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# Use-phase memory: a tool for the sustainable construction and renovation of residential buildings

Lucile Picon<sup>a,b</sup>, Bernard Yannou<sup>a,1</sup>, Toufic Zaraket<sup>a</sup>, Stéphanie Minel<sup>a,c</sup>, Gwenola Bertoluci<sup>a,d</sup>, François Cluzel<sup>a</sup>, Romain Farel<sup>a</sup>

<sup>a</sup> Ecole Centrale Paris, Laboratoire Genie Industriel, Grande Voie des Vignes, 92290 Chatenay-Malabry, France

<sup>b</sup> Ecole Nationale Supérieure de Création Industrielle, 48 rue Saint Sabin, 75011 Paris, France

<sup>c</sup> Ecole Supérieure des Technologies Industrielles Avancées, Technopole Izarbel, 64210 Bidart, France

<sup>d</sup> AgroParisTech, 1 avenue des Olympiades, 91744 Massy Cedex, France

[lucile.picon@gmail.com](mailto:lucile.picon@gmail.com), [bernard.yannou@ecp.fr](mailto:bernard.yannou@ecp.fr), [toufic.zaraket@ecp.fr](mailto:toufic.zaraket@ecp.fr), [s.minel@estia.fr](mailto:s.minel@estia.fr),  
[gwenola.bertoluci@agroparistech.fr](mailto:gwenola.bertoluci@agroparistech.fr), [francois.cluzel@ecp.fr](mailto:francois.cluzel@ecp.fr), [romain.farel@ecp.fr](mailto:romain.farel@ecp.fr)

## Abstract

Residents' usages and behavior play a determining role in the variability of the energy consumption and environmental impact of residential buildings during their use-phase. At present, however, they are inadequately documented and understood, as well as being highly variable. In this paper, we propose a use-phase memory model for residential buildings, whose aim is to store energy consumption and usage patterns. This storage can be done automatically or voluntarily. We give examples of useful information extracted from the data captured. The objective of this data analysis and synthesis is to provide building experts two specific use-cases: designing a new sustainable building, and renovating an existing one. Our model is deployed on a residential building, integrating the beneficial services for all stakeholders to demonstrate a sustainable relationship between designers, the residential building and the users.

## Keywords

Use-phase memory, environmental impact, user behavior, built environment, design tools

## Introduction

The residential sector is a major energy consumer, accounting for an average of 30% of total national energy consumption worldwide (Hoes et al., 2009; Masoso and Grobler, 2010; Saidur et al., 2007). In France, ADEME (Agency for environment and energy saving) reported that the building sector consumes 43% of total energy consumption and ejects more than 24% of national CO<sub>2</sub> emissions every year (ADEME, 2011). The statistics show that this sector consumes and pollutes more than industry (22% energy) or transport sectors (32% energy). Reducing and controlling energy consumption and environmental impacts of buildings is thus a critical challenge for governments and building experts. Sustainable development in buildings has been developed along several avenues: for example, the eco-design domain introduces an environmental dimension in product design in order to make products and services more environmentally friendly throughout their life cycle. One of the main steps of an eco-design is to model the life cycle of existing products - for example through Life Cycle Analysis (LCA) - to identify where meaningful improvements could be implemented. This approach clearly concerns residential buildings.

Recently, the French authorities have established a number of standards and regulations to enforce national commitments regarding greenhouse gas reduction. The latest French thermal regulation (TR 2012) defines building performance norms, especially heating and cooling consumption bounds in tertiary and private buildings. This regulation is an ambitious step towards promoting green buildings,

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<sup>1</sup> Corresponding author

since it plans to reduce by two-thirds the energy consumption of new buildings starting from the end of year 2012. It recommends the limitation of energy consumption for five specific end-uses: space heating, space cooling, domestic hot water, lighting, and ventilation and auxiliary equipment (Molle *et al.*, 2011). Constructors can achieve this energy reduction only by integrating renewable energies such as water-heating solar systems, and by optimizing aspects such as orientation, solar heat gains, day lighting, thermal insulation level, inertia, and compactness.

In general, the performance of a building is governed by various parameters, such as its physical characteristics (e.g. type and surface area), its internal service systems and equipment, and its external environment (e.g. solar radiation, wind velocity). The most important factor is however occupant behavior and activities (Pachauri, 2004; Page *et al.*, 2008; Yu *et al.*, 2011). This is rather complex to look into, because resident usages and behavior vary widely and are far from being satisfactorily known and understood.

Alternatively, the influence of appliances on energy consumption of buildings and environmental impact is clearly negative. For instance, National Resources Defense Council indicated in 2007 that a new high-definition set-top box and its attached television consume more energy per year than a refrigerator, while the US Department of Energy underlined in 2011 that the number of appliances had increased tremendously.

The tendency towards constructing low-consuming and nearly zero-energy buildings is pushing the design phase to become more and more sensitive to consumption characteristics. Moreover, a so-called “performance contract”, which is a performance commitment between building constructors and owners, is a new market expectation emerging in France. By this contract, constructors commit to deliver an eco-efficient building and to guarantee this performance threshold for a certain number of years after handover. For this reason, they devote considerable effort to finding tools, techniques and approaches that will enable them to better understand and interpret complex usage phenomena of buildings.

Current works fall into two categories: first, energy modeling and simulation tools such as eQuest or EnergyPlus which are designed to predict energy consumption for the use-phase of a building. The main drawback of these tools is always related to occupants' fuzzy behaviors, whose unpredictability leads to inaccurate and unreliable energy estimates. The latter typically deviate by more than 30 percent from real energy consumption levels (Soebarto and Williamson, 2001), and this variability can reach as much as 150 percent in some cases (Clevenger and Haymaker, 2006). Moreover, simulation tools can only imitate human behavior patterns in a rigid way (Yu *et al.*, 2011a).

In the second category, research studies have been developed to give a precise estimate of energy usage in buildings, basically through applying average behaviors for people (Muratori, 2012; Richardson *et al.*, 2009; Shimoda *et al.*, 2004; Wang *et al.*, 2005; Widén *et al.*, 2009). While a remarkable evolution has been witnessed in the assessment of energy-related behaviors of buildings, no notable work is established to better assess building usage as a whole, nor to communicate this knowledge to concerned actors. Some research (eg Shen *et al.*, 2012) aims at developing tools to make communication easier between designers and building users. Thanks to such tools, users understand design better and their feedback can be collected.

In summary, we perceive an increasing need to know more about the way people transform, renew or degrade their equipment and appliances, which in turn influences the resulting energy eco-efficiency, equipment life duration and environmental impact. Building experts such as engineers and architects would benefit from a better understanding of users' needs. This knowledge would be useful when redesigning a sustainable construction as well as renovating an existing one. This information can comprise different types of data collected in real situations: quantities of energy and resource consumption and any unexpected usages and patterns of behavior, which may lead to inquiries into

reasons and causes of unexpected and unpredictable building performance variability. Data should then be interpreted and any unexpected information extracted from a use-phase memory. Concurrently, building users, such as residents, building administrator and employees, would benefit in getting feedback to improve their usages, tasks and quality of everyday life. The establishment of links between building users, building experts and residential building lifespan is essential for more sustainable building designs and renovations. In addition, a clearer understanding of detailed usage trends in residential buildings enables decision-makers to apply energy conservation procedures, to implement advanced environmentally-friendly technologies and to propose appropriate and targeted incentives. This is why we propose in this paper a use-phase memory model for application to residential buildings; this model will store throughout the building's lifetime any information that can be useful for both construction firms and residential stakeholders.

In the first section, we present a literature review concerning usages and appliance influence for variability in the environmental impacts of products (section 1.1). In section 1.2, we extend this study to the methods and tools used to understand usages and their underlying reasons, focusing on the case of buildings. Then, we study the transmission of knowledge using storytelling tools in section 1.3 and, in section 1.4, we consider several types of memory developed by companies. Finally, we explore different ways of supporting relationships between companies and the end-users of their products and/or services (section 1.5). In section two, we present the main aim and beneficial services of our model of use-phase memory of residential building, outlining a model for a sustainable relationship between building experts, the residential building and its users. We conclude by demonstrating the potential of use-phase memory for building experts. Some usage scenarios are shown, either by automatic analysis of the use-phase memory or at the request of building experts. We illustrate how useful information can be obtained in these two use-cases for the purpose of the design of a new sustainable building, or the renovation of an existing one.

## 1. Review of literature

Our literature review is presented in five parts. The first evokes the influence of users and their behaviors on product performance. The second focuses on building energy consumption and environmental performance and how they are influenced by user behavior. The third looks at the theories, methods and tools developed for prediction of these usages and the ways in which end-users handle, use and adapt products to satisfy their needs. Storytelling is a tool for facilitating communication of knowledge and experiences, enabling us to look into the potential benefit in the case of building study. The fourth part deals with the existing types of memory developed by companies and their key factors of usefulness. And finally, we evoke the relationships between a company and its customers and the benefits for companies by integrating customers' experience and knowledge into their activities.

### 1.1 Influence of usages and appliances on the variability of product performance

During the life cycle of a product, energy and materials are consumed and waste is generated. Designers are supposed to control and to reduce the environmental impacts of a given product during both its manufacturing process and its end-of-life phase. Even so, the life cycle of a product is not limited to these two steps. Telenko *et al.* (2012) underline the fact that for many products "*the environmental impacts during use can be more significant than manufacturing and end-of-life impacts.*" The authors quote very different products which share this problem: an example is automobiles, for which more than 60% of the total energy consumption is realized during the use-phase. Nevertheless, this assessment is also noticed for less complex products. Telenko *et al.* (2010) analyze three kettles and conclude that the utilization stage impacts, in terms of energy, are more substantial than the kettle's environmental impacts.

## **The case of buildings**

### **1. Performance determinants in domestic environments**

Various factors play a role in determining the global performance of buildings concerning energy, water, waste and other environmental issues. Demanuele et al. (2010) declare that the performance of a building in general is influenced by several factors manifesting themselves from design stage through construction and use. They give examples such as simplifications in energy-models, commissioning and maintenance techniques used, or the arbitrary behaviors of occupants during the use phase. Other authors detailed the determinants of energy consumption of buildings (Lutzenhiser and Bender, 2008; McLoughlin et al., 2012; Santamouris et al., 2007; Yu et al., 2011). Yun et al divide these determinants into seven categories: climate (e.g outdoor temperature, solar radiation and wind velocity), building-related characteristics (e.g. type, area and orientation), user-related characteristics (occupants presence), building services system and operation (e.g space cooling, heating and hot water supplying), occupant behavior and activities, social and economic factors (e.g education level and energy cost), and finally indoor environmental quality required by building users (Yu et al., 2011). Lutzenhiser and Bender reveal major key variables such as household income and education, family size and age, dwelling type and surface area. Significant correlations have been identified between all these factors, making it complicated to have a clear understanding of buildings'energy-behavior determinants (Morley and Hazas, 2011; Santamouris et al., 2007; Yun and Steemers, 2011)

### **2. Energy usage in domestic environments**

Several studies found in the literature investigate energy usage trends in domestic buildings. All of these studies agree that energy-related behavior is considered to be the most complex process taking place within a building. These behaviors are not only due to the presence of occupants in their dwellings (e.g. internal heat gains, emission of pollutants), but also to their activities inside them. (Ellegård and Palm, 2011) confirm that energy use is embedded in most aspects of daily life. Several studies present the energy-related activities that residents undertake in their domestic environments (Chiou, 2009; Muratori, 2012; Tanimoto et al., 2008). People perform daily living activities such as sleeping, cooking, eating and washing. They also control the operation of inherent building systems (e.g. HVAC and lighting) to attain their indoor environmental comfort (Page et al., 2008; Robinson, 2006). These interactions have important implications on a building's energy balance and environmental impact. (Robinson, 2006) identifies a number of these interactions such as window and door opening, use of lighting appliances, use of electric appliances, and controlling heating and cooling systems. The way these interactions are undertaken depends on the habits and lifestyle of occupants, as well as the characteristics of the building and the surrounding environment.

Another key factor influencing a building's eco-efficiency and the energy usage within it is related to appliances. The latter could already be integrated in the building by the constructor, or could be added later on by the residents. Borg *et al.* (2011) demonstrate the effect of energy efficiency on domestic electric appliances. According to them, it is possible to reduce the energy consumption of electronic appliances by 30%, and the energy consumption of lighting by 50%, through appliance energy efficiency measures. They underline stand-by consumption as an increasing problem.

