Perspectives and Future works

Let us recall our research question defined in the first part of the thesis: “**Which interactional bricks can be considered for building interactive persuasive systems that makes causality observable, support the decision and facilitate inhabitants to change in sustainable manner”**. In this perspective, the two main design requirements based on an analysis of existing persuasive interactive systems for energy are pinpointed.

- R1: designing persuasive user interactions that take into account the long-term dimension of behavior changes.
- R2: designing persuasive user interactions to get users involved in the behavior change process: explain, recommend, and support action.

In this chapter, section 7.1 outlines how our contributions answered to the research question. Before defining the future directions for the research in 7.4, we present our perspectives and future improvements to extend current works (section 7.2 and 7.3). We complete the manuscript by listing the publications published during the thesis (section 7.5).

7.1. Summary of contributions

User / System / Phenomenon	Understand Enlightener	Decide Recommender	Act Facilitator	Protect Protector
Cause (Behavior)	**Mondrian UI** *Reflect behavior*	**Plan4Actions** *Recommend actions*	**Sliders4DM** *Engage*	Prevent
Effect (Situation)	**Mondrian UI** *Reveal situation*	**Plan4Actions** *Suggest situation*	React	**Plan4Actions** *Alert*
Causality	**Plan4Actions** **Sliders4DM** *Explain*	**Plan4Actions** **Sliders4DM** *Simulate*	**Plan4Actions** *Manage*	Anticipate

Figure 7.1. UP+ persuasive functions and evaluation grid;
(Light blue) Persuasive functions proposed in Mondrian UI; (Green) Persuasive functions which have been targeted and evaluated in Sliders4DM and Plan4Actions; (White) Persuasive functions to be considered for improvements and future works.

We present here the summary of our four contributions, what we have proposed, what we have evaluated. Figure 7.1 maps our contributions on the framework UP+; In light blue background, we show the persuasive functions proposed in Mondrian UI; In green background, the persuasive functions targeted by Sliders4DM and Plan4Actions.

UP+, a framework for persuasive interactive system (Chapter 2)

Our first contribution UP+ is a framework organizing functions of persuasion according to three dimensions: two related to the process aspect of behavior change, at two levels: micro (cause-effect-causality) and macro (long term)); one related to the psychological aspects of motivation.

We conceived UP+ as a conceptual tool for the designer of Persuasive Interactive Systems to explore the design space for persuasive interactive systems (generative property). It is also served as an analysis grid to review existing persuasive interactive systems, thus opens some ways to review current PIS for energy (descriptive and evaluative properties). The design space is built upon our literature reviews presented in Chapter 2 and it conducted a state-of-the-art of existing PIS for energy.

Compared to several existing classifications, UP+ explicitly considers the process dimension of behavior change. The goal is to take into account, at design time, that persuasive user interaction should be adapted in order to present the appropriate persuasive functions according to the current behavioral change phase. Furthermore, UP+ reasons in terms of motivational affordances and psychological outcomes from an HCI perspective through a mapping on the classical action-reaction process.

Mondrian user interface concept (Chapter 4)

Our second contribution is Mondrian User Interface, a proof-of-concept serving as a framework for persuasive interaction; the design of Mondrian UI based on two principles: eye-catching and interaction at multi-levels. From this concept, we derive several guidelines with the objective of structuring persuasive interactional bricks and making visible different stages of behavioral change process as well as its outcomes.

In Mondrian UI, we aim at sustaining daily use and maintaining inhabitant's awareness and motivation over time. Through three levels of interaction (Glanceable, One-Click UI, Zoomable UI), the Mondrian interface is conceived to provide coherent and composite tools for everyday multiple use-contexts and purposes. By means of eye-catching factor, the ambient artistic interface concentrated on promoting intrinsic motivation and more engaged change from inhabitants.

In comparison with other design concepts, Mondrian UI effectively combines three approaches: informative art, UI interaction at multi-levels and the integration of social utility functions. The combination provides a conceptual answer to our defined research question since it promotes long-term engagement and motivation (R1), involves inhabitants in the process with different use-contexts (R2).

Sliders4DM (Chapter 5)

The third contribution lies on Sliders4DM, a novel widget to assist inhabitants in their decision-making process and change preparation. Specifically, Sliders4DM revisits classical sliders to allow non-expert users to find an appropriate trade-off between (possibly) conflicting criteria in the home via a *what-if* approach.

We conceive Sliders4DM as a tool for supporting the exploration of a solution space through *what-if* scenario. In order to plan their actions for the change, the Slider4DM widget allows users to express their appropriate definition in terms of comfort, sobriety to the system. It establishes a first step towards a co-decision loop between users and the smart system. We evaluated the Sliders4DM widget with two experiments: a qualitative one (16 participants) and a quantitative one (177 participants). The results of the evaluation confirm widget's affordance and usability; Besides, it is reported that Sliders4DM facilitates the understanding of the mutual influence between the criteria of the optimization problem.

Compared to existing solutions in Multi-Criteria-Decision-Making, Sliders4DM widget effectively hides the complexities of the underlying mathematical model. Furthermore, the non-constraint sliders offer inhabitants with flexibility while exploring the solution space. Last but not least, while current solutions mostly target the domain-experts in some specific application domains, Sliders4DM addresses novice and non-expert users and provides aid decisions for optimization in the household context.

In response to the research question, the Sliders4DM widget constitutes a first interactional brick that reaches the first requirement (R1) as it targets different persuasive functions regarding the process of the behavior change: (Enlightener) it explains the mutual relationship between the home criteria; (Recommender) it simulates situations and suggests the appropriate compromises in a way that balances the user requirements and the system capacities; (Facilitator) it engages users in planning for serious actions. Moreover, by means of putting inhabitants in the decision-making loop, Sliders4DM is considered as a mediator to help users establish their definition of how to be sustainable in an engaged and interactive manner (R2).

Plan4actions (Chapter 6)

The fourth contribution is Plans4actions, a novel concept of user interface for planning daily actions with respect to inhabitants' preferences and schedule. The interface concept is based on the exploration of plans empowered by co-decision between inhabitants and the home management system.

