

# Chapter 17

## A Model for Internet of Things Enhanced User Experience in Smart Environments



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**Keywords** User experience design · Transtheoretical Model · Behaviour change · Internet of Things · Energy management · Water management · Dataspaces

### 17.1 Introduction

Smart environments have emerged in the form of smart cities, smart buildings, smart energy, smart water, and smart mobility [24], where the Internet of Things (IoT)-based infrastructure can support the efficient use of resources within the environment (e.g. water, energy, and waste) [289]. To this end, smart environments can engage a wide range of end users with different interests and priorities, from corporate managers looking to improve the performance of their business to school children who want to explore and learn more about the world around them. Creating a compelling user experience within a smart environment (from smart buildings to smart cities) is an essential factor to success. In this chapter, we reflect on our experience of developing intelligent applications using a Real-time Linked Dataspace within a smart airport, office, home, mixed-use, and school, where the goal has been to engage a wide range of users (from building managers to business travellers) to increase water and energy awareness, management, and conservation.

This chapter explores the use of a Real-time Linked Dataspace in the context of delivering enhanced user experiences. Section 17.2 details a model for delivering an Internet of Things (IoT)-enhanced user experience within a smart environment. The use of the Transtheoretical Model of behaviour change to guide a user’s journey to improve their sustainability is explained in Sect. 17.3. Section 17.4 details specific intelligent applications that were developed using the dataspace to support users on their journey guided by the Transtheoretical Model. Section 17.5 details the user study and the results achieved in the pilots. The chapter ends with lessons learnt from our experiences in the pilot deployments in Sect. 17.6 and a summary in Sect. 17.7.

## 17.2 A Model for Internet of Things Enhanced User Experience

A key challenge in delivering smart environments is creating a compelling user experience with new digital infrastructures within the environment. We assess this challenge within the Physical-Cyber-Social (PCS) computing paradigm [14] that supports a richer human experience with a holistic data-rich view of smart environments that integrate, correlate, interpret, and provide contextually relevant abstractions to humans. Building useful Internet of Things (IoT) applications for smart environments requires the combination of technology, techniques, and skills from multiple disciplines, including electronic engineering, data engineering, and data science, to user experience design and behavioural science.

In Chap. 16, we used the *Observe, Orient, Decide, and Act* (OODA) decision loop to provide a framework to structure the different types of data management support that intelligent applications needed from the dataspace. In this chapter, we take a user-centric perspective of a smart environment that builds on our previous work [16] by formalising the model and providing enhanced details on the intelligent applications created. In Fig. 17.1, we illustrate a model to structure the landscape that

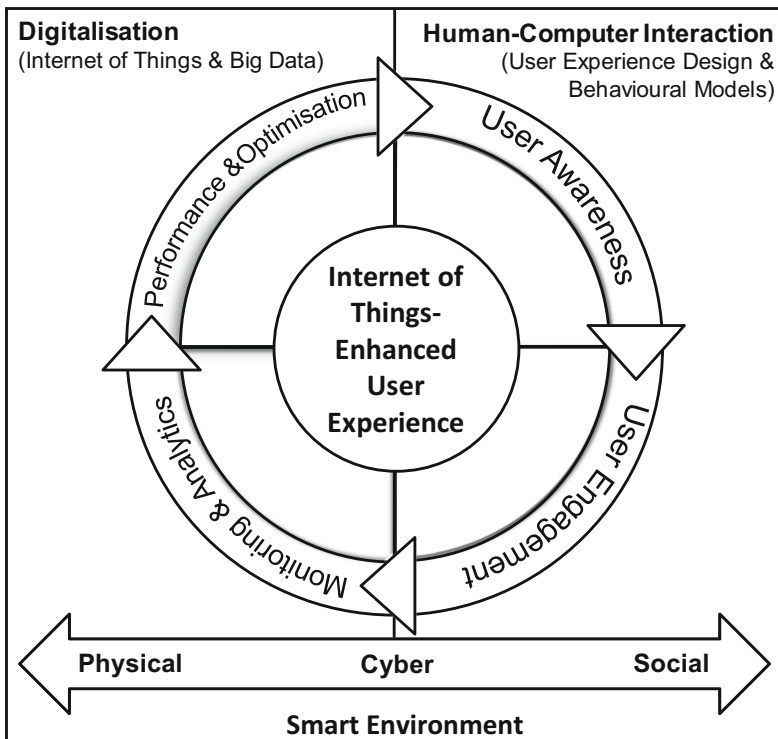


Fig. 17.1 A model for IoT-enhanced user experience

is broken down into two parts, one with a focus on Digitalisation of the Environment using IoT and Big Data, and the other on Human–Computer Interaction (HCI), with a focus on the users’ journeys using behavioural models and user experience design [16].