Zaraket *et al.* (2012) also study the combination of usage and domestic lighting appliances on energy consumption. Their results show that energy consumption is influenced by three factors: the presence of the occupant at home, the domestic activities and corresponding usages, and the types of lighting appliances. They have measured that between two similar apartments, energy consumption may be 5 times greater simply due to the number of bulbs and the type of technology used.

In 2002, this problem was also highlighted in a report by EnerTech (2002) on the assessment of potential electricity savings in European households, since the use of stand-by on appliances accounts on average for 11.5% of the total electricity consumption of households.

These studies demonstrate that the energy consumption and environmental impacts of products are deeply influenced by characteristics of product utilization and, beyond, by the purchasing choice people make more or less consciously. That is why, in order to reduce the variability of residential buildings' environmental impacts, it is essential to understand residents' usage trends and to make an inventory of appliances owned and used by them.

## 1.2 User behavior: Better understanding the reasons

In order to have a clear image about how users perceive, judge, reason and decide when performing a certain behavior, we present in this section some of the theories whose objective is to assess human behavior and its complex structure.

### 1. Human behavior: cognitive and behavioral theories

These theories stem from disciplines such as sociology, psychology, ergonomics and anthropology. Theories such as the *theory of reasoned action*, the *theory of planned behavior* and the *activity theory* are well-known in this domain.

The *theory of planned behavior* (TPB) describes the factors that determine an individual's decision to follow a particular course of behavior. This theory is itself an extension of the widely applied theory of reasoned action (Ajzen, 1991). TPB proposes that the proximal determinants of behavior are *intention to engage* in that behavior and *perceptions of control* over that behavior. Intentions represent a person's motivation in the sense of his/her conscious plan or decision to exert effort to perform the behavior. Perceived behavioral control is a person's expectancy that performance of the behavior is within his/her control. Control is seen as a continuum with easily executed behaviors at one end and behavioral goals demanding resources, opportunities, and specialized skills at the other. Intention is itself determined by three sets of factors: attitudes, which are the overall evaluations of the behavior by the individual; subjective norms, which consist of a person's beliefs about whether significant others think he/she should engage in the behavior; and perceived behavioral control, which is the individual's perception of the extent to which performance of the behavior is easy or difficult (see Figure 1)

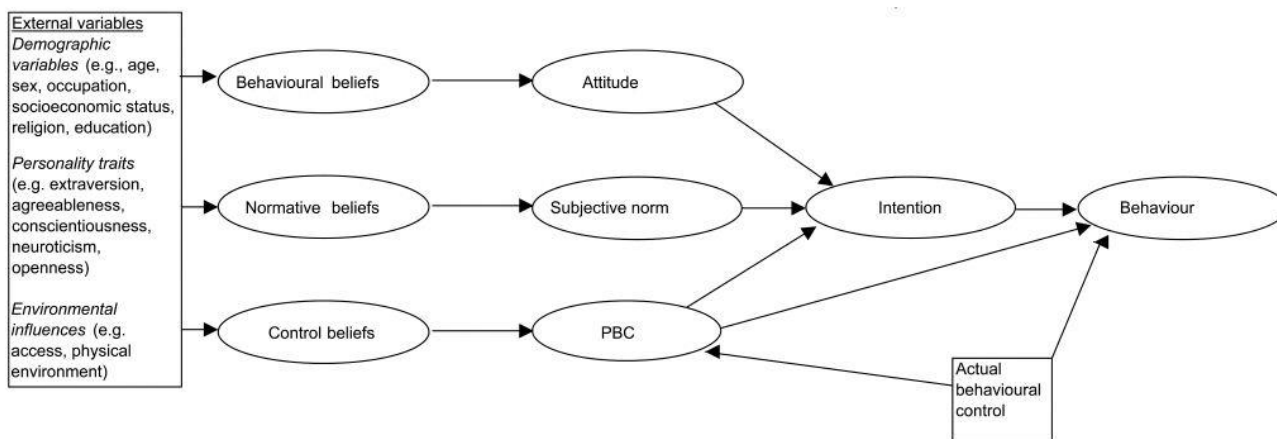


Figure 1. Theory of planned behavior [Excerpt from (Conner and Norman, 2005)]

*Activity theory* is another paradigm describing human behavior from a socio-cultural perspective (Kaptelinin, 2012). The foundational concept of the framework is “activity”, which is understood as purposeful, transformative, and developing interaction between actors (subjects) and the world (objects). Psychologists such as (Leontiev, 1981; Rubinshtein, 1946; Vygotsky, 1978) define human behavior using a three-layer model comprising activities, actions and operations. Complex relationships between motives (i.e., what motivates the activity) and goals (i.e., what directs the activity) is a characteristic feature of humans.

Different usages within a building are the result of certain human behaviors. The above theories

present potential to assess human behavior and the complex phenomena influencing it. They can help us explore and comprehend such usages. This will be a focal point in developing a tool which offers functions from the collection of data to the dynamic interaction between different users and stakeholders of a building

## **2. Usages and user behavior in the design of products/services**

Some causes lead designers to analyze existing usages and patterns of behavior; examples include the increase in end-user satisfaction, innovative product and/or service design, the probability of misuse and the reduction of unsustainable usage.

To understand usages, designers often apply a User Centered Research approach. Lilley *et al.* (2005) define User Centered Research as “*the process of gaining information about practices, habits or behaviors in order to inform the design of a product, service or system.*” The authors describe a pilot study on mobile phone usages based on a user diary and questionnaire. Study results demonstrate that these tools, user diary and questionnaire, do not allow designers to understand reasons for particular usage, but they give more information about practices, problems and needs of users. Lofthouse *et al.* (2006) present a range of other techniques, also based on a User Centered Research approach, which can help designers to better understand the end-users of their products and/or services. For instance, a Scenario of Use aims at identifying unexpected needs using role-play. This tool provides designers with verbatim and unsatisfied needs in existing markets. The authors also describe the Product in Use method, which allows designers to record what people really do, not what people say they do. The key requirement is to conceal the problem under study so as to record natural usages and patterns of behavior. Subsequently, after people have given their permission, a research team films some activities, usages and behaviors to highlight points of interest contingent on the problem being studied. Using this method, designers discover misuse of products and ways in which end-users adapt products to better satisfy their needs. A residential building, like a social building, is a complex system, and reducing energy depends on design choices as well as current user behaviors (see Lilley *et al.*, 2010).

## **3. Modeling and predicting energy usage in residential buildings**

As mentioned earlier, building experts rely on different simulation tools to predict the energy performance of buildings in the design phase. However, large deviations are still recorded between predicted and real values. This deviation can be mainly attributed to that fact that these modeling techniques account for building occupants as static elements with constant energy use characteristics and predefined usage scenarios. The term ‘occupant’s energy use characteristics’ is defined as the presence of people in the premises and the actions they perform (or do not perform) to control their indoor environmental conditions such as internal air quality, thermal comfort, visual comfort, etc. (Hoes *et al.*, 2009). Yu *et al.* (2011, a) confirm that “current simulation tools can only imitate human behavior patterns in a rigid way”.

For this reason, there is a growing need to establish more precise methods to predict occupants’ energy-related behaviors. Several research studies try to understand, analyze, model and predict these complex behaviors. Some studies focus on modeling only occupants presence (Wang *et al.*, 2005; Yamaguchi *et al.*, 2003), others on lighting control (Newsham *et al.*, 1995; Reinhart, 2004; Richardson *et al.*, 2009; Widén *et al.*, 2009), or HVAC systems (Saelens *et al.*, 2011; Schweiker and Shukuya, 2009), while others tackle the issue of domestic appliances (Firth *et al.*, 2008; Page *et al.*, 2007). A number of authors (Muratori, 2012; Page *et al.*, 2007; Robinson *et al.*, 2007; Shimoda *et al.*, 2004) modeled the totality of energy consumption end uses in a building.

Even though such models offer good representations of the energy consumption of buildings, they still fail to take into account some important points related to human behavior. Knowing that an individual’s actions are frequently the result of a decision-making process, it is important to take into account the socio-psychological process which influences the energy consumption trends of occupants. It is essential to consider these complex aspects - perception, memory, planning, cognition, emotions,

and decision-making - when we talk about human behavior. However, these facets of behavior are still not sufficiently integrated in the scope of energy usage of buildings due to the complexity required in their modeling. This issue has been tackled by several studies which aimed at developing so called *integrated models* (Barr et al., 2005; Van Raaij and Verhallen, 1983; Weber and Perrels, 2000). These models adopted approaches comprising aspects from different disciplines such as engineering, economics, sociology, anthropology, and psychology. In spite of their importance, integrated frameworks have yet to spark a significant debate within the literature about how they can be structured and implemented.

So far, no notable work has been established to better assess building usages as a whole, or to communicate this knowledge to concerned actors. Shen *et al.* (2012) develop an interactive platform to facilitate communication between designers and building users by means of a realistic 3D representation of the building. This tool allows building users to improve their understanding of the design, help them to specify their activities in the new building and increase their involvement in communication with designers. In that way, designers can realize pre-occupancy evaluation and collect building users' feedback on the design.

These methods and tools show the difficulties and problems in gaining access to significant information which will allow interpretation of existing usages and patterns of behavior, and they also allow designers to note unexpected needs. The methods of observing and collecting data and information obviously influence the results obtained. Consequently, suitable methods and tools for implementing data gathering need to be identified. These methods and tools must not be intrusive, because we need to gather people's true behavior and their usages.

### 1.3 Transmission of knowledge via storytelling

Storytelling is the fact of telling stories. It is often used by marketing and advertising to facilitate communication of the message between the authors and their audience, or by designers to capture users' narratives and use them for insights into how to innovate.

Denning (2000) was the first to theorize storytelling as a way for people to tell what they live, their habits, their expectations in a way that appears natural for everyone "*Storytelling is an activity that is practiced incessantly by everyone. It is so pervasive that it has almost become invisible. We are like fish swimming in a sea of narratives*". Storytelling may be used to collect expectations, needs and usages because it allows one to storyboard oneself, to feel like an actor of a process rather than someone being passively interviewed. Swap *et al.* (2001) claim that "*because stories are more vivid, engaging, entertaining and easily related to personnel experience than rules or directives... (they) would be given more weight, and be more likely to guide behavior... they are ideal carriers of tacit knowledge (although what is ultimately encoded by the listener may not correspond closely to the intentions of the storyteller)*". Escalfoni *et al.* (2011) use storytelling as a means to transfer knowledge to an organization and as a tool for innovation. They develop a method for capturing innovation features and allowing a company to reuse them in the future. Participants of a past project are invited to tell stories about their experiences, the characteristics of the project, and difficulties encountered. Specific events, facts and topics are selected and discussed among participants. The authors explain that the narrative of stories is a natural form to pass knowledge between people, groups and organizations, as well as being a way of making public tacit knowledge and expressing unconscious experiences. To support their proposal, they develop a web-based collaborative prototype used by participants: whatever their location, they can tell stories, answer pre-established questionnaires on their experience during the project, or discuss a specific topic. Their results demonstrate that the collective story about a project, told by all participants two years later, contains more valuable information than the official report generated at the time of the project. Bran (2010) shares storytelling's positive contribution to communicate through a personal voice. The author analyses 78 digital stories created by first year students in journalism. She notices by incorporating images, audio



narration, video clips, music, etc., that the students relate an expressive story. These different kinds of media elements help the students to express themselves and to choose a medium depending on the type of information that they would like to express.

Narration seems appropriate to convey a fact, an event, or an experience including some tacit data and knowledge. Applied in a collaborative context, storytelling can be a way of creating a meaningful memory of a residential building. Each person who has taken part in the lifetime of a building, possesses experience, information and knowledge, all of which are very useful when combined. Similarly, Kankainen *et al.* (2012) propose using storytelling in a group as a co-design method for service design. This is what is also proposed in this paper for conveying the non-quantitative information about consumption and usages in buildings. Of course, other techniques exist to elicit issues and needs in a group of users, such as the Delphi method, focus groups and expert workshops. In the present situation, storytelling of volunteers is the most appropriate because usages concern the behavior of particular persons in a community; more participative methods like focus groups are less adapted since residents must feel free of the influence of their neighbors and of the building administrator.

#### 1.4 Recording data, information and knowledge

The knowledge of an organization and its sharing are important for developing innovation, which is a way to improve the quality of products and services, identifying new activities and business opportunities (Escalfoni *et al.*, 2011). Indeed, knowledge, collected, developed or created by an organization is a very useful capital (economic, technical, or cultural) which can help maintain a competitive advantage. That is why its conservation is essential for their future.