Plan4actions revisit planning interfaces based on explanation and recommendation features. It relies on three facets: action plan (generated by the system), user preferences (Sliders4DM) and Status Man (overall status of the home). In comparison with existing energy management systems, Plan4actions exploits the principle of **equal opportunity** to implement the co-decision that governs the coupling of the three facets. It provides inhabitants with flexibility in planning their daily actions in order to satisfy their objectives in terms of comfort and sobriety. Furthermore, it pushes further the cooperation between users and the system with *what-if* scenario.

In response to the research question, The Plan4Actions is a second interactional brick that meets the first requirements by considering different aspects of the behavioral dimension. Moreover, by means of supporting the cooperation between users and the system, while keeping inhabitants in control, it involves them in the decision-making and action-taking loop (R2). Last but not least, a twofold evaluation presents a favorable assessment from the 13 participants in terms of the Plan4actions' comprehension, usability and potential utility in the domestic context.

7.2. Perspectives

We identify several perspectives and avenues of research for the works presented in this manuscript:

7.2.1. UP+

Completeness of persuasion functions

In UP+, we identify the four classes of functions: **enlighten** for making the user *understand*, **recommend** for helping the user to *decide*, **facilitate** positive *actions* and **protect** from negative behaviors. Each category consists of three functions covering the phenomenon-based user interaction, creates condition for twelve persuasive functions to be introduced. However, could the conceptual tool sufficiently cover all the necessary functions to promote the sustainable change? We believe there might be room for more domain-specified functionalities to effectively induce the behavioral change in context.

Refining and mapping of the psychology dimension of motivation.

In UP+, the third dimension is related to psychological aspects of persuasion and behavior change. This dimension is orthogonal and complementary to the two other dimensions. To reinforce the persuasion means, three main psychological factors are taken under consideration: Social influence, Gameful experiences and Aesthetics. The analysis of current PIS for energy (Chapter 3) demonstrates two interesting point about the application of the factor: firstly, each factor could be effective in many functions; secondly, for a specific function, there seems to be a pattern while applying the psychological feature. For instance, social influence shows its effectiveness in revealing user's (i.e., as social comparison), in suggesting for alternative situation to be reached (i.e., as social normative). These remarks referred to the necessary to refine the psychology factors in a more concrete manner in order to efficiently convey motivation. For example, the classification of Hamari [72] presents other dimension of psychological impacts to approach.

Furthermore, as discussed in section 2.2.3, an effective persuasive user interaction requires a right motivational affordance (e.g., playfulness through gamification, social comparison) as well as an appropriate psychological outcome (e.g., reward, greetings). These affordances are essential to motivate users to perform actions as well as maintain their desired behaviors. In relation to UP+, the mapping of appropriate motivational affordances and psychological outcomes in each persuasive function would provide notable benefits for the design of persuasive interaction. For instance, for functions to reveal current situation, the social comparison means might be effective as motivational affordances. Meanwhile, rewards could be the suitable psychological outcomes for designing react function. We consider this mapping as one potential solution for improving our current conceptual design space.

Towards an interactive tool for designing PIS for energy

UP+ is conceived as a tool for facilitating the design of PIS with the central point on HCI aspect. From the engineering point of view, it is difficult for designing appropriate persuasive functions without mastering the state-of-the-art of PIS for energy. Besides, other noteworthy factors could be mentioned in the design are the type of indented interface (e.g., whether it is graphic-based or tangible), the target behaviour (e.g., whether it is electricity or water). To help designers in such a task, UP+ could be evolving towards an interactive tool for effectively defining the appropriate functions or providing guidelines, principles for a given problem. With that in mind, UP+ must consider some other aspects beside the initial three-dimensional framework. Moreover, various concrete examples (e.g., for design a function to reveal current user's situation, interactive suggestion, etc.) might be useful. For instance, Behaviour Wizard [55] could be considered as one source of inspiration.

7.2.2. Mondrian User Interface

Adaptation for users who possess different levels of expertise.

In Mondrian UI, we proposed interaction at three levels for multiples contexts of use. However, how the UI adapts to users with multiple levels of expertise (i.e., novice, expert) is an interesting point to be further investigated. For instance, a user who has already familiarized with the system might require a different way of presenting information comparing with a person who starts to explore the smart system. Similarly, depending on their motivation and ability, users might not be in the same process of the behavioral change, strategies, which persuasive function has to be implemented and presented accordingly. Moreover, another question is how to evaluate if a user is a novice or an expert. One solution could be to employ the gamification notion of level or score, which have been introduced in [66].

7.2.3. Sliders4DM

Scalability for more than three criteria

Although Sliders4DM can be instantiated with more than three criteria, scalability has not been addressed. Some of our visual cues, such as the dynamic dashed lines, which worked well for three criteria, may lead to visual cluttering, impeding the decision process. In addition, decision making with more than three criteria is indeed cognitively demanding, possibly requiring additional assistance. However, as demonstrated in [1, 115], one can draw on mathematical methods, such as dimension reduction, to address the problem of visualizing Pareto solutions for more than three objectives. Alternatively, a locking mechanism, similar to that developed by Monz et al. for surgeons [115], may be used to select the three dependent criteria and thus reduce the dimension to three objectives.

7.2.4. Plan4actions

Towards the design for exceptions

The complex and nuanced daily life of people may produce many exceptions, which makes the work of modeling and predicting their routines harder. Especially, the exceptions might not come from the inhabitants themselves but also from their surrounding contexts (i.e., construction works beside the home, noisy neighbors, etc.). For the system of energy management, the ability to recognize these exceptions would promote a twofold advantage: Firstly, it helps to avoid inappropriate recommended actions, which might not interest but rather disrupt inhabitants; Secondly, it increases the credibility and trustworthiness of the system. Therefore, it is necessary to take the exception factors into account when designing PIS for the home. In regard to our co-decision approach grounded in Plan4actions, we envision a cooperative process which the users can override their current settings and preferences in case of exception; in the other hand, the system could learn overtime to provide suggestions to optimize energy consumption within the given context. In all, it opens another perspective of modeling the complex daily schedule of the inhabitants.

7.3. Improvements

This section presents the possible improvement of current works in a near future.