### ***17.2.1 Digitalisation: IoT and Big Data***

The digitalisation side of the model is primarily focused on (*Monitoring and Analysis*) using IoT platforms and Big Data processing infrastructure that collects and analyses the data from the smart environment. It is essential to follow a systematic approach to information gathering, analysis, visualisation, and decision-making within a smart environment. This data can then be used within data analytics and decision support (e.g. predictive and perspective analytics, and simulations) that support the *Performance and Optimisation* of the smart environment (e.g. reduced energy or water usage) [31]. These are common steps used in the creation of digital twins, as discussed in Chap. 16.

### ***17.2.2 Human–Computer Interaction: IoT-Enhanced User Experience and Behavioural Models***

The Human–Computer Interaction (HCI) side is where we look at how the data and insights generated from the digitalisation side can be used to provide a seamless, personalised IoT-enhanced user experience; providing the right data to the right users at the right time. The key activities on this side of the model look to increase *User Awareness* using targeted information delivery via personalised usage dashboards and task-oriented applications. *User Engagement* with the smart environment is through alerts, notifications, or spatial tasks where users are requested to take physical actions in the environment in the form of citizen actuation [265].

When designing intelligent applications for humans, it is important to consider well-established guidelines and best practices for HCI. For example, within the context of intelligent energy and water management, it is necessary to study the design of conservation interventions in the workplace, user preferences for information visualisations, and the psychology of persuasion and motivation (among others). We will now detail how this model can be used to develop IoT-enhanced user experience for intelligent energy and water systems.

## 17.3 An IoT-Enhanced Journey for Smart Energy and Water

There is a significant opportunity to improve energy and water resource management and conservation by analysing, designing, and implementing intelligent systems to increase demand and supply efficiency. To manage energy and water holistically within a smart environment, it is essential to use decision support tools that present meaningful and contextual information about usage, price, and availability of energy and water intuitively and interactively to users. Smart environments by leveraging IoT can support the development of intelligent applications for efficient and effective management of the resource within the environment. Users will need different information to manage their energy and water consumption, from home users managing their personal water usage, business users managing the water consumption of their commercial activities, to municipalities managing regional distribution and consumption at the level of a city or a region. To deliver a compelling user experience for these diverse users, it is necessary to leverage knowledge from several different sources, from IoT-based devices to contextual data sources (including environmental impacts, water quality, energy usage, end-user feedback, occupancy patterns, and meteorological data). This mass of data needs to be analysed to extract insights which then must be packaged within a set of personalised applications, designed within the context of a holistic user journey for the targeted user.

Over the past years, we have been involved in a number of projects [18, 62, 63] concerned with investigating the use of next-generation information platforms for smart environments, specifically targeting intelligent energy and water management systems. The five pilot smart environments are detailed in Chap. 14. Within these projects, we have developed user applications following the IoT-enhanced model of user experiences detailed in the previous section (Sect. 17.2). Within our pilots, the model was implemented using a Real-time Linked Dataspace for the digital-side and behaviour change theories for the HCI-side (see Fig. 17.2).

### 17.3.1 *Digital: Real-time Linked Dataspace*

To manage a resource sustainably, it is essential to follow a systematic approach to information gathering, analysis, visualisation, and decision-making. Critical to successful resource management is the visualisation of that data, and its use in decision-making to reduce consumption. Intelligent systems and decision support tools need to present meaningful and contextual information about usage, price, and availability in an intuitive and interactive manner. This requires a data platform that is capable of bringing together multiple dynamic and contextual data sources from the smart environment [1] (see Chap. 2). In this book, we advocate the use of the dataspace paradigm in the design of data platforms to support data ecosystems for intelligent systems.