Different types of memory are developed by organizations. Dieng *et al.* (1998) quote Tourtier (1995), who defines four typologies of corporate memory: company memory, profession memory, individual memory and project memory. Grundstein and Barthès (1996), also quoted by Dieng *et al.* (1998), underline two typologies: technical company knowledge, for daily use, and strategic corporate knowledge, for strategic use by the company managers. Lastly, Dieng *et al.* (1998) complete these definitions by distinguishing between internal memory, knowledge and information used and produced by a company, and external memory, which is knowledge and information useful for the company and stemming from the external environment. But it is not always easy to define knowledge. It may take the form of data, information, results, or know-how, because of its dependence on sources: people, profession, activity and memory end-use. Firestone (2001) quotes Davenport (1994) who defines Knowledge Management as “Processes of capturing, distributing, and effectively using knowledge.” As expressed by Davenport, the main aim is to reuse knowledge for activity improvement, new knowledge development, and avoid past mistakes. The concept of memory does not just concern data storage. After identifying company needs, Dieng *et al.* (1998) define several steps to develop a corporate memory such as the construction of the memory, its diffusion, its use, evaluation, maintenance and evolution. Matta *et al.* (1999) identify other steps to develop a project memory such as the identification of the sources of data, the construction of the memory and the means of access to the memory. These methods are different because corporate memory is large scale, whereas project memory focuses on specific company tasks. In these two cases, organization of use of memory and its sharing appear to be essential. Chang *et al.* (2008) point out that the mere storage of data, information and knowledge in memory is not sufficient: it must effectively be shared (cf Jared *et al.*, 2011).

Different kinds of memory exist and they are developed by organizations to preserve their knowledge and to reuse it in the future. Nevertheless, we do not find any reference in the literature of an existing memory of product or service in use, including at the same time end-user satisfaction, problems encountered, and the ways people use, handle, and/or adapt a product or service. Building product

and/or service memory may be a way of understanding how they are used, how people adapt them to better satisfy their needs and how products are damaged in the course of time. It may be useful to identify insights allowing improvement of these products, services, or complex systems such as a residential building. The link between memory and time is important for our work because of residents' usages and behavior, and their consequences, change, evolutions, updates and interactions over time.

### 1.5 Existing relationships with end-users

Though centralized data and information about a product or service in use are difficult to find in the literature, companies possess a great deal of information on customers, because customer satisfaction is one of the keys to their success.

To succeed in establishing a long-term relationship with their customers, companies use Customer Relationship Management (CRM). Zablah *et al.* (2004) identify five dominant perspectives. CRM is defined as a process to develop and to maintain relationships with external marketplace entities and end-users. It is a strategy identifying valuable customers for the company and a philosophy to retain customers by satisfying their needs. CRM also gives a company the capability to adapt supply depending on customer demand and a technology allowing management and circulation of information about sales, marketing, and customers. Sigala (2005) points out a link between CRM and Relationship Marketing. The author explains that customer communication channels support the identification of profitable customers, the differentiation of product or service to other existing product or service, the interaction with individual customers and the personalization of customers' experiences. CRM appears to be a tool to circulate and to manage data, information and knowledge about customers as underlined by Gibbert *et al.* (2002). The authors distinguish CRM from Customer Knowledge Management (CKM), the latter being customers' knowledge such as their experiences, habits, or activities. Knowing customers needs and tastes is a good way to satisfy them. However, understanding customers, their needs, their ways of using and transforming a product and/or service, is a strategic key to innovate. The authors demonstrate the potential of customers' knowledge with the examples of Amazon.com and Holcim, an international cement company. They developed collaborative platforms motivating customers and users of their products and services to share their knowledge and point of view. These platforms appear to be highly appreciated by customers. Gibbert *et al.* (2002) define CKM as "*a continuous strategic process by which companies enable their customers to move from passive information sources and recipients of products and services to empowered knowledge partners.*"

These existing relationships with end-users such as CRM linked to Relationship Management and CKM highlight the different roles played by customers. Often considered as passive sources of information, customers become valuable partners when their knowledge and experiences are integrated into the company's activity. This last point, considering CKM as a continuous process allowing end-users to be active and to become valuable partners, is essential for our model of use-phase of residential building.

## 2. Model of use-phase memory for residential buildings for future sustainable constructions and renovations

We propose a system for collecting and storing useful information during a residential building's lifetime that will allow building experts to gain insight to renovate this building or to design a new more sustainable and usage-oriented one. But this system cannot be sustainable without building users' collaboration and motivation. Consequently, one of the issues we consider is the identification of building users' involvement. What is their motivation, interest or benefit in conveying private

experience and knowledge to building experts?

## 2.1 Concept and objectives

Our proposition consists of a system which collects and stores different data such as energy consumption, resource consumption, residents' usages and behaviors. Useful information can then be extracted, assisting building experts in the design of sustainable buildings or the renovation of existing ones. The design of a new sustainable building requires access to general information about levels of consumption, waste, usages, and behaviors. The aim is to obtain insight and to create new solutions based not on supposed reality, but on tangible reality. During the renovation of an existing building, the main requirement concerns the resolution of building issues/problems. Time is gained because some important information about the building is centralized in its use-phase memory.

Building constructors and owners define a set of design specifications for each of their buildings. They modify these specifications according to the type of the building, the residential zone, and the socio-economic characteristics of its future users. This is achieved by relying on their past experience or on information coming from surveys conducted in the residential zone. However, until now no intelligent tool has been developed or used for providing such information. These arguments are confirmed by building experts met in the scope of a project dedicated to improving performances of residential buildings in France. Architects, designers, site engineers, building administrators, occupants and guardians acknowledged the potential advantages of having an intelligent system which performs all these functions from the collection of data to the dynamic interaction between different users and stakeholders of a building.

A well-known French construction firm has already started installing some tools in their newly constructed green buildings. For example, occupants of 54 social housing units delivered in 2012 in a suburb of Paris have access to a touch screen tablet which measures and monitors consumption of space heating, hot water and electricity. The installation of the instrument is included in a global offer which also involves technical maintenance of the building for several years. The screens in the apartments can be enriched by a range of services (e.g. weather forecasts, public transport timetables), depending on the needs and demands of tenants and landlords. These tablets are used for two main objectives: (1) to provide real-time information for occupants about their energy consumption levels (heating and hot water) and (2) to supply building owners and constructors with large data sets of energy consumption.

It should be noted, however, that such tools do not provide detailed consumption information per end-use. Occupants are only informed about their temperature setting-point and their hot water consumption through a simple graphic interface (Smiley's). The apparatus is limited in this case, as in France, service fees paid by social housing tenants are determined by the building owner as a function of the type, area and floor of the dwelling. As a result, building owners avoid delivering detailed consumption information to occupants so as to avoid conflicts. For ethical and social reasons, tenants could claim a reimbursement if they have lower consumption levels than others.

As mentioned above, to succeed in providing relevant information during the use-phase memory, we need real and lasting involvement of building users. As they live in the residential building, working on-site, or acting as an intermediary between the residential building and its residents, they can provide some very useful information. Consequently, we develop profitable services for each building user in exchange for their collaboration and motivation.

The building administrator may be interested in getting general information on energy and resource consumption and costly and/or frequent problems of the residential building. This "general building health" assists the building administrator with the daily tasks of improving the quality of life in the residential building and controlling the state of the building over the course of time. As the building administrator hires the building employees, input into the use-phase memory could also be included in their tasks. It cannot however be an obligation for the residents. Would it be possible to reward

residents' involvement for their input on their everyday life in the building and in their accommodation? How could they be rewarded? What could their motivations, interests or benefits be? Karjalainen (2011) studies resident preferences for feedback on household energy consumption. The results of his study reveal that *“some consumers are very interested in saving household electricity”*. Residents are also interested in understanding detailed costs of their energy bills, and would like to identify the appliances that consume the most energy, including their ability to chart efficiency improvements over time. We propose to obtain residents' detailed electricity bills in exchange for their collaboration. For instance, a family feeds the building's memory with information on events in the residential building, their satisfaction and dissatisfaction, or problems encountered. Afterwards, they obtain a monthly electricity bill with a break-down of costs per appliance across time. They can start to identify potential expenditure reductions by themselves. Next, if residents are interested in continuing the collaboration, a customized diagnostic can be undertaken with the aid of an adviser, appointed by the building administrator or a private company. This customized diagnostic helps to find causes of problems, such as old or faulty appliances, excessive use, or misuse of appliances. Each stakeholder is thus satisfied. The building experts obtain more detailed data and information on energy and resource consumption, residents' usages, needs, activities and misuses. It helps them to understand these usages and patterns of behavior, and so obtain insights on solutions for improving and/or satisfying these needs, misuses and patterns of behavior. In exchange for their collaboration and motivation, the building administrator is assisted in controlling the state of the building over the course of time, and residents are helped to reduce their energy spending. Of course, the details of a precise business model remain to be developed, but the technical and motivational principles have been explained. We illustrate the concept of our proposition and established relationships between stakeholders in figure 1.

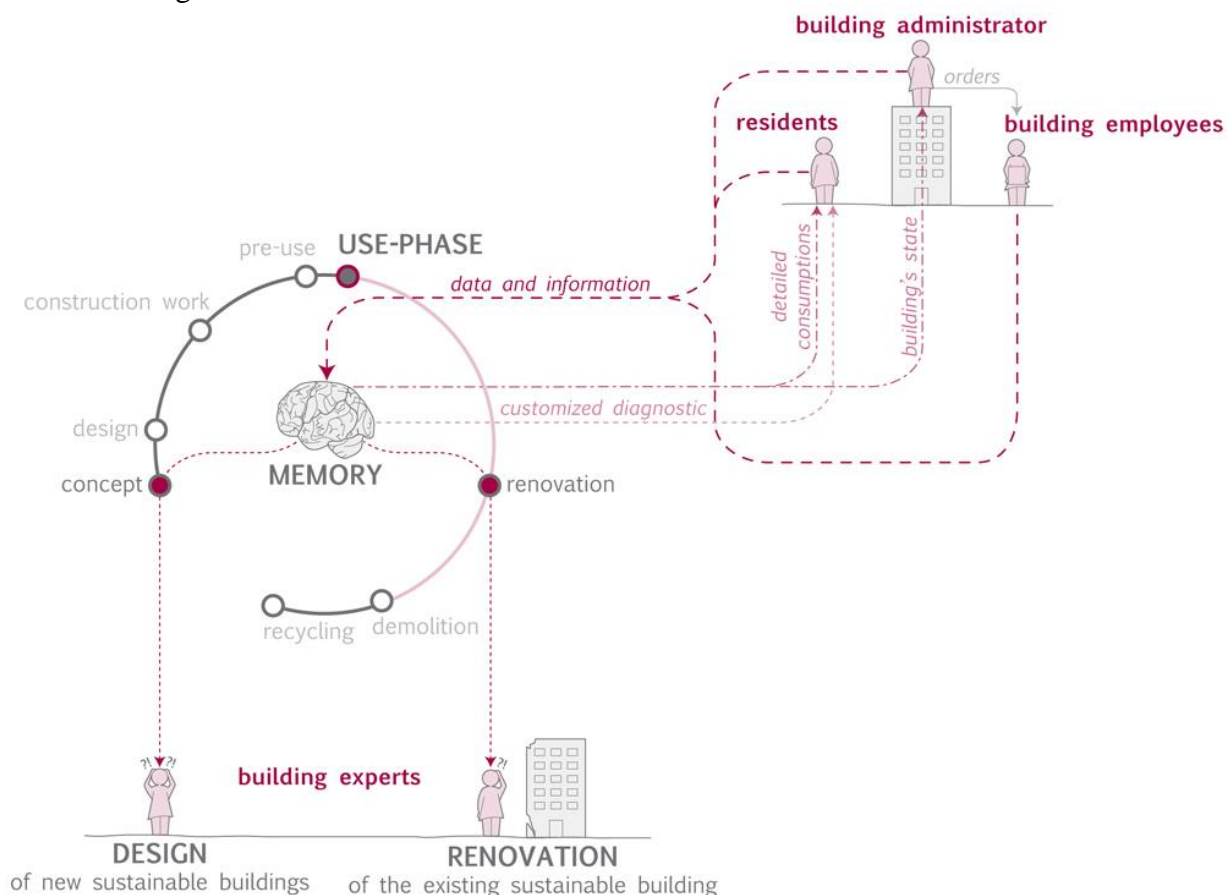


Figure 1: Use-phase memory of residential building and established relationships with stakeholders

## 2.2 Methodology

Our design and structure of use-phase memory is based on Dieng *et al.* (1998) and Matta *et al.* (1999). Of the three steps - gathering, storage and reuse - we focus on the input stage (gathering) and on the output stage (reuse).