7.3.1. Mondrian UI

Improve the Informative art design

In Mondrian User Interface, the Mondrian style has been served mostly as a layout for the mapping of block of functionalities and navigation between different use-contexts. Although we have implemented the clock view to represent household consumption using an informative illustration, the adoption of informative art technique limited, it served only as a baseline for the aesthetics of the UI. We believe that we could improve our current informative design to take more advantage of this technique. Augmenting the Mondrian elements can convey energy consumption data. For instance, we can imagine an ambient display where each tile of the Mondrian painting represents a source of energy (e.g., electricity, water, heater). Any change in the home energy usage will be reflected through the transformation in size, or color of these tiles.

More into the personalization

Our Mondrian interface offers guidelines for designing the UI of a smart system for the home. The designs need to adapt to different contexts, purposes and people because there is no “one-size-fit-all” solution. The needs to personalize the system in terms of functionalities and design elements are obvious. For instance, customization could be a way to invoke self-reflection, elicit sense of freedom and raise intrinsic motivation [50]. In our context, it is reasonable to consider the aesthetic tastes of end-users into the design of the management tools. Based on that, we propose rather than Mondrian style, alternative art styles could be given for customization purposes. Besides, we could imagine artistic styles as items that can only be unlocked for usage when inhabitants accomplished certain tasks and challenges.

Increase social influence

Social features are widely employed in persuasive interactive system for energy. The analysis results in chapter 3 have shown various functionalities of social factors. In our design, we have employed the notion of challenges and social comparisons to persuade users. However, we believe there is still room in our design for exploring more about this factor. For instance, we can let the users set goals on their own. In fact, as pointed out by Locke and Latham [107] self-set goals seem to be more effective than goals set by the system. Besides, it is somewhat relevant to our intention of designing an open-ended system (see chapter 3.3.3). Moreover, social-interaction is no doubt a promising solution, one popular approach is to let inhabitants share their performance other households or communicate with their friends.

7.3.2. Plan4Actions

Notification support (Ambient or Mobile)

Plan4actions generates actionable plan coupled with explanations for satisfying the user preferences. These actions and explanations are found to be useful and facilitate the understanding and interest of the users (see chapter 6). However, despite its usefulness, inhabitants might not follow the recommended plan, as it requires a commitment from users. The inhabitant might not be able to check the plan because of their busy daily life or when exceptions occur. These observations lead us to consider a notification engine for supporting the interactive tool. This tool would be connected to the home management system and would make it possible to notify inhabitants of the next action to be done. It could also rewards inhabitant of their good performance (i.e. React function in UP+) or alert when they are missing too many actions (i.e. Alert function).

Two types of notification system appeared to be promising: mobile and ambient. For instance, the management system could be easily adapted some functionalities on a mobile application, which would allow users to analyze their consumption, check their to-do tasks anywhere. In essence, the advantage of mobile devices (i.e., mobility, availability) would provide more contexts of use. As example, it could be a pushing notification to gently remind users of the action to do within next hour. This engine can sync with the user calendar and other services (e.g., mail, SMS). The second type of support is ambient notification. The notification system could be adapted to connected household appliances such as lamp, clock or else. For instance, the lamp can use different light colors or flashing, on/off events to deliver notification to inhabitants.

Non-recommended actions taken by end-users

Another possible improvement is the consideration of non-recommended actions realized by the end-users. Our Plan4actions provides inhabitants with a contextual plan containing actions for the day. The user can change or modify the plan in a way that best fit their preferences and routines. Nonetheless, inhabitants might, due to different usage-scenarios, provoke other either indented or unintended actions, which could affect their preferences at the end of the day. For instance, the user forgets to make an action (e.g., opening window of the living room at 11 am) and wish to take it later (e.g., at 1pm). The system might consider the action at 11am as missed. However, it would be valuable if the system can record the non-recommended action at 1pm and show its effects on the overall preferences. In our view, it could not only support the exploration process but also help inhabitants understand better their household.

Learn and Predict user's interaction for better action plan

Last but not least, being able to learn and predict users' ways to interact with recommended action plan could provide different means to improve the e-coach engine. It could base on user's pattern during interaction for always/never propose certain actions. One possible way is to let the user to tell the reason why s/he always/never wanted to follow the recommendation. Besides, by anticipating similar contexts (e.g., similar weather condition) and users' interaction, the e-coach engine could provide more suitable set of actions of the day, therefore, keep the user motivated in the long-run. It is also relevant to the Anticipate function presented in UP+.

7.4. Future Works

This section defines our directions for future works.

Fully functional e-coach (Mondrian UI + e-coach engine)

Besides the possible improvements for the Mondrian UI and Plan4actions for the short-term, we plan to fully connect the e-coach engine with our contributions (Mondrian UI, Sliders4DM, Plan4Actions) for real use. The system could directly connect to the home service to push/retrieve data. In essence, the system can have access to the equipped sensors data leading to information about real-time consumption, home status etc. Besides, input information from the interface such as the inhabitant's preferences and schedules would automatically be access and analyzed by the home services. Towards this end, the system could provide contextual advice and actionable plans that respect inhabitants' values. The home management system is envisioned to be deployed in a real domestic context.

Longitudinal evaluation study

As behavior change is a long-term and complex process, the study must involve a longitudinal evaluation in order to measure the effectiveness of persuasive aspects. Therefore, our future work includes the deployment of our home management system, the implementation of design principles proposed, its evaluations and finally a longitudinal study of whether persuasive interaction respecting on user values actually motivated behavior change. Besides, literature review indicates that user's interaction faded overtime when using home management system. Hence, it would be necessary to measure the end-user's interaction in the long run. Moreover, we are still interested in evaluating the usefulness of what-if approach and contextual actionable plan coupled with explanation. How inhabitants cooperate with the system for balancing the control and user autonomy is another noteworthy aspect. From these points of view, a long-term evaluation constitutes a mandatory perspective.