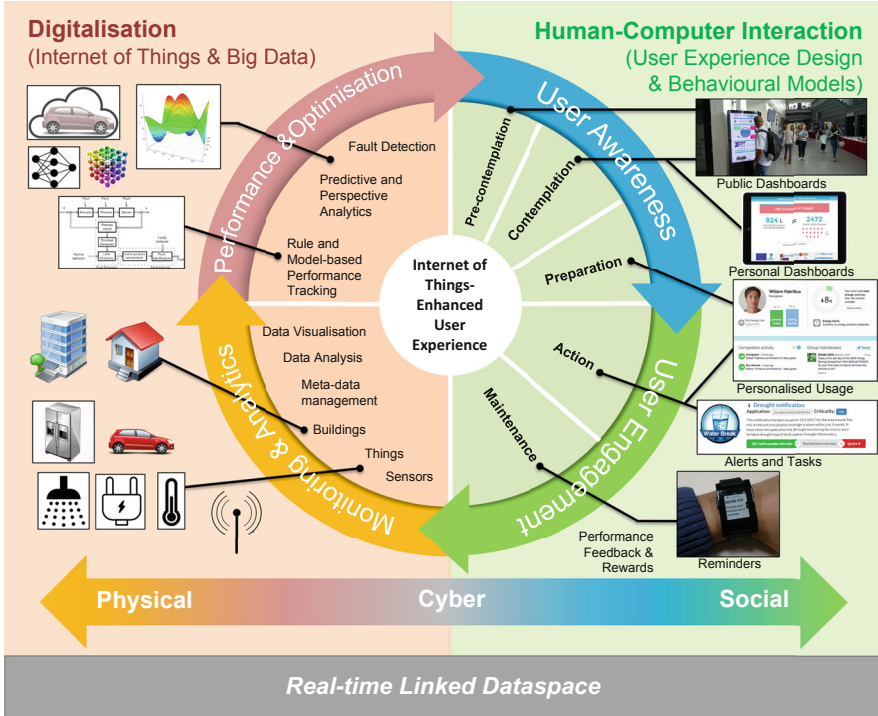


Fig. 17.2 A model for IoT-enhanced user experience. Adapted from [16]

A dataspace is a data management approach that recognises that in large-scale integration scenarios, involving thousands of data sources, it is difficult and expensive to obtain an upfront unifying schema across all sources [2]. We have created the Real-time Linked Dataspace (RLD) as a data platform for intelligent systems within smart environments. The RLD combines the pay-as-you-go paradigm of dataspace with linked data, knowledge graphs and real-time stream and event processing capabilities to support a large-scale distributed heterogeneous collection of streams, events, and data sources [4]. The RLD has support services specifically designed to support the management and processing of data from IoT-based smart environments and further details on the RLD is available in Chap. 4.

**17.3.2 HCI: A User’s Journey to Sustainability Using the Transtheoretical Model**

A key aspect of reducing water and energy usage is increasing user awareness about of their resource usage and changing their consumption behaviour. At the core of the HCI-side of the model, we leverage behaviour change theories. The central

assumption behind attitudinal theories of behaviour change is that by influencing a person's attitude positively towards a behaviour, they will subsequently act it out.

The 40-year history of Environmental Psychology research has provided a wealth of theoretical models and best practices for influencing sustainable behaviour. What remains a substantial challenge for designers in the HCI community, however, is the translation of these theories into useful and engaging experiences that have the potential to influence behaviour in a meaningful and long-lasting way. Many eco-feedback designs researched within the HCI community have lacked a theoretical connection to established psychological theory (from a recent review, it was less than half of the papers surveyed [342]).

### 17.3.2.1 Transtheoretical Model

As a framework with which to bridge multiple strands of behaviour change theory, the Transtheoretical Model (TTM) can be used as a guiding heuristic for the high-level design of the user experience. Developed by Prochaska et al. [343, 344], the TTM describes the “stages of change” a person goes through when modifying their behaviour. The model has been developed and applied primarily within the field of healthcare, for example, in exercise and addiction treatment. The TTM has also been researched as a framework for energy feedback technology design [345]. Below is a list of the TTM stages:

- *Pre-contemplation (“Not Ready”)*: User is unaware that their behaviour is problematic.
- *Contemplation (“Getting Ready”)*: User is aware of the problem and the desired behaviour change with an understanding of the pros and cons of their continued actions.
- *Preparation (“Ready”)*: User intends to take action in the immediate future and may begin taking small steps towards behaviour change.
- *Action (“Doing”)*: User is undertaking the desired behaviour.
- *Maintenance (“Check”)*: User works to sustain the desired behaviour change.