Several issues need to be dealt with: what data to collect, how to collect the data, what tools should be used for the input stage, how this information should be consulted, and how useful information should be extracted.

Our model is made up of three main elements: data gathering, means of accessing the use-phase memory, and useful information and knowledge retrieval for building experts, building administrators and residents. It is to the detailed steps of these three elements that we now turn.

### 2.2.1 Data gathering

The main issues are what data to collect, and how to collect it. This information is outlined in table 1.

Based on Escalfoni *et al.*'s (2011) classification for story fragments - descriptions, background and facts- we identify four kinds of information fragments: subject (what), characteristics (how, why and detailed what), measures (how many and how much) and background (when, where). *Subject* refers to related facts such as *electricity consumption, events, successes, or problems*. This kind of fragment should help identify the topic of the information. *Characteristics* describe the subject and somebody or something included in the subject such as *user or kind of appliance*. *Measures* indicate quantities and dimensions linked to the subject. *Background* refers to the context of the subject's environment. It includes descriptions and/or locations of persons, places.

We need to collect two kinds of information: fixed information, which rarely changes, and variable information, which often changes and requires frequent collection. Fixed information is mainly related to a building's physical characteristics and residential zone, while variable information is related to the usage of the building and its performance.

The choice of the variables presented in table 1 is based on a number of studies presented earlier in the literature review (cf. section 1.1).

Table 1: Collected data and information, and ways of gathering

Subject (What)	Characteristics (How, why & detailed what)	Measurements (How many & how much)	Background (Where & when)	Means of gathering (means of collection)
Residential building (Fixed data)	Location			
	Age			
	Floors	Number	Location	Building administrator Building modeling and documents (On demand)
	Floor area	Surface area (m <sup>2</sup> )	Climate	
	Accommodations (per type)	number	Social environment	
	Technical information (e.g. insulation variable, glazing, sources of energy, etc.)			
Accommodation (Fixed data)	Type	Number of rooms	Location	Building administrator Building modeling and documents (On demand)
	Size	Surface area (m <sup>2</sup> )	Residents	
	Residents	Number		
	Initial appliances (per type)	Number, type & power rating (kW.h)		
Residents (for each household) (Fixed & variable data)	Family type	Number of occupants		Building administrator and residents List of residents' information and owned appliances (Voluntarily)
	Age	in years	Location	
	Status (tenant or owner)		Accommodation	
	Gender		Habits	
	Occupation profile	Number of presence hours		
Electricity consumption (Variable data)	Appliance holdings (per type)	Number & power rating (W)		Building administrator and residents Smart meter installation (On agreement & automatic)
	Appliance usage	frequency and duration	Location	
	Residents	Number	Accommodation	
	Consumption per household + Total consumption of building	Kwh	Period	
			End-needs	
Gas consumption (Variable data)	Appliance holdings (per type)	Number,	Location	Building administrator and residents Gas meter (In collaboration & voluntarily)
	Appliance usage	frequency and duration	Accommodation	
	Residents	Number	Period	
	Consumption	quantity (m <sup>3</sup> ),	End-needs	
Waste water (Variable data)	Appliance holdings (per type)	Number	Location	Building administrator and residents Water meter (In collaboration & voluntarily)
	Residents	Number	Accommodation	
	Consumption	quantity (m <sup>3</sup> ),	Period	
			End-needs	
Everyday life in building and in accommodation (Variable data)	Events	Number	Location	Building administrator, building employees and residents Human Machine Interface-Users (In collaboration & voluntarily)
	Successes	Duration	Building	
	Problems	Level of satisfaction or dissatisfaction (low, medium or high)	Accommodation	
		Cost (€)	Period	
Specific diagnostic (Variable data)	Used appliances	Number, power (kW.h), frequency and duration	Location	Residents Interview, user diary and questionnaire (In collaboration & voluntarily)
	Kinds of end-needs		Building	
	Residents	Number	Accommodation	
			Period	

Information on building, accommodation and residents helps us understand the context of usages and patterns of behavior. It allows building experts to know the kind of accommodations, who the residents are, their type of household, their appliances, and so on.

Energy and resource consumption and waste water figures must be gathered for each household. One method for collecting detailed electricity consumption according to kind of end-use and appliance is described below.

Following the categories of energy end-uses in residential building used by Yu *et al.* (2011, a), we define six kinds of end-uses: 1. Heating, Ventilation and Air-Conditioning (HVAC); 2. Kitchen; 3. Lighting; 4. Entertainment & Information; 5. Housework & Sanitary; and 6. Other. These end-uses are not specific for each type of energy and resource consumption. Gas consumption for instance may only apply to HVAC, kitchen, housework & sanitary and other. However, each end-use contributes to electricity consumption.

The subject “Everyday life in building and in accommodation” is characterized by three kinds of facts. “Events” describe each surprising and/or unusual fact occurring in the residential building, which may be positive or negative. “Successes” define satisfaction, improvements and benefits, due to the residential building, accommodation and services. And “problems” include technical problems, deterioration, damage, and dissatisfaction in the residential building, accommodation and other spaces. The last line of table 1, “Specific diagnostic”, details the second level of beneficial service for residents. It is the customized diagnostic allowing them to understand and to reduce their energy and resource spending according to their end-uses, end-needs, appliances, and usages and patterns of behavior.

These data and information are essential to building experts. As explained and demonstrated below, extracting useful information makes it possible to understand and to identify existing usages, patterns of behaviors, misuses and unsatisfied needs.

In this section, we detail the automatic means of gathering data, such as electricity and gas consumption, and waste water.

The building administrator and residents authorize measurements by automatic means. Anon-disclosure agreement with data providers is integrated into the agreements between the building administrator, residents and the use-phase memory of the residential building.

The most important part is undoubtedly the electricity data recorder, but there are also gas and water data recorders. Global solutions exist to identify, manage and optimize energy flows in the industrial sector (see for example (Pacific Controls, 2013; Siemens, 2013; Johnson Controls, 2013; Spectral, 2013; Environmental Automation, 2013)). Such intelligent building management systems (BMS) are adopted mainly in industrials sectors and tertiary buildings. They provide automatic control of building system functions such as heating, ventilating, and air-conditioning systems. However they do not offer detailed energy flow information, at the apartment and appliance level, as proposed in the present paper. In addition, the access to the functionalities of these technologies and their usage are limited to building administrators, leaving no real role to building occupants to give their real feedbacks during the use-phase of the building. The last point is a major functionality which is proposed in our use-phase memory model..

We have chosen to focus on an emerging technology, an electricity consumption recorder adapted to offices or accommodation. For this study, we collaborate with a startup company that commercializes an electrical signal analysis box, the *smart meter*. This *smart meter* is a box which is connected to the electrical terminals of the electrical board in a private apartment. The current and voltage signals are continuously recorded, and these records transmitted each day to a centralized computer. Here, using patented algorithms, these signals are decomposed into elementary signatures of well-known electrical patterns of household appliances contained in a database. This algorithm is then able to assign each elementary signal to an electricity consuming category like: a washing machine, a toaster, a coffee machine, a vacuum cleaner, lighting for a certain kind of electrical power and bulb technology. For our

purposes, breakdown feedback on daily electricity consumption was highly satisfactory. At the moment, existing installed gas and water meters are being used without detailed and automatic analysis. Consequently, residents or the building administrator (depending on the meters' location) must read the meters and transmit these data each month. Data input requires means of accessing the building's memory. Besides, the stakeholders who feed and consult the building's memory are very different. It is necessary to adapt these means of access depending on the specific needs of the stakeholder, be they building experts, residents, building administrator or employees.

### 2.2.2 Means of obtaining access to the memory

Five specific contexts and aims allowing access to the building memory can be identified.

1. Data input by residents, building employees and building administrator is done through an oriented Human Machine Interface user (HMI-User). This HMI-User is connected to the use-phase memory of the residential building and allows the users to enter data and information directly on the 3D representation of the building. This choice is inspired by the platform described by Shen *et al.* (2012). We have developed this interface, which turns out to be intuitive for residents, building employees and the building administrator. The HMI-User is accessible to them by Internet and its access is protected by individual login and password.
2. Feeding the use-phase memory with electricity consumption is automatic for the residents benefitting from the *smart meter* solution at home: it is the first level of returned service. If the number of subscribers corresponds to a representative part of residents, it becomes possible to define a "reference consuming and service registered resident", providing a first reference frame for comparison of any resident utility bill on a monthly and yearly basis.
3. The consultation by building experts of the stored data and information is allowed through an oriented expert Human Machine Interface (HMI-Expert). Like HMI-User, HMI-Expert is also connected to the building's memory. This HMI-Expert gathers useful information for building experts either by automatic analysis of the building's memory or on demand. We define two use-cases, which are the design of a new sustainable building and the renovation of an existing one. First, the building experts need general information when designing a new sustainable building, so the HMI-Expert displays statistical representations in this case. To renovate an existing building, as they are looking for specific information on the given building, HMI-Expert automatically displays the tagged building maps by most costly facts and problems. Further information on these kinds of representation, their content and the two modes, automatic or on-demand is given in the next section, "Useful information and knowledge retrieval".
4. The building administrator consults the residential building's state by the HMI-User, allowing him or her to feed the use-phase memory with overall consumption of the residential area. The HMI-User displays factors such as energy consumption, most costly facts, and successes through the 3D representation of building and statistical representations.
5. Residents are also able to consult the residential building's state and their detailed energy consumption thanks to HMI-User. It displays the residential building's state through the 3D representation of building and statistical representations, and also the energy bills highlighting unusual consumption end-uses and appliances compared to a "reference consumption and service registered resident". A second comparison is made globally with an "averaged resident" for the global electricity, gas and water consumption.

These different means of accessing the memory enable the different categories of information availability and confidentiality contingent on the users to be defined. Building experts, building administrator and residents are allowed to consult reported events, successes and also problems, as



well as global energy and resource consumption. It is moderated and anonymous. Furthermore, access to private information on residents is restricted to building experts and the residents concerned (Figure 2).

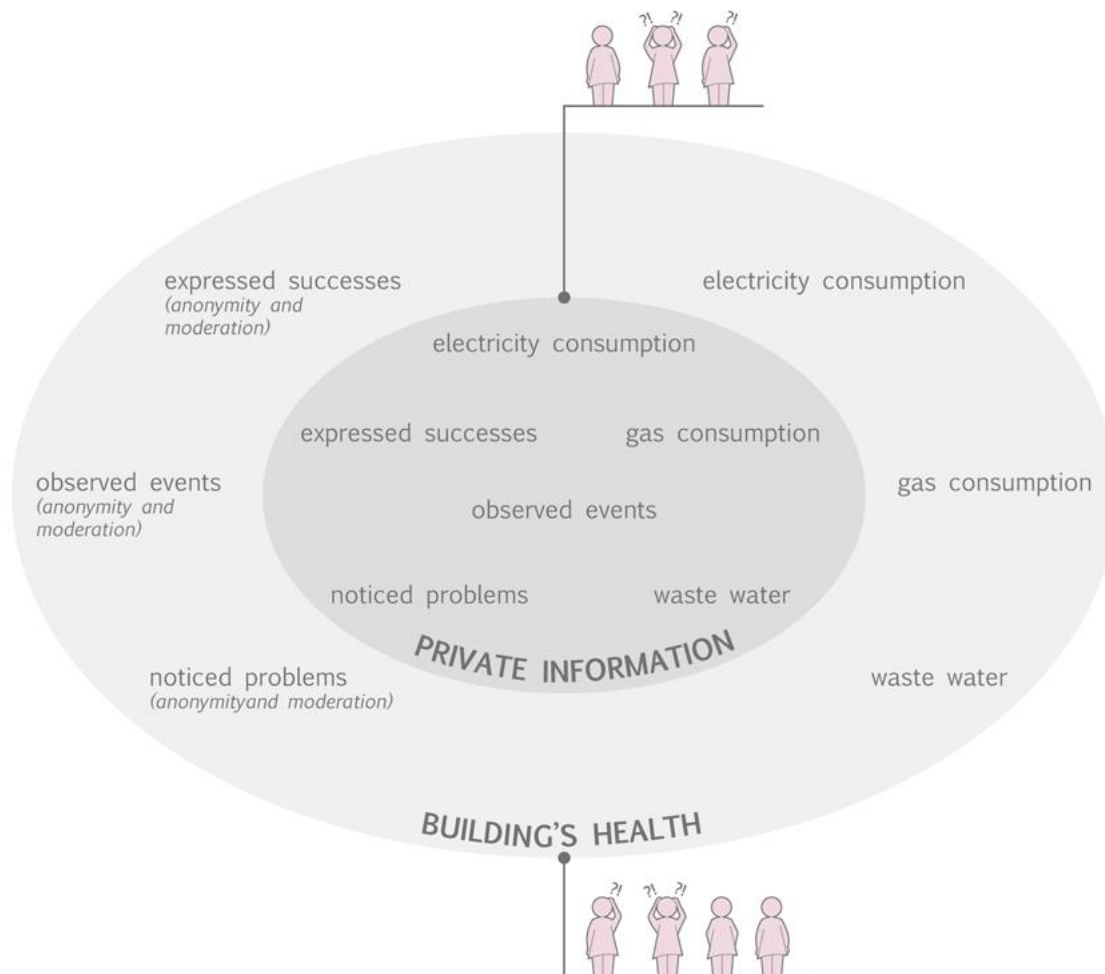


Figure 2: Available and confidential information according to the different stakeholders

### 2.2.3 Useful information and knowledge retrieval

The main aim of the use-phase memory for a residential building is to provide building experts with useful information on usages and patterns of behavior in residential buildings. Thanks to data crossing and different means of visualizing data, we extract, from the data collected, information and knowledge for the building experts, as well as for the building administrator and residents in return for their collaboration.