7.5. Publications

The works presented in this thesis are the subject of four publications:

- **Energy Consumption in Smart home: Persuasive Interaction Respecting User's Values (2017)**
  Van Bao Nguyen, Hélène Haller, Gilles Debizet, Yann Laurillau, Joëlle Coutaz, Gaëlle Calvary;
  In 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications. pages 804-809. 2017.
- **UP! Engineering Persuasive Interactive Systems (2018)**
  Yann Laurillau, Gaëlle Calvary, Van Bao Nguyen
  In Proceedings of the 10th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS'18). pages 13:1-13:16. 2018.
- **The TOP-Slider for Multi-criteria Decision Making by Non-Specialists (2018)**
  Yann Laurillau, Van Bao Nguyen, Joëlle Coutaz, Gaëlle Calvary, Nadine Mandran, Fatoumata Camara, Raffaella Balzarini
  In Proceedings of the 10th Nordic Conference on Human-Computer Interaction (NordiCHI '18). pages 642-653. 2018.
- **From Usable to Incentive-Building Energy Management Systems (2018)**
  Amr Alzhouri Alyafi, Van Bao Nguyen, Yann Laurillau, Patrick Reignier, Stéphane Ploix, Gaëlle Calvary, Joëlle Coutaz, Monalisa Pal, Jean-Philippe Guilbaud
  In Modeling and Using Context 18(1). pages 1-30. 2018.

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8. Annexes

8.1. Sliders4DM experiment

8.1.1. Questionnaires

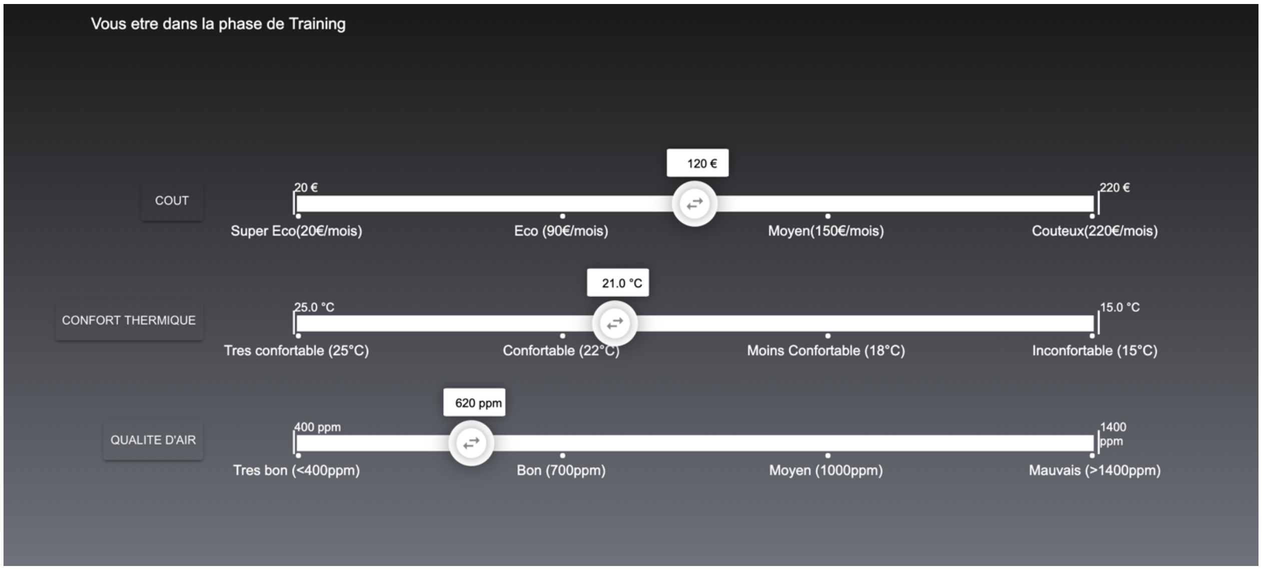
At the end of the qualitative experiment of the Sliders4DM experiment, we have asked the participants to answer these following questions:

1) What do you think about the use of sliders for the management of energy consumption?
2) How do you do at your home, to control energy consumption?
3) By moving the sliders, you have seen values and areas of colors appear. What did you understand during the experiment?
4) Can you give concrete examples (about the visual elements)?
5) Can you describe what visual indicators you have understood when moving them?
6) How do you manage to find the compromise?
7) How do you determine an ideal choice?
8) The possibility of moving the cursor gives rise to different combinations, that lead you to look for several solutions?
9) For what type of choice in everyday life, have you ever used sliders?

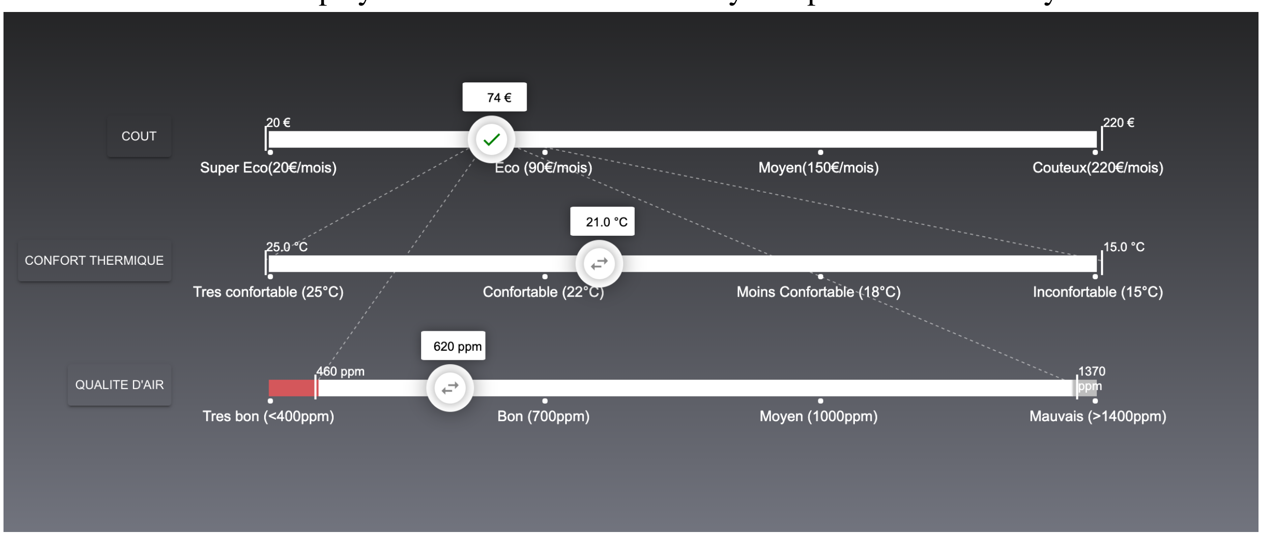
Besides, we also asked the participants to answer the SUS questionnaire (see 8.3)