We use the TTM within the HCI side of our model to help identify user informational needs and appropriate persuasion strategies at each stage of change, acting as a guiding design heuristic. It should be noted that other models of behaviour change could also be considered, including the Behaviour Change Model (BCM) for sustainability by Geller [346]. BCM can be described as more focused on user behaviours and needs and is specific to the sustainability context. The TTM was preferred due to its perspective from the user's personal experience, which was useful in considering the user journey. Some applications focused on social influence and gamification strategies, and the TTM was seen as being more flexible when guiding design decisions outside of those aspects focused on sustainability.

### 17.3.2.2 User Journey

Using the TTM, we defined the user journey scenarios, as illustrated in Fig. 17.3. This strategy helps to consider the activities of users at multiple stages of engagement with intelligent energy and water systems. The user’s journey map is:

- *User is unaware of the problem (Pre-contemplation):* Create awareness about the issue. Highlight social norms, and the benefits of changing behaviour. Ensure a balanced argument and limited detail.

*Example intervention:*

- Receive an email invitation:  
“As an office worker, I want to receive information about how I can participate in the new energy and water saving initiative within my workplace.”

- *User is aware of the problem and the desired behaviour change (Contemplation):* Make a case for using the system. Appeal to values, and use persuasion strategies such as loss aversion, cognitive dissonance, and foot in the door technique.

*Example intervention:*

- Visit the promotional page:  
“As an office worker, I want to learn what the system does and how it can benefit my organisation and me.”

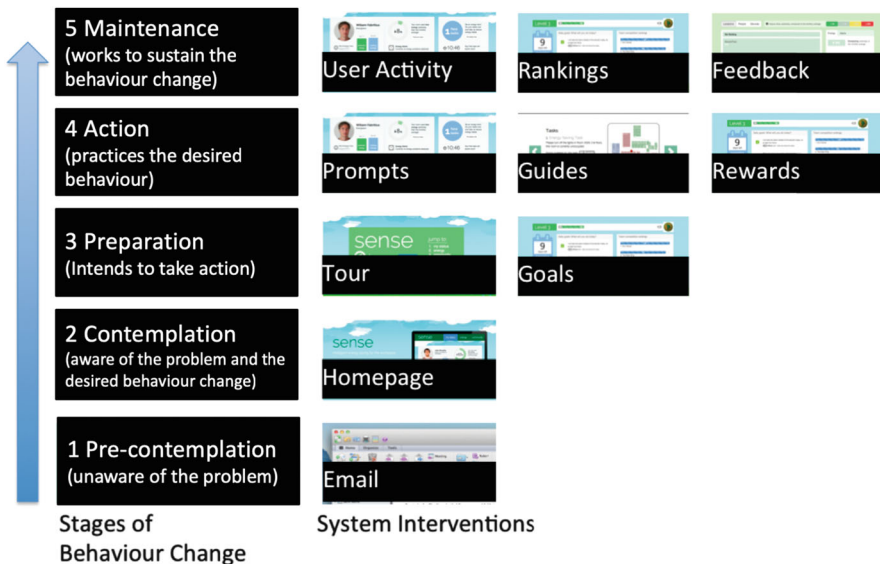


Fig. 17.3 Stages of behaviour change in the Transtheoretical Model aligned with interventions

- *User intends to take action (Preparation)*: Help users plan for change. Implement persuasion strategies such as goal setting and commitment. Provide support through mentoring.

*Example intervention:*

- First-time access to the dashboard:  
“As an office worker, I want to learn how to use the website and start saving energy within my workplace.”
- *User practices the desired behaviour (Action)*: Provide timely feedback and positive reinforcement for targeted actions. Encourage intrinsic motivation through personalisation.