Several types of information may be displayed and some results are conventional, such as electricity consumption relative to surface area per year ( $\text{kW.h/m}^2/\text{year}$ ) and electricity consumption by an equivalent resident number per year ( $\text{kW.h}/\text{nbr}/\text{year}$ ). Taking residents' characteristics into account may help calculate an equivalent number of resident parts. For instance, an adult may be represented by 1 part, 0.75 parts for a teenager, 0.5 for a child or an animal and 0.25 for a baby. This is the solution that has been adopted in the French "Thermal Regulations 2012". Of course, these ratios remain adjustable. And several other normalizations can logically be made, such as electricity consumption per appliance, waste water by kind of family, cost according to types of technical problem and residents' level of satisfaction according to kinds of successes noticed.

The building administrator gets the building's state regarding energy and resource consumption, costly facts, and successes from the use-phase memory of the residential building through the HMI-User. Data gathered allow a first reference consumption resident to be defined on the scale of a building.

The residents obtain the building's state and also their own consumption levels, which may be

compared to the “reference consuming resident”. This comparison is a source of energy saving questions and insights, and potentially an important source of motivation for change.

As noted earlier, we define two use-cases for the building experts. During the design of a new sustainable building, they automatically obtain general information and averages on gathered energy and resource consumptions and noticed events, successes and problems in several residential buildings. Then, they can ask for specific information from the use-phase memory thanks to the request mode based on Structured Query Language. Figure 3 shows result for the request: “*electricity consumption according to the surface area and the equivalent resident number*”.

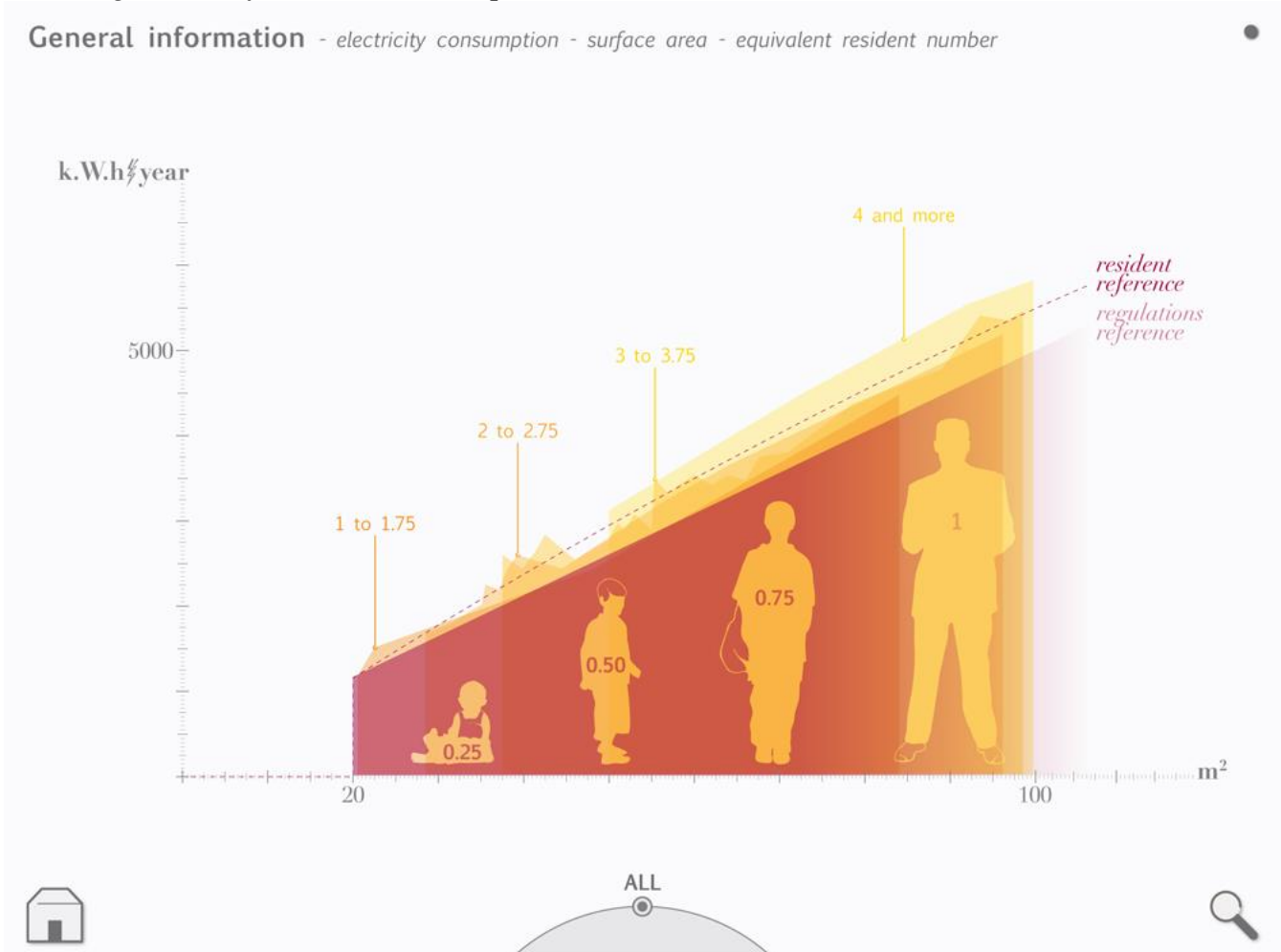


Figure 3: Result for “*electricity consumption according to surface area and equivalent resident number*”

These modes, automatic and on-demand are also proposed for the renovation process. The building experts automatically display costly problems on the maps of the residential building. They can also request some detailed and specific information on the residential building in question.

## 2.2 Presentation of model of use-phase memory of residential building

We propose here a model of use-phase memory for a residential building to assist building experts during the design and the renovation processes of a more sustainable building. To succeed in gathering data and obtaining useful information, we establish sustainable and profitable relationships between the residential building, its stakeholders and its use-phase memory. These relationships are based on services provided to the building administrator and the residents. They are helped in identifying potential savings, in controlling the sustainable and environmental state of the building, and in reducing their energy and resource consumptions (figure 4).

This memory, considered as a database, is made up of the use-phase memories of several residential

buildings. As we explained above, this allows building experts to obtain general information and real insights during the design process.

Our proposition is not limited to an experimental period gathering data and rewarding stakeholders with beneficial services. The data and information on usages and patterns of behavior in residential buildings must be collected and used continuously, because they evolve through time. New residents' needs appear without being clearly expressed; and the residential building sector must evolve to respect and contribute to environmental conservation as well as to the current and future needs of our society, its citizens, and their expectations in terms of quality of everyday life.

We demonstrate the potential of use-phase memory by automatic analysis and on-demand of building experts in the two use-cases in the next section. Some scenarios are shown by screenshots of the HMI-Experts that we developed.

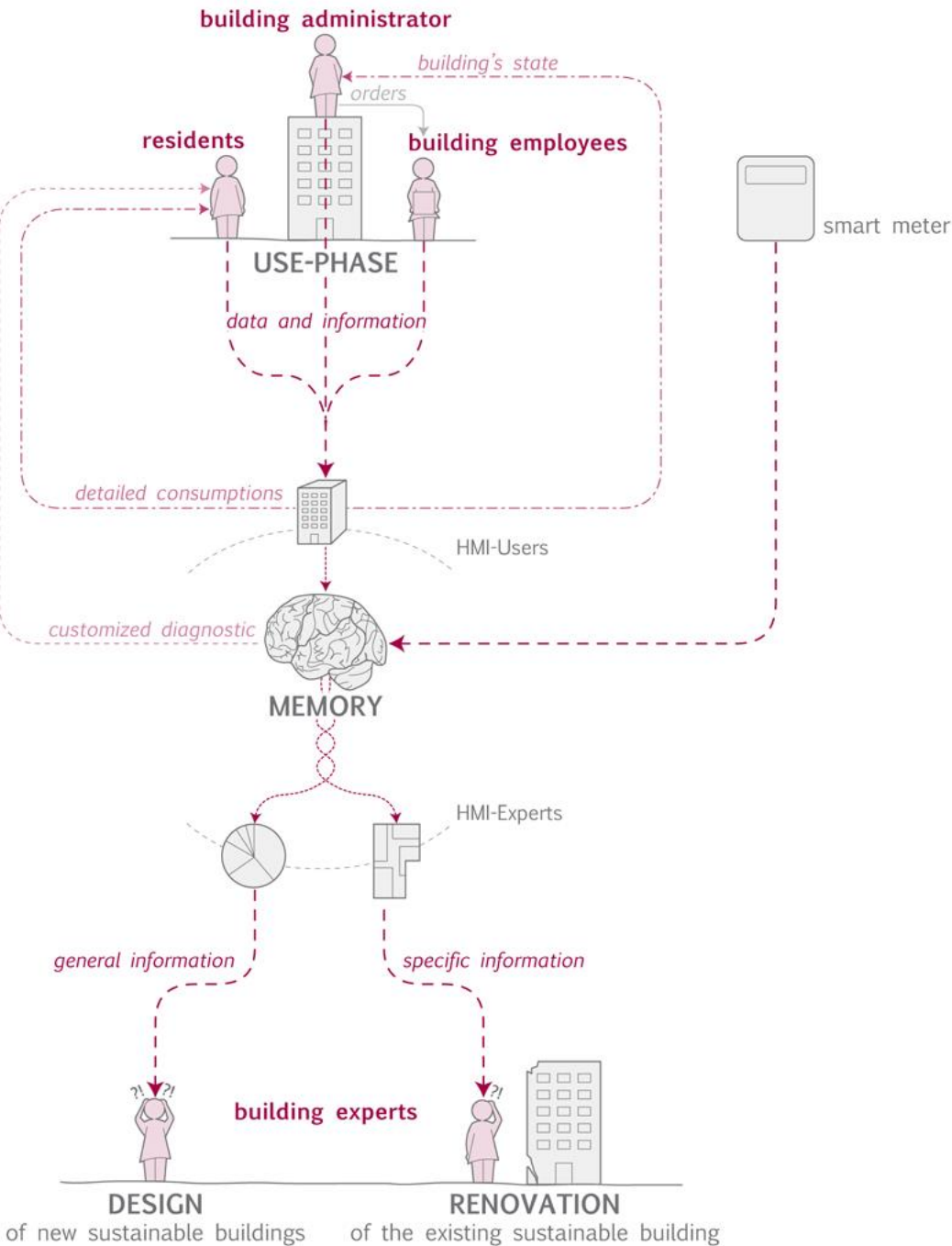


Figure 4: Model of use-phase memory of residential building

### 2.3 Ethical implications of gathering and sharing information

After Oz (2011), three schools of thought exist in ethics: relativist, deontological and consequential. This latter includes Bentham's utilitarianism which proposes to decide whether or not to undertake an action according to its propensity to maximize the satisfaction of most people. The present work applies this principle. The objective is indeed to serve the interests of consumers (to reduce their bills and perhaps satisfy environmental aspirations), but also help manufacturers to establish good practices and society as a whole to reduce its environmental footprint.