8.1.2. Sliders4DM prototype

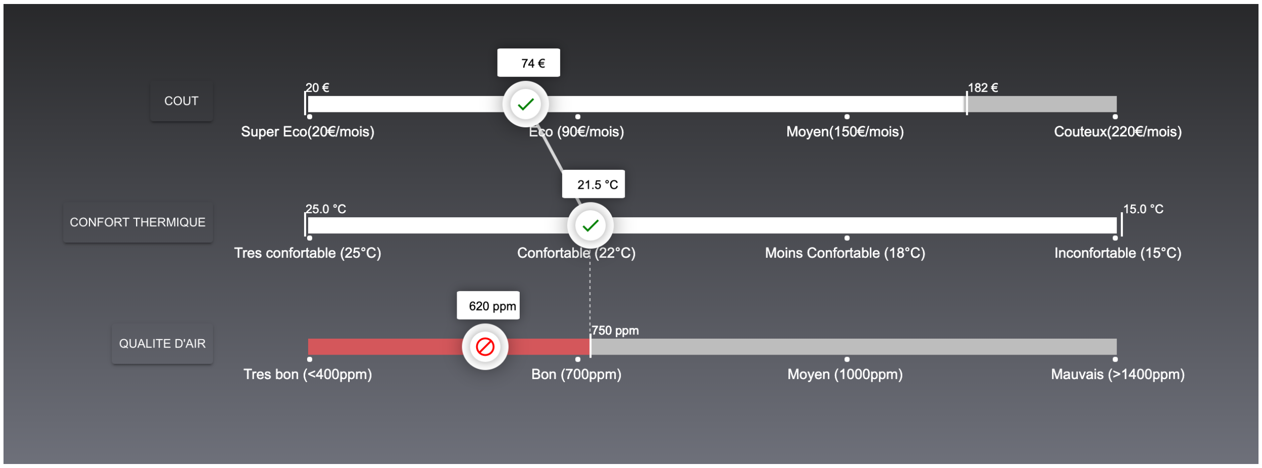
The following sequence of screenshots explains more about the functioning of the prototype which we utilized for the experiment.



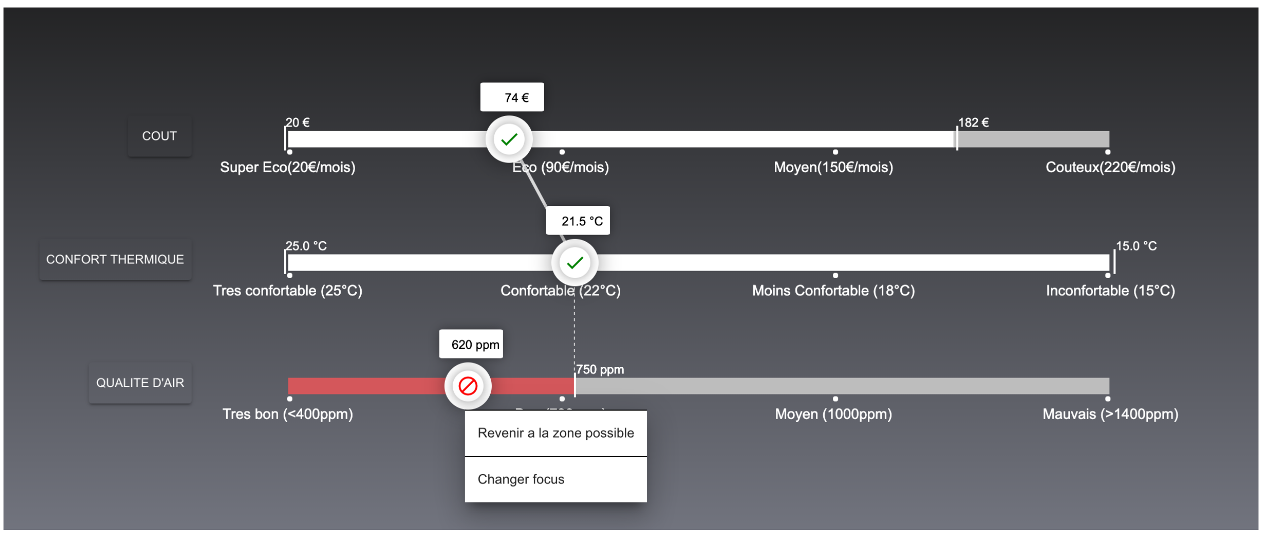
#1. The training screen: Three sliders are initially placed randomly (i.e., based on previous setting). The users were asked to play with the sliders and find any compromise which they found suitable.



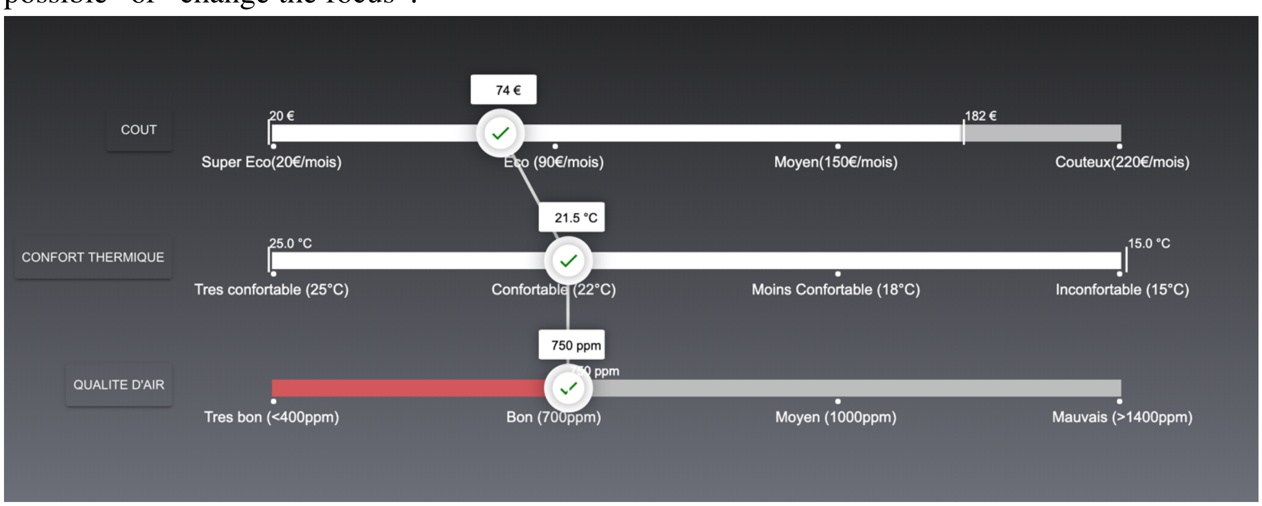
#2. For instance, the user placed the first slider (cost) at 74 €. He/she sees the applicable range of other criteria based on the dashed lines.