*Example interventions:*

- Automatically assigning tasks to optimise energy usage:  
“As an office worker, I want to perform tasks assigned by the system so that I can help save energy in my building.”
- Automatically assigning tasks to monitor the environment:  
“As an office worker, I want to help the system in monitoring my building environment so that it can make better decisions about energy saving.”
- Automatically assign tasks to maintain occupant comfort:  
“As an office worker, I want to use the system to monitor my building temperature, to help maintain a comfortable working environment.”
- *User works to sustain the behaviour change (Maintenance)*: Help users form new habits. Use reminders and feedback towards goals. Encourage mentoring of others and keep journals.

*Example interventions:*

- View energy consumption feedback:  
“As an office worker, I want to use the system to monitor the energy consumption of my room and see the effect of my energy saving actions.”
- View competition feedback:  
“As an office worker, I want to use the system to monitor my personal and team’s progress within the energy saving competition.”
- Suggest a new energy saving goal:  
“As an office worker, I want to use the system to share new ways of saving energy with my co-workers.”
- *Relapse*: Relapse between stages can happen at any time.



## 17.4 TTM Intelligent Applications

Across the five pilot sites, we developed 25 different intelligent applications to support users to optimise resource usage from highly technical leakage detection applications for building managers, to the personal dashboard for office workers and children at home and at school. The process started with design examples of conservation systems within the HCI literature [342] and the commercial sector. User experience tests helped improve the final designs and revealed a high level of engagement from the users. To illustrate this process, we present the intelligent applications developed for the Smart Office Pilot in Galway.

In this pilot, the intelligent system was called SENSE, and it focused on the management of energy within the smart office, mainly targeting the office workers of the building. The following user interfaces were designed for SENSE users to support all the use case intervention scenarios described in the previous section, which follow the stages outlined in the TTM [343]. The three primary SENSE user interfaces we will detail are:

- *Promotional Homepage*: An information resource for describing the SENSE system.
- *Dashboard Tour*: A tour page providing a walk-through of the SENSE dashboard.
- *SENSE Dashboard*: A web application consisting of four sections, including Energy overview, Personal status summary, Community participation, and Tasks.

Each of these user interfaces supports the user journey identified in Sect. 17.3, by providing personalised and relevant information to the user. Table 17.1 details the five stages of the TTM aligned with the user journey together with suggested interventions [345] and the applications we developed for each stage.

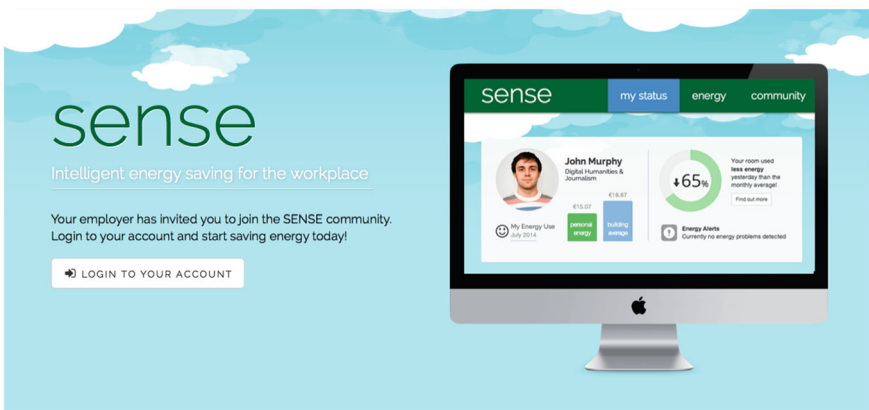
### 17.4.1 Promotional Homepage

The promotional homepage serves as an informational resource, helping new users to learn about the SENSE system (see Fig. 17.4). Through its design and the information provided, it seeks to establish credibility with the user and gain their trust, helping to bring users from the contemplation stage to the preparation stage of the TTM-based user journey. Design techniques used to establish credibility follow the guidelines outlined by Fogg [347]. The homepage aims to answer common questions new users may have such as: What is SENSE about? What can I do with SENSE? How does it work? What should I do next?