What is currently permitted when gathering and sharing consumer data? In Europe, according to Directive 94/46/EC, only individual citizens are entitled to authorize use of their personal data (name, surname, social security number, address) by third parties. In the U.S., there is no federal text on this matter, but the choice of gathering and sharing data is regulated by charter agreements in various business or professional sectors. In Europe, consumers must also have the right to withdraw this authorization and to edit or delete the data. The use of data for the construction of statistics also requires anonymizing them previously. Key concerns for consumers and associations are:

- By crosschecking between multiple databases supposed to have been anonymized beforehand, it is possible to find a specific person (CNIL, 2013).
- Data collected by an organization or a company can be sold to a third party (CNIL, 2013) (Sipior *et al.*, 2006) as soon the consumer has ticked the acceptance of data release.
- Fear of Big Brother surveillance and taking enforcement action. It cannot be excluded under the “*polluter pays*” principle of sustainable development.

In the case of the current study, the agreement between the residents, the building administrator and the building constructor must guarantee that the personal data will not be sold and that the agreement may be cancelled on demand.

## 3. Demonstration of useful information retrieval from use-phase memory of residential building for building experts

In this section, we present the potential of our use-phase memory of residential building in terms of consultation of useful information and knowledge by building experts in the two use-cases stated above, namely the design of a new sustainable building and renovation. For each use-case and mode of consultation, we show one example of a possible scenario.

### 3.1 Usage scenario during the design of a new sustainable building

Building experts quickly obtain global and useful information on energy and resource consumption. They can then browse and consult more detailed information on electricity consumption by end-uses and appliances, as shown by figures 5a and 5b. By crossing data by automatic electricity consumption measurement and information passed on by residents, it is possible to identify which end-uses and appliances consume more energy, and their causes such as reduced energy-efficiency of an appliance or misuse.

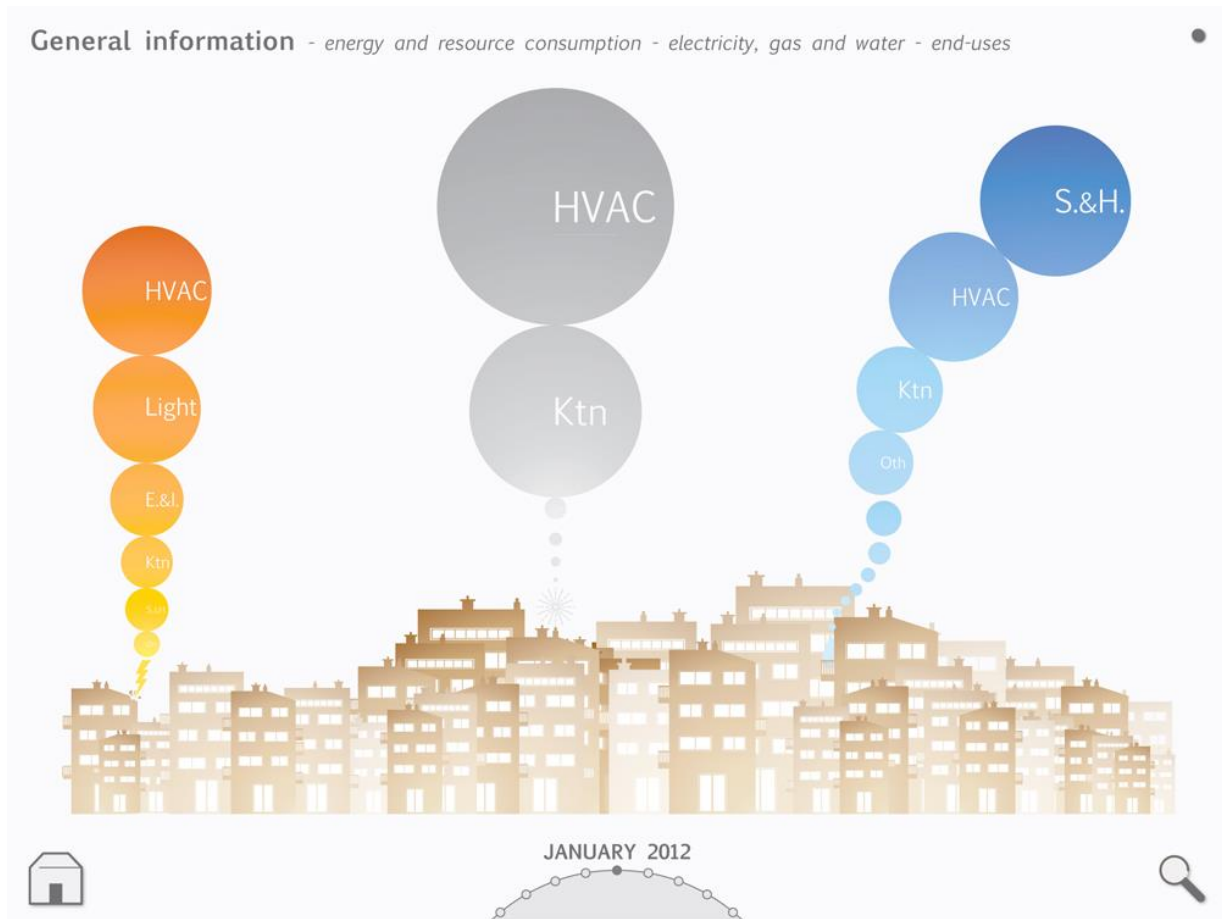


Figure 5a: Automatic display of energy and resource consumption: electricity, gas and water according to kind of end-use

They can obtain information on specific subjects from the use-phase memory through the request mode. Building experts must specify the subject and the chosen setting(s), and then they enter information.

The request mode based on Structured Query Language is made up of two categories of information: subject and settings. The subject defines the type of information being researched. Subjects are selected according to the data gathered detailed in section 2.2.1 (*Data gathering*) and in table 1. Two kinds of subject are proposed, namely *Consumption* and *Activities & needs*, and each is divided into several sub-categories. Under *Consumption*, building experts may select electricity consumption, gas consumption or waste water. Events, successes and problems may be selected under *Activities & needs*. Further refining the request, several kinds of successes and problems may be also selected, such as *savings*, *quality of everyday life*, *sustainable and environmental efforts* and *other* for the sub-category *successes*, and *technical problem*, *damage*, *deterioration* and *other* for the sub-category *problems*. At present, the sub-category *Events* includes each surprising and/or unusual fact. It will be divided into themes after analysis of noticed facts by the building administrator, building employees and residents.

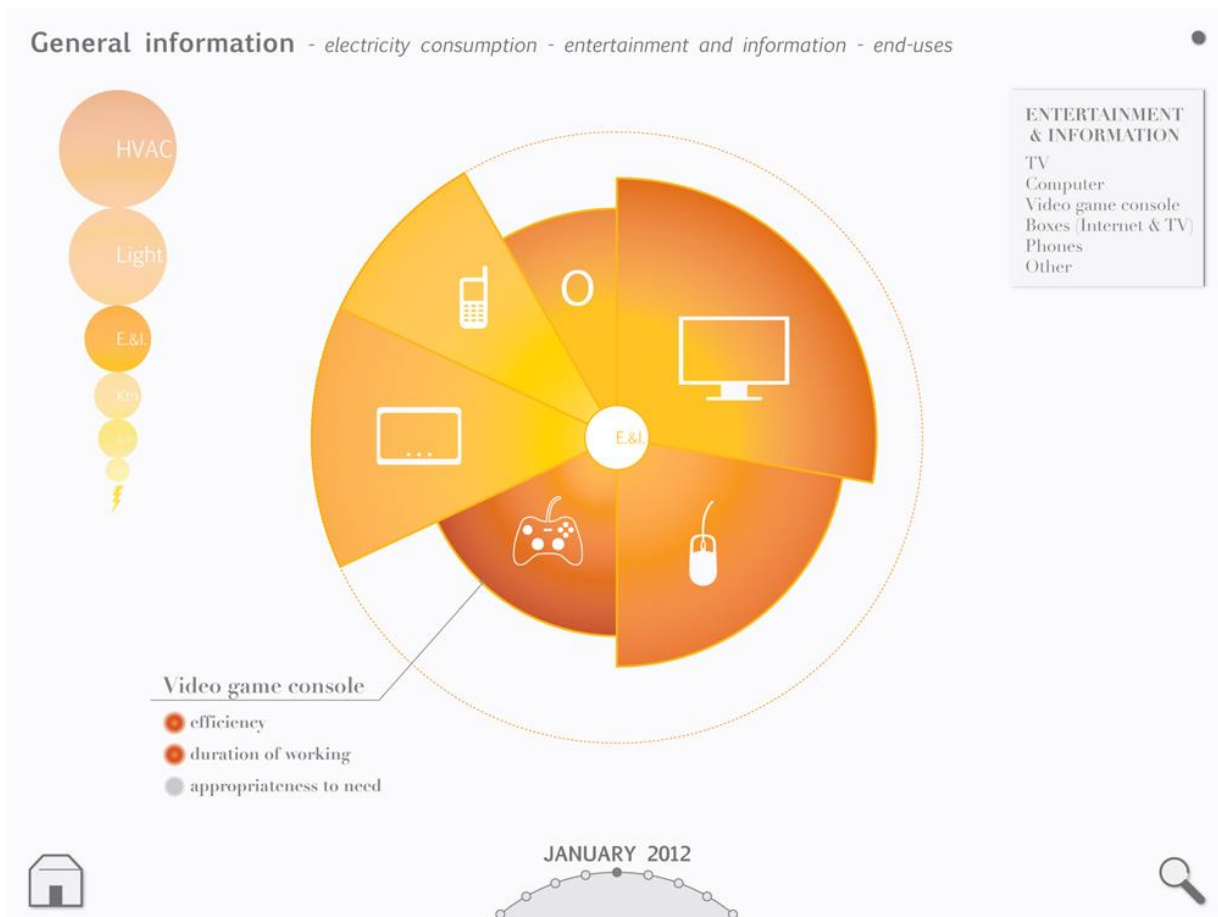


Figure 5b: Consultation of electricity consumption details according to kind of end-use and appliance

The settings allow building experts to specify their request. We selected 10 different settings, which are duration (long, short or indication of specific duration), frequency (frequent, infrequent or indication of specific frequency), period (spring, summer, autumn, winter or indication of specific period), cost (costly, cheap or indication of specific cost), surface area (according to the number of rooms: T1<sup>2</sup>, T2, T3, T4, T5 or indication of specific surface area), equivalent resident number (indication of specific number), kind of household (single, aged couple, single-parent, couple, family and family with more than 3 children), level of satisfaction or dissatisfaction (all expressed satisfaction, all expressed dissatisfaction or indication of specific level of satisfaction or dissatisfaction), kind of end-uses (Heating, Ventilation and Air-Conditioning (HVAC), kitchen, lighting, entertainment & information, housework & sanitary or other) and kind of appliances (according to an appliance inventory, which is in progress).

It is not possible to select several subjects for the same request. However, several settings may be combined (e.g. figure 6a) with the subject *waste water* and the two settings *kind of household: all kinds of household* and *period: summer and winter*. Figure 6a presents the request mode, while figure 6b presents the result displaying difference of waste water quantity during summer and winter. Depending on the kind of household, this difference may be interpreted by the change in temperature. This event leads to changes in activities and end-uses, for instance an increase in the number of showers taken, water used for gardening, etc. These changes of usages and behavior are linked to the period and influence the variability of residential building's resource consumption.

<sup>2</sup> "T+number" is a French designation defining the number of rooms in a flat excluding kitchen and bathroom.