#3. The user moved the second slider, he/she fixed temperature at 21.5 °C. He/she can see that the current air quality (620 ppm) is impossible to achieve (block icon), he/she also observe that the best air quality which he/she can obtain is 750 ppm.

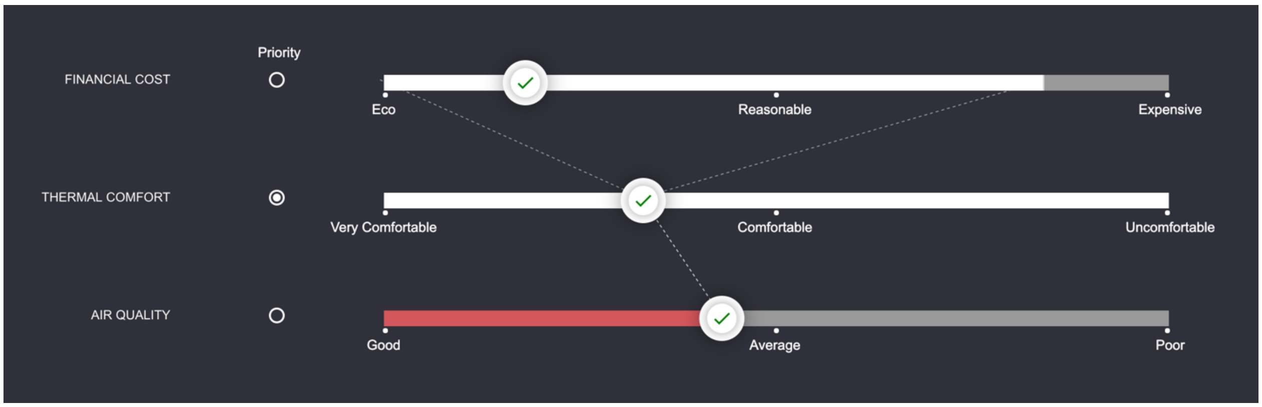


#4. The user clicked on the cursor, a dialog is opened showing two options: “go to the zone possible” or “change the focus”.



#5. The user clicked on “go to the possible zone”, the system automatically placed the cursor at 750 ppm. Now a compromise has been made. The user can valid this preference or continue to explore other solutions.

After the first experiment, we have made some improvements for the prototype (i.e., priority setting) The current version of the Sliders4DM widget can be found here: https://pareto-sliders.firebaseapp.com/.



8.2. Plan4actions experiment

8.2.1. Questionnaires

Session 1

At the beginning of the first session of the Plan4actions experiment, we have asked the participants to answer these following questions:

1) What is your gender?
2) How old are you?
3) What is your profession?
4) Who lives in your home?
5) What type(s) of energy do you have?
6) What is the type of the heating in your home?
7) Do you have a device for energy management at home?

At the end of the first session of the Plan4actions experiment, we have asked the participants to answer these following questions:

1) Could you understand the explanations provided by the system?
2) Would you formulate the explanations differently?
3) Do you find the explanations useful?
4) Do you think that explanations are necessary to understand how the e-coach works?
5) Would you find it useful to provide the system with explanations regarding your behavior?
6) Do you think the e-coach would help you better manage energy in your home?
7) Would you like to get the e-coach at home?
8) If you had the e-coach at home, how often would you use it?

Session 2

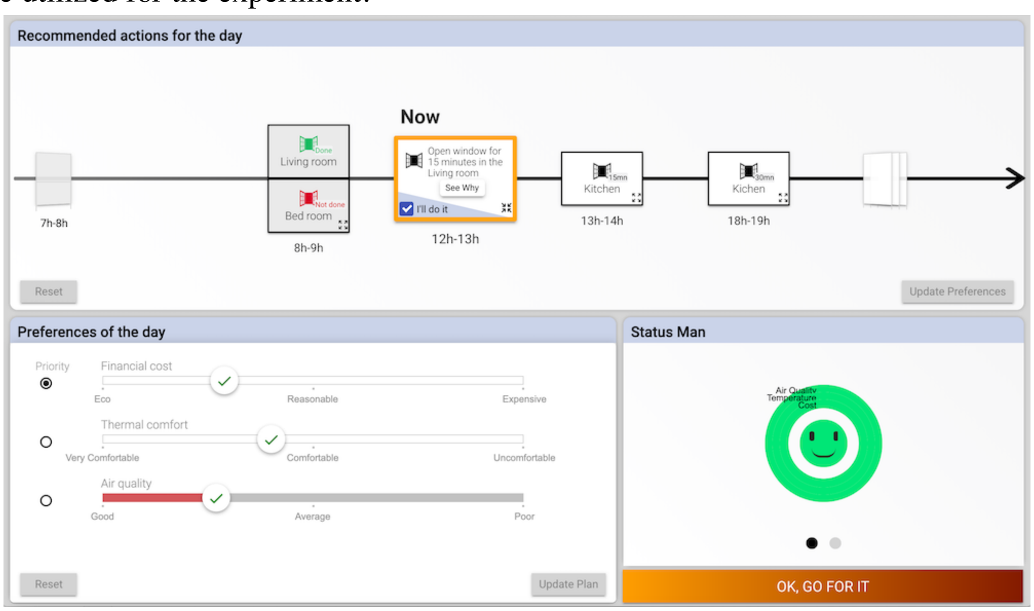
At the end of the second session of the Plan4actions experiment, we have asked the participants to answer these following questions:

1. Do you think the e-coach would help you better manage energy in your home?
2. Would you like to get the e-coach at home?
3. If you had the e-coach at home, how often would you use it?