The homepage is limited to providing a general overview of the SENSE system when a user would like to learn more about how to engage with the site; they are encouraged to login and take a tour of the SENSE dashboard. For returning users, the homepage serves as a login portal, with easy access to the login dialogue provided.

**Table 17.1** Stages of behaviour change in the Transtheoretical Model aligned with interventions. The five stages of the Transtheoretical Model are used to define a user journey for smart energy and water environments. Adapted from [16]

TTM stage	User journey	User-centric intervention [345]	SENSE applications
Pre-contemplation	User is unaware of the problem	Create awareness about the issue. Highlight social norms, and the benefits of changing behaviour. Ensure a balanced argument and limited detail.	–Public dash-board –Newsletters
Contemplation	User is aware of the problem and the desired behaviour change	Make a case for using the system. Appeal to values, use persuasion strategies such as loss aversion, cognitive dissonance, and foot in the door technique.	–Personalised dashboard
Preparation	User intends to take action	Help users plan for change. Implement persuasion strategies such as goal setting and commitment. Provide support through mentoring.	–Personalised dashboards –Tour –Goals
Action	User practices the desired behaviour	Provide timely feedback and positive reinforcement for targeted actions. Encourage intrinsic motivation through personalisation.	–Personalised dashboards –Alerts Tasks –Guides, –Rewards
Maintenance	User works to sustain the behaviour change	Help users form new habits. Use reminders and feedback towards goals. Encourage mentoring of others, keep journals. Relapse between stages can happen at any time.	–User activity –Rankings –Performance feedback and reminders



**Fig. 17.4** The homepage top panel with a purpose statement and login button

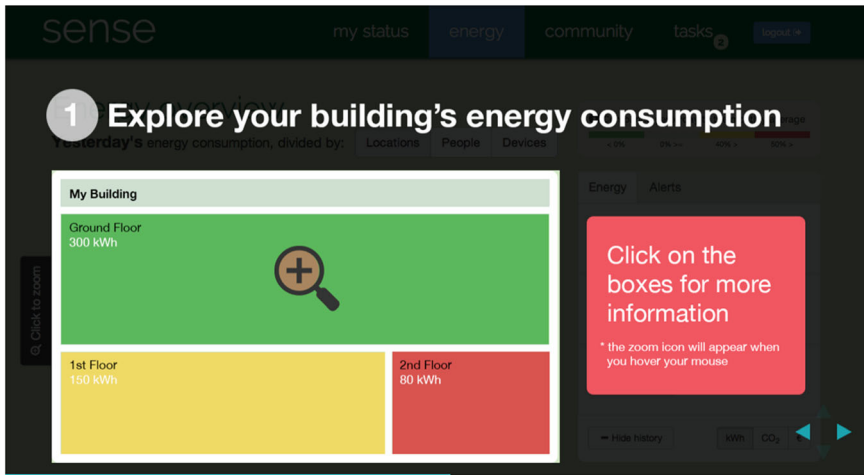


Fig. 17.5 Tour describing the interaction with the building energy overview

### 17.4.2 Dashboard Tour

The tour section aims to provide users with a brief overview of the SENSE dashboard. It supports the user in the preparation stage of the TTM-based user journey by providing a walk-through of each section, intending to help users to understand the building energy consumption and personal status feedback provided (see Fig. 17.5). The content of the tour includes:

- Understanding the meaning of personal energy consumption feedback in the *My Status* section.
- Interpreting and interacting with the building overview visualisation in the *Energy* section.
- The game mechanics underlying the *Energy Saving* competition
- Using task guides for performing energy saving (citizen actuation) and room inspection tasks.

The tour supports multiple modes of interaction to progress through the presentation, including mouse clicking the slide or using the keyboard arrow keys, space bar, or enter key. These interaction channels ensure that users do not spend significant time learning new interactions for a likely one-time activity. To allow for the use of the entire screen when presenting information, the visible controls are minimal arrows confined to the bottom-right corner of the screen.

### 17.4.3 Sense Dashboard

The SENSE Dashboard plans an important role for multiple stages of the user journey from contemplation and preparation to action and maintenance. The dashboard consists of four sections, including *Energy Overview*, *Personal Status Summary*, *Community Participation*, and *Tasks*.