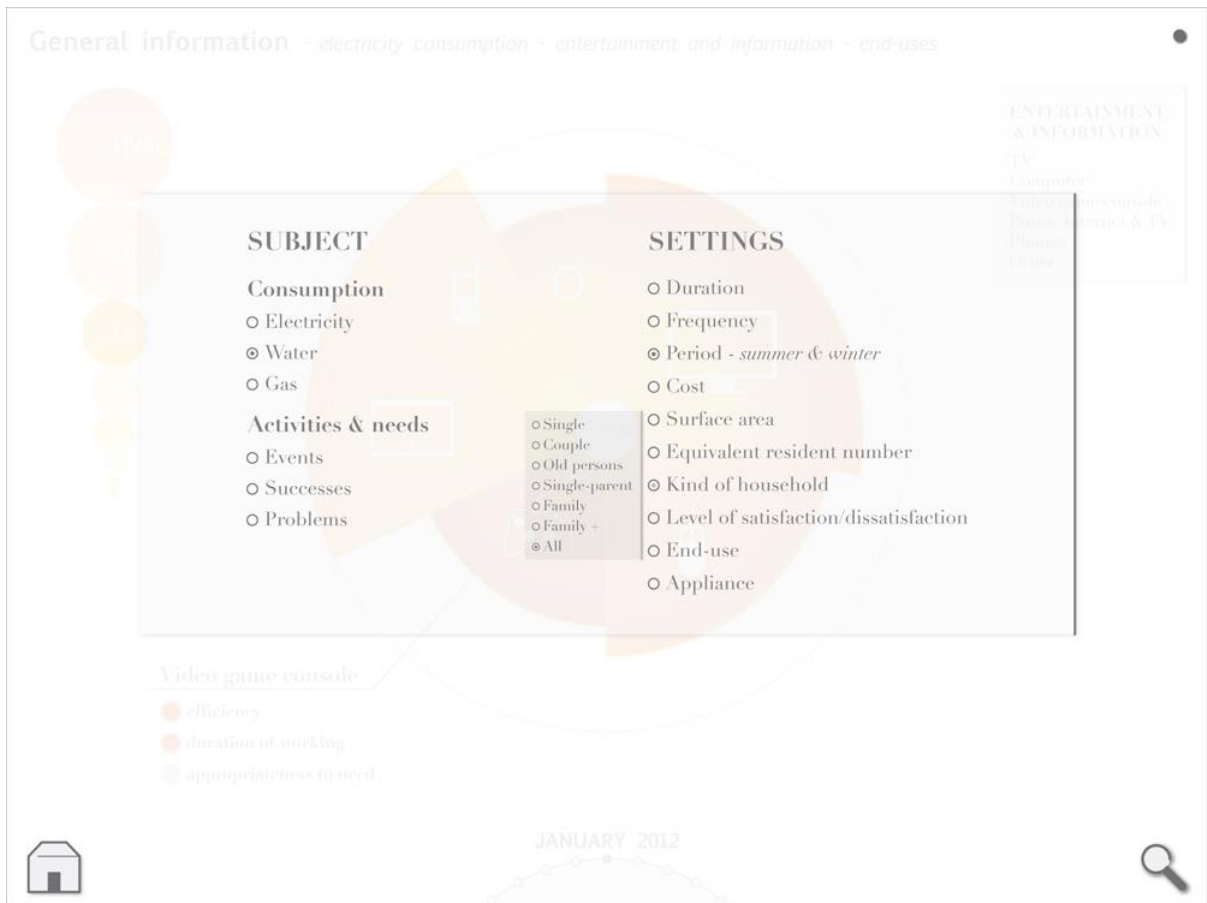


Figure 6a: Request mode



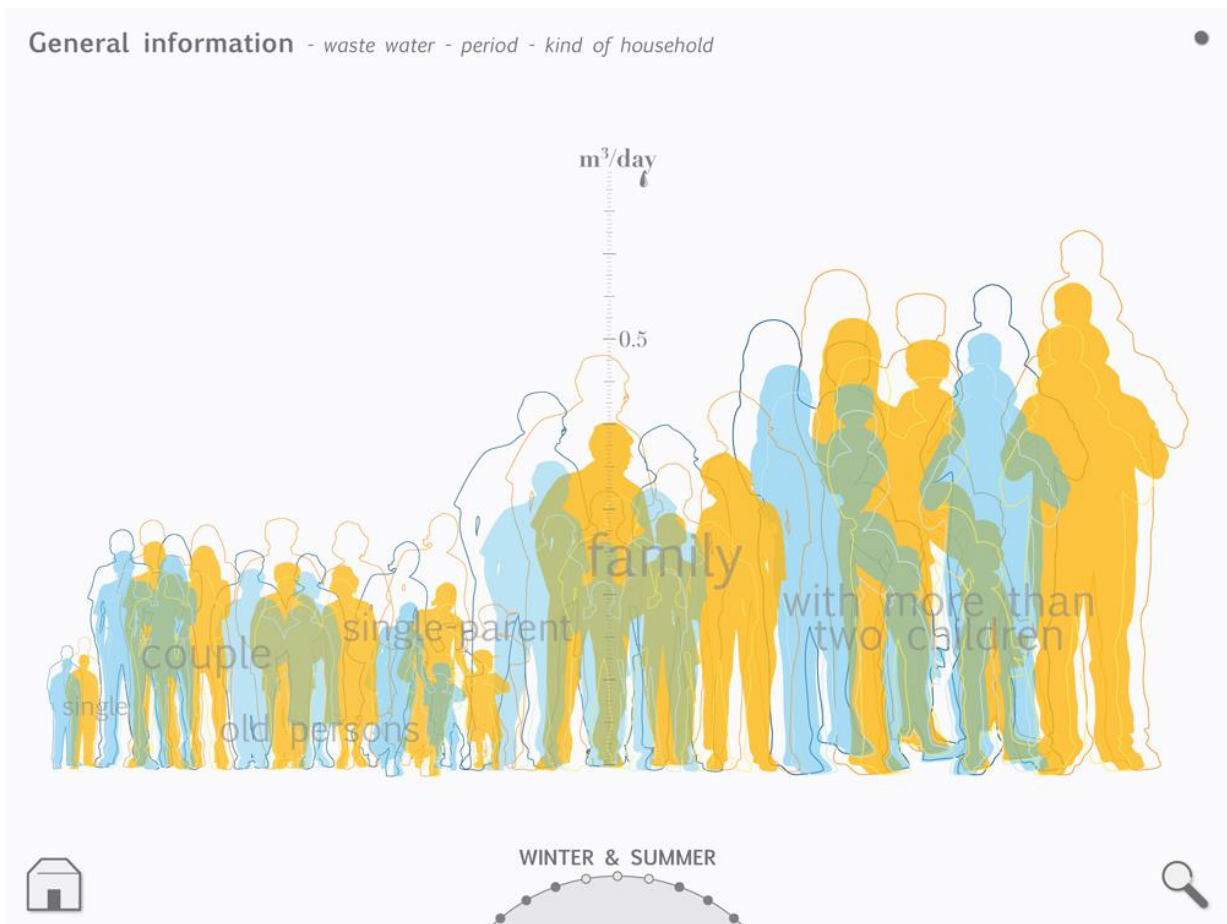


Figure 6b: Displayed result for “waste water according to period: summer and winter and kind of household: all kind of household”

### 3.2 Usage scenario during the renovation of an existing sustainable building

Building experts automatically display specific information on the most costly problems of the residential building. The ten most costly problems are located on the maps of the residential building, their financial importance being represented by the size of the bubble. Building experts can consult details of the problems thanks to information reported by the building administrator and building employees. They can also browse in the different surface areas of the building. Information on costly problems is updated according to the scale of residential building such as block of flats, and accommodation and service spaces. Figures 7a and 7b show the scenario of this automatic display of the ten most costly problems, consultation of their details and browsing between block of flats and building.



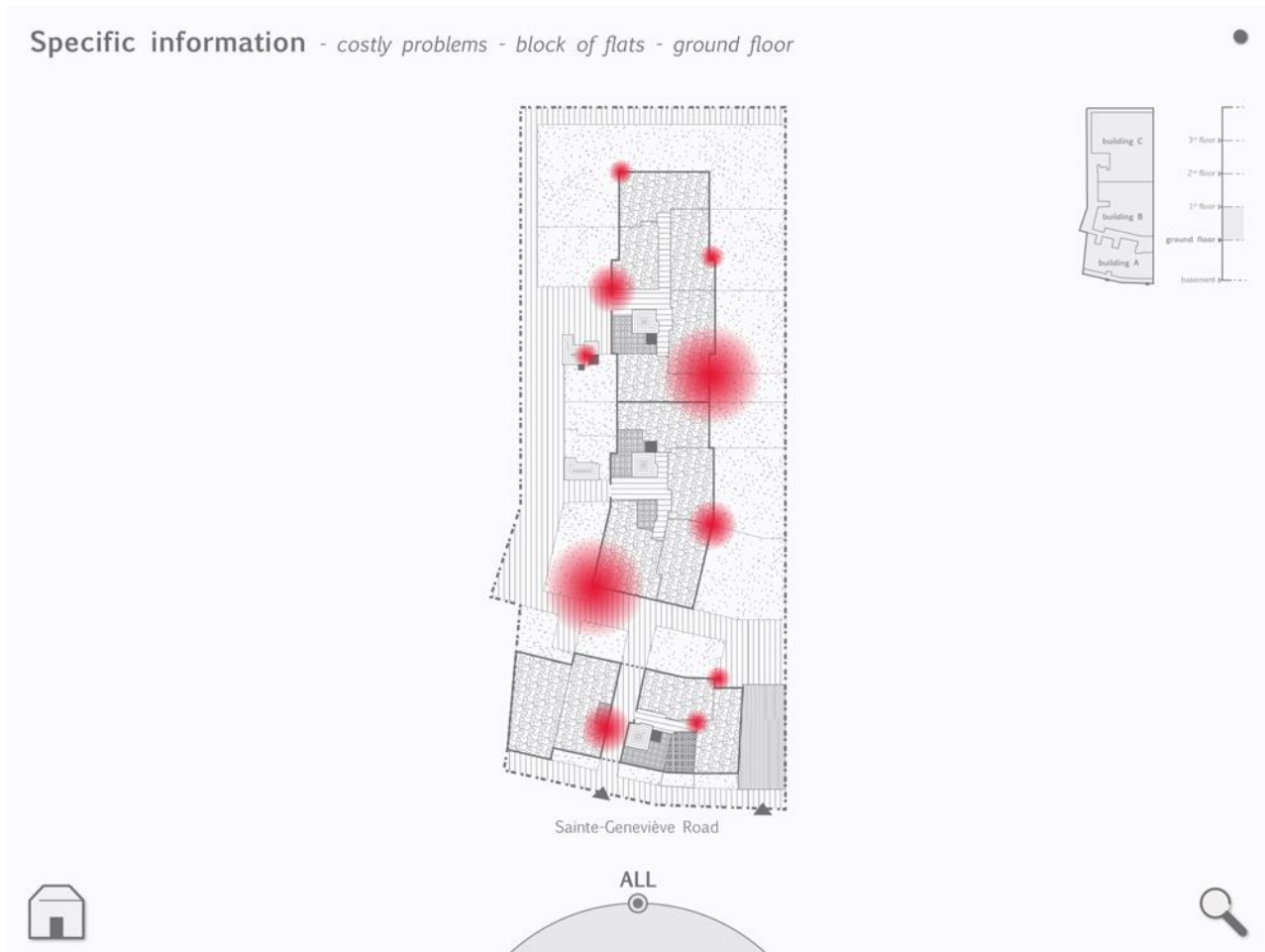


Figure 7a: Scenario of automatic display of the ten most costly problems

Requesting information on a specific subject is also possible. We have shown how building experts must specify the subject and the chosen setting(s) such as *problems* according to *cost* and *level of dissatisfaction* for instance. Then, building experts display located and represented information on the maps of residential building and/or by statistical visualizations. Figure 8a presents a request scenario for *problems: technical problems, damage, deterioration and other* according to *cost: costly* and *level of satisfaction/dissatisfaction: all expressed dissatisfaction*. The results display the level of dissatisfaction for each costly problem (figure 8b). For instance, it is possible to notice that for a costly problem, the level of dissatisfaction is also very high, and understand the reasons why. Of course, cost may not be the immediate problem for a resident: it could be the problem's duration, frequency or level of inconvenience. However, these details allow building experts to understand the problem, its reasons and also its consequences for residents.