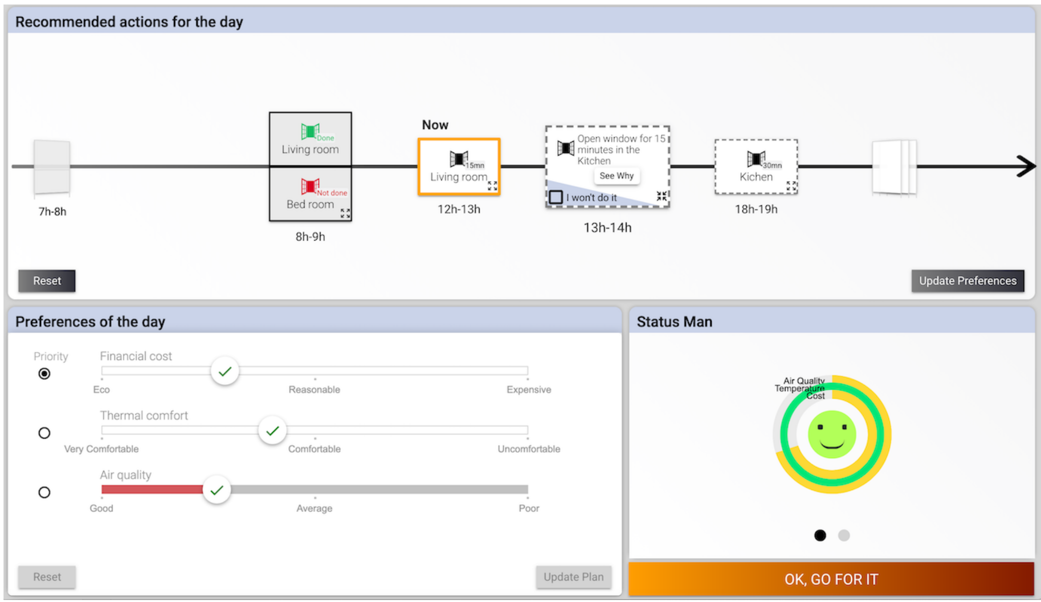
Besides, we also asked the participants to answer the SUS questionnaire (see 8.3).

8.2.2. Plan4actions prototype

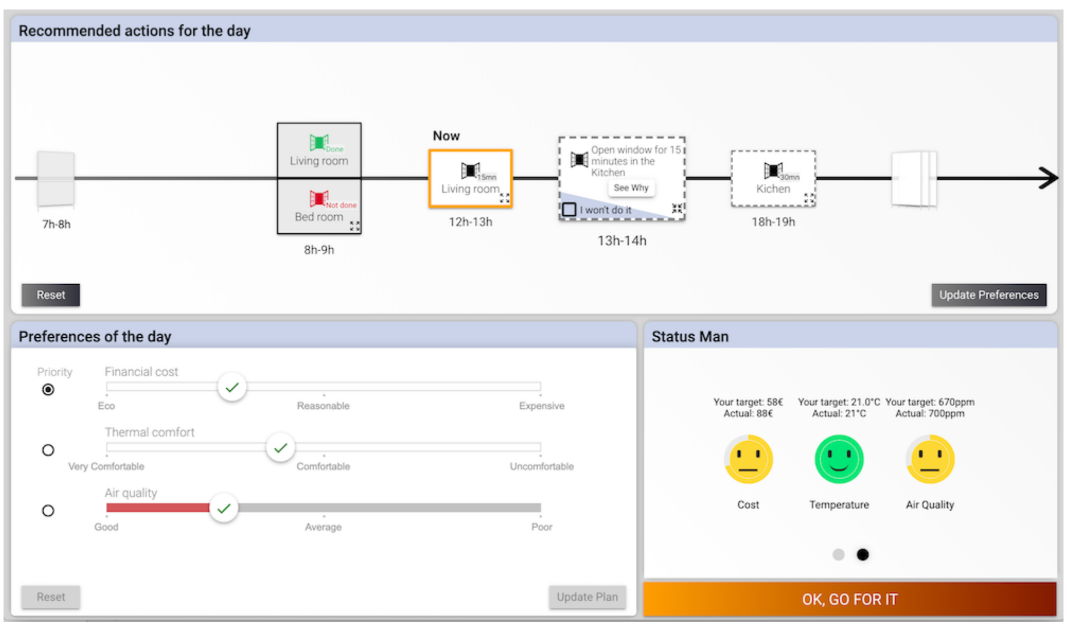
The following sequence of screenshots explains more about the functioning of the prototype which we utilized for the experiment.



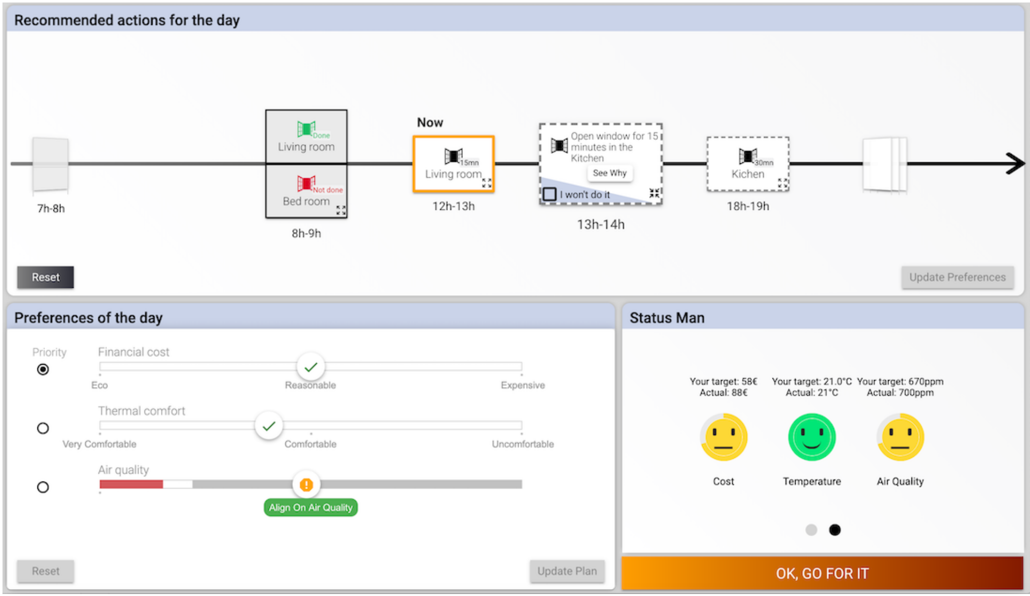
#1. The initial screen. Three components are presented: Recommended actions for the day; Preferences of the day and Status Man. We are at noon, the e-coach displayed the action plan in order to achieve the defined preferences.