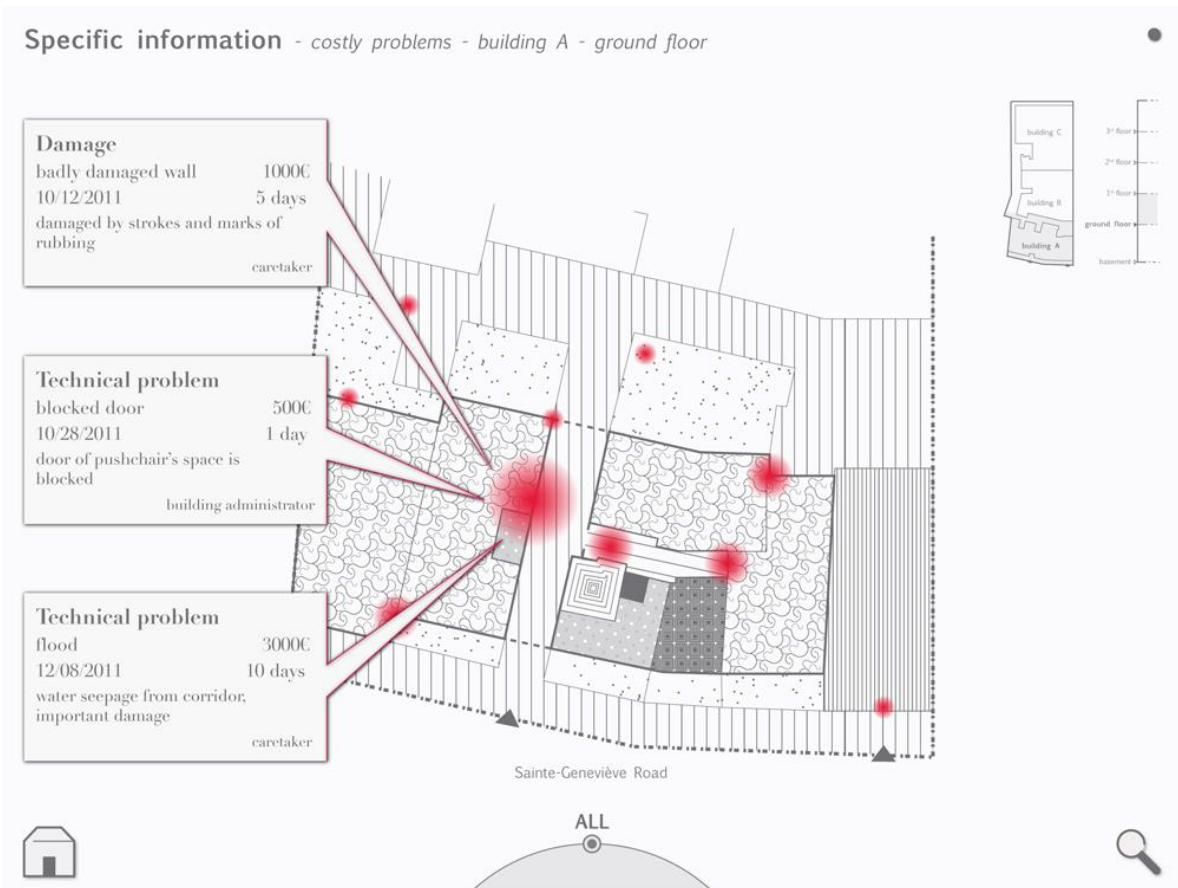


Figure 7b: Consultation of detailed problems and browsing between block of flats and building

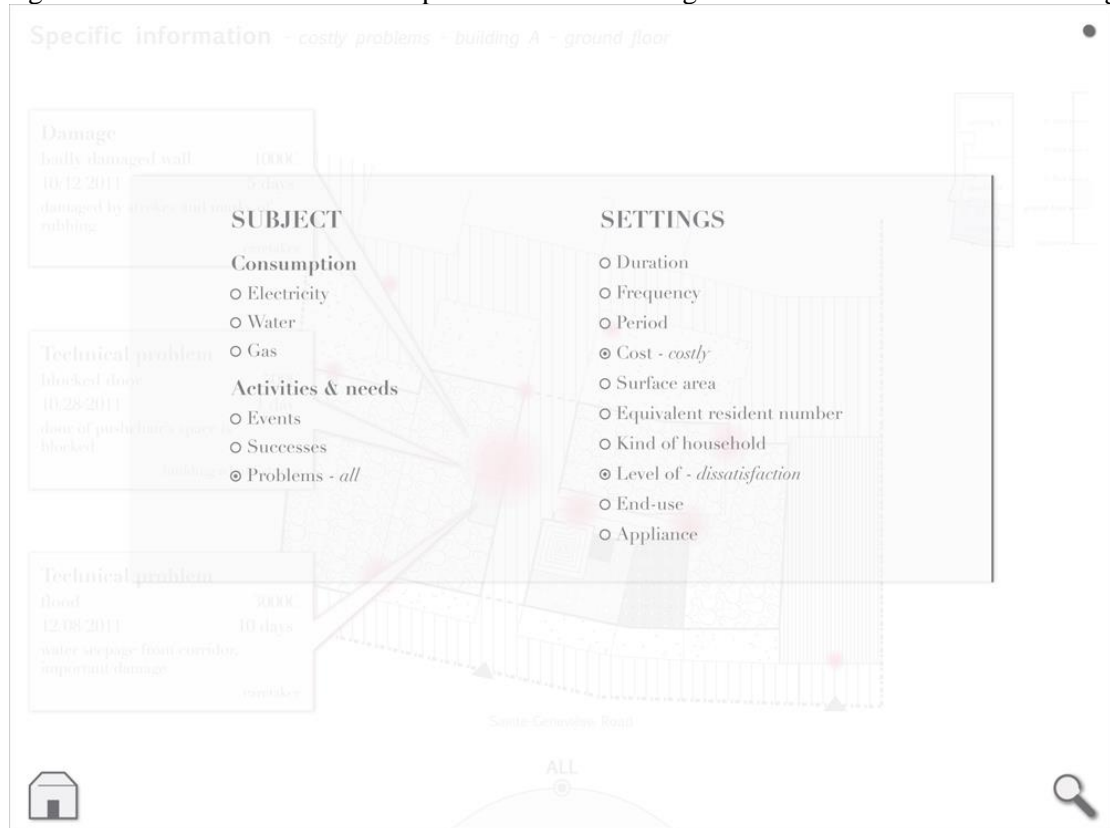


Figure 8a: Request mode

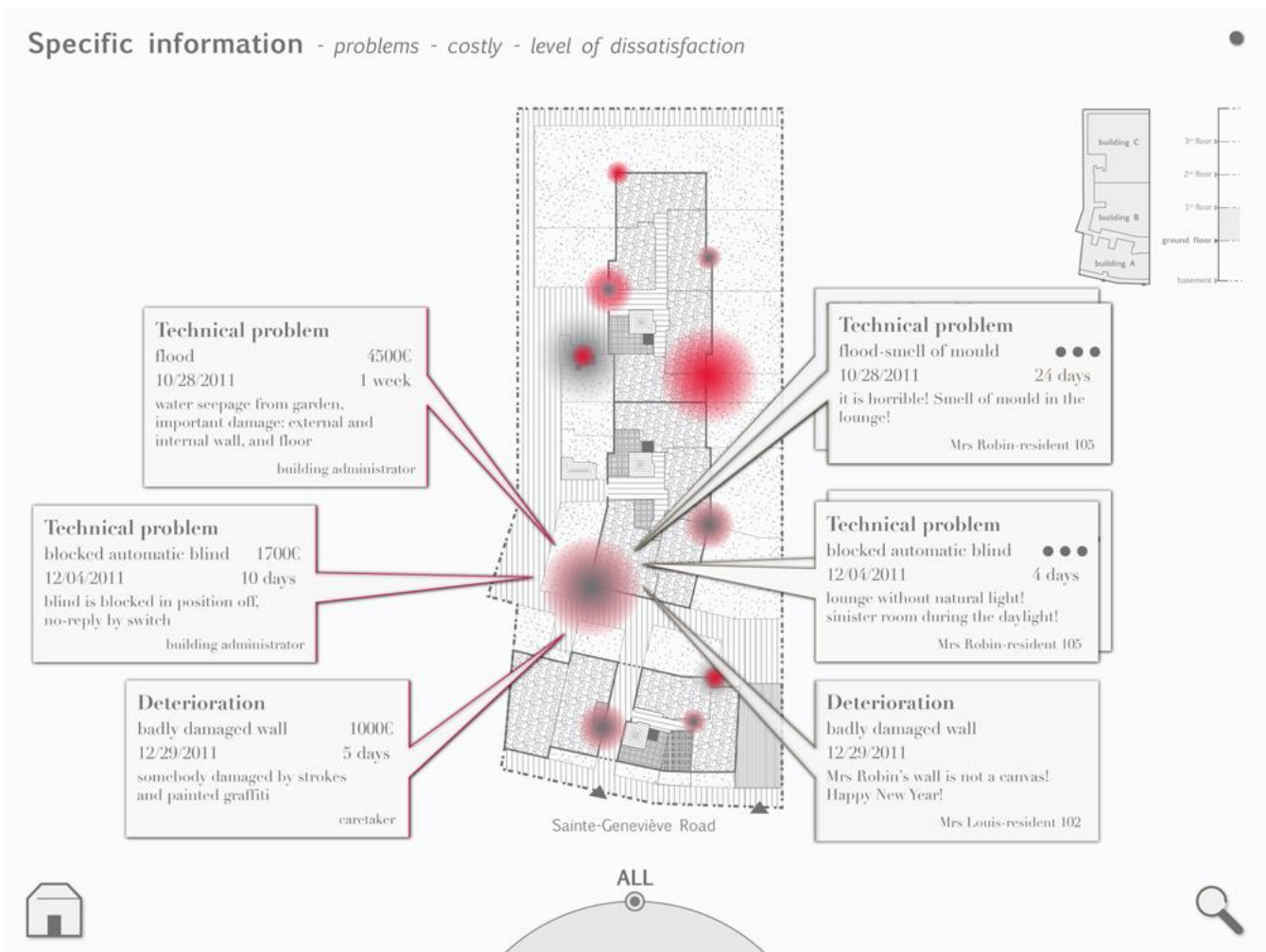


Figure 8b: Displayed result for “problems: technical problems, damage, deterioration and other, according to cost: costly, and level of satisfaction/dissatisfaction: all expressed dissatisfaction”

## Conclusion

This paper contributes to the study of user behavior in buildings and proposes a model for capturing the influence of user behavior on energy consumption and environmental impacts of a building. Our use-phase memory model for residential buildings uses storytelling for its benefits in conveying and sharing knowledge, and the existing relationships with end-users. This happens thanks to gathered data and information on energy and resource consumptions, and also the events, successes and problems noticed and reported by building administrator, building employees and residents. The paper depicts the proposed model for use-phase memory on residential buildings and explains which services and relationships are developed between building experts, building administrator and residents. As a result, this study contributes to the knowledge building experts need for both the design of and the renovation processes of sustainable buildings.

The originality of our approach lies in the association of both types of data which can provide useful feedback both monthly and yearly for residents and for building administrators and designers. Concerning the first type of data, information on energy and resource consumption, the most advanced methods we found are those of Yu *et al.* (2012) who use data mining techniques to discover useful knowledge by association of building operational data. This is what we do when a resident is allowed to compare his or her consumption levels to an averaged resident consumption or a national averaged one. For building experts, it is a means to obtain insights to develop or to improve solutions that will reduce the building's energy consumption and its environmental impacts. The use-phase memory also allows building experts to gain time during the two use-cases because information and data are centralized internally.

Nonetheless, the quality of studies using data gathering and analysis is highly sensitive to the process of gathering, and to data characteristics. For example, this study used data from residents who have just started to participate in the electricity/gas/water consumption bill feedback service. For electricity, data are automatically transferred to a central data treatment and warehouse; for gas and water, it requires a monthly personal declaration by Internet. Hence, at least two years will be required to draw solid conclusions about how people behave both when they compare their detailed consumption bill with others and when providing relevant and useful storytelling. Indeed, in the test web platform, we noticed some people moderating their stories before publishing them to all registered members.

For future works, it will be important to look into HMI development, in terms of requirements for users and experts, but also in defining technical aspects to feed, to share, to consult and to question the use-phase memory.

Other issues must be looked at, in particular the existing design and renovation processes, and the integration of use-phase memory into these processes. Building experts work with specific processes according to the project, its context and its aims. In our context of residential buildings, there are many steps dividing up tasks, responsibilities and also building experts' dialogue. It may be necessary to change these approaches to designing and to renovating a sustainable building, or to invite other experts such as sociologists and lifecycle experts for instance. This study developing a model of use-phase memory of residential building places the emphasis on residents because they influence the variability of a building's energy consumptions and environmental impacts, but also because they hold much useful knowledge allowing innovation and the development of more sustainable buildings. We think that such building use-phase memory will result in better design and renovation of buildings for residents, and in better usages.

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<sup>3</sup> Title translated from French "Privacy in the 2020, words of experts - Focus on key changes at the intersection of usages, technologies and economic strategies - What new landscape for personal data, the freedom and privacy? Protect, control, innovate tomorrow"



[http://www.cnil.fr/fileadmin/documents/La\\_CNIL/publications/DEIP/CNIL-CAHIERS\\_IPn1.pdf](http://www.cnil.fr/fileadmin/documents/La_CNIL/publications/DEIP/CNIL-CAHIERS_IPn1.pdf), visited on June 20<sup>th</sup> 2013.

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