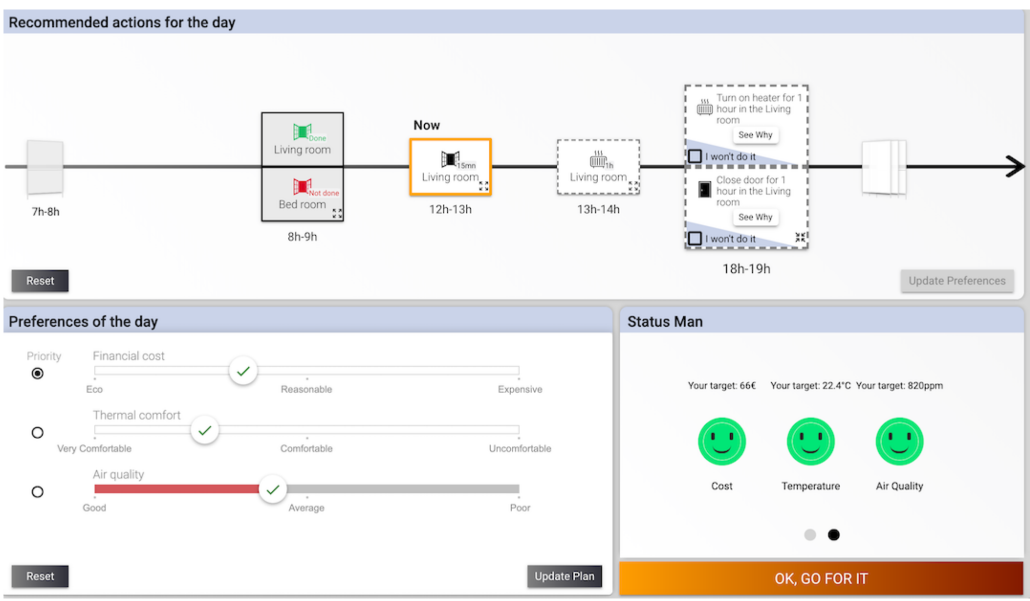
#2 The user declared that he/she cannot do the actions at 13-14h and 18-19h timeslots. The system shows direct impact on the Status Man.



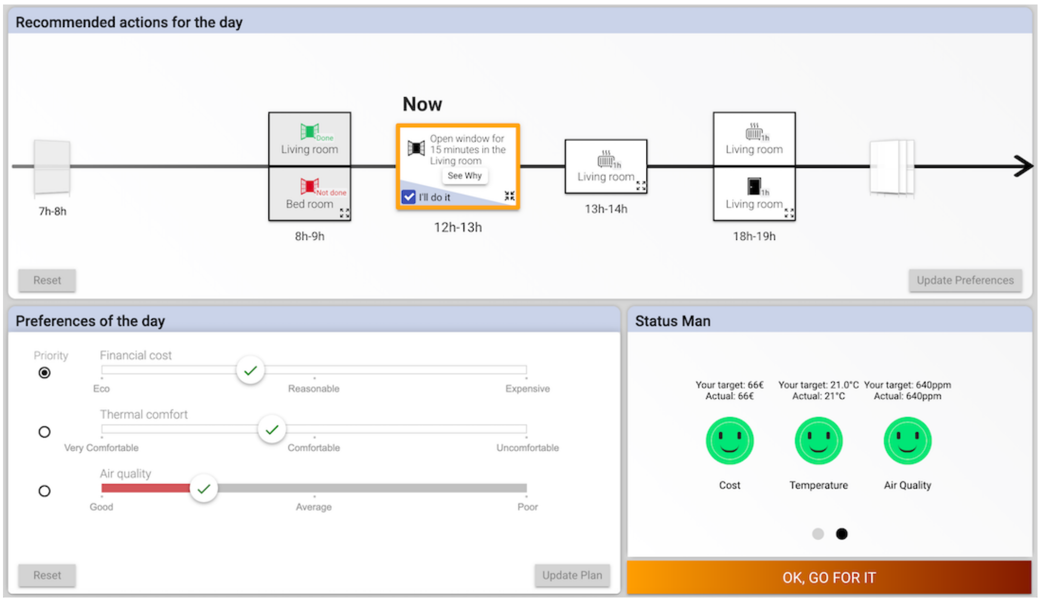
#3 The detailed view of the Status Man presents each criterion separately. The view shows the impacts of missing actions via its color-coded and progress bar values (both visual and numeric). The button "Update preferences" is enabled, indicating that the user can update his/her preferences based on this current plan.



#4. The user clicked on "Update Preferences", the sliders are automatically moved to the values which correspond to current action plan. The user can either accept this plan/preference or continue to explore more the solutions space.



#5. The user is not satisfied with current preference. Using the Sliders4DM, the user found another compromise in terms of cost, thermal comfort and air quality. He/she click on "Update Plan" to get the action plan associated with the preference he/she has just set.



#6. The e-coach took into account the new set of preferences and propose a new action plan. The user can continue to interact with the system to find the suitable set of action plan/preferences trade-offs. Once the compromise is set, the user can click on "Go for it" to valid his/her choice.

8.3. SUS questionnaire

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this website frequently.	☐	☐	☐	☐	☐
2.	I found this website unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this website was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this website.	☐	☐	☐	☐	☐
5.	I found the various functions in this website were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this website.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this website very quickly.	☐	☐	☐	☐	☐
8.	I found this website very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this website.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this website.	☐	☐	☐	☐	☐