#### 17.4.3.1 Energy Overview

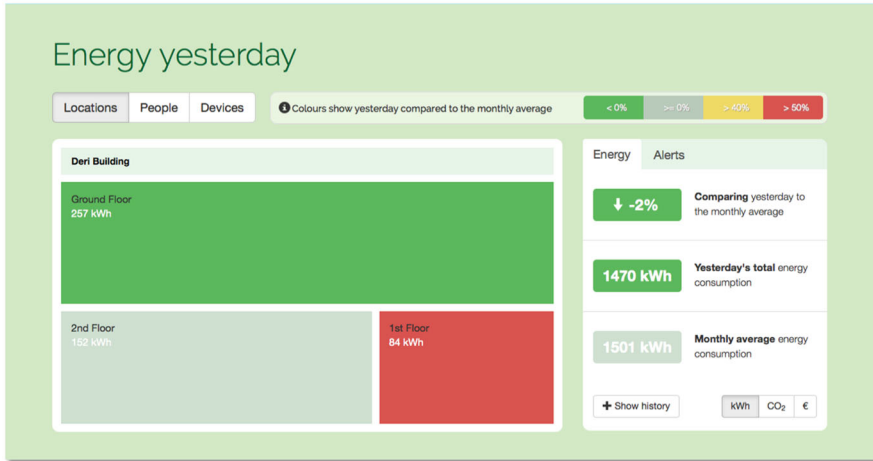
The energy overview section grew out of user requirements for detailed energy consumption reporting. Requirements outlined by users for displaying the energy data included:

- Showing a breakdown of energy consumption by building occupants, location, and devices.
- The ability to monitor energy consumption over specific time intervals (e.g. 1 day, 1 week).
- Showing trends and highlighting abnormal energy consumption to building occupants.
- Displaying energy consumption metrics in Kilowatt Hours, CO<sub>2</sub>, and Euros.

These requirements are primarily following the user research regarding preferences for energy information visualisations in the workplace [348, 349]. The energy overview section provides three perspectives on energy use within a building, each seeking to answer specific questions, examples of which are:

- *People-centric* (e.g. *personal activity, teams*):
  - How am I doing compared to others?
  - When is my energy consumption the highest?
  - Which is the best performing team in the building?
- *Location-centric* (e.g. *desk, room, floor, building*):
  - Which rooms are the most significant consumers/problem areas?
  - How does my room compare to other rooms?
- *Device-centric* (e.g. *lighting, heating, sockets*):
  - What device is consuming the most energy in my room? When does this occur?
  - Which devices are causing energy waste problems in my building?

To this end, several visualisations were researched to answer the questions outlined above. The primary challenge for selecting a visualisation was its ability to display a wide variety of information in a condensed area while still maintaining ease of learning. After consideration, the zoomable Treemap visualisation design



**Fig. 17.6** Energy consumption Treemap visualisation

(see Fig. 17.6) was chosen. The Treemap design, originally developed by Ben Schneiderman [350], follows the Visual Information Seeking Mantra, described as “providing an overview first, support zoom and filter interactions and provide details on demand” [351]. The design has gained broader appeal in recent years and has been recommended as a promising solution for displaying energy consumption trends [349].

### 17.4.3.2 Personal Status Summary

The personal status summary page provides a personalised overview of the user’s relationship with energy and their engagement in the SENSE system, including personalised feedback about the user’s energy consumption, the status of their room, the current tasks assigned to them and the activity occurring within their work community (see Fig. 17.7). The personal status summary is central to the action and maintenance stages of the TTM-based user journey.

The panel in Fig. 17.8a compares the user’s personal energy consumption to that of their colleagues, utilising the Social Proof strategy outlined by Cialdini [352]. The financial cost of the user’s personal energy consumption is contrasted with that of the average person in the building. Costs are aggregated over a calendar month, allowing users to track their progress while also having a normative influence (Social Proof [352]). Visual feedback is alternated depending on the status of this comparison. For example, if the user’s consumption is higher, their personal energy bar is coloured red and the face displayed beside their name is given a neutral expression. When consumption is below average, the colour is green, and a smiling expression is used. These indicators invoke Social Norms which are both descriptive (showing monetary values) and injunctive (showing moral judgement through facial expressions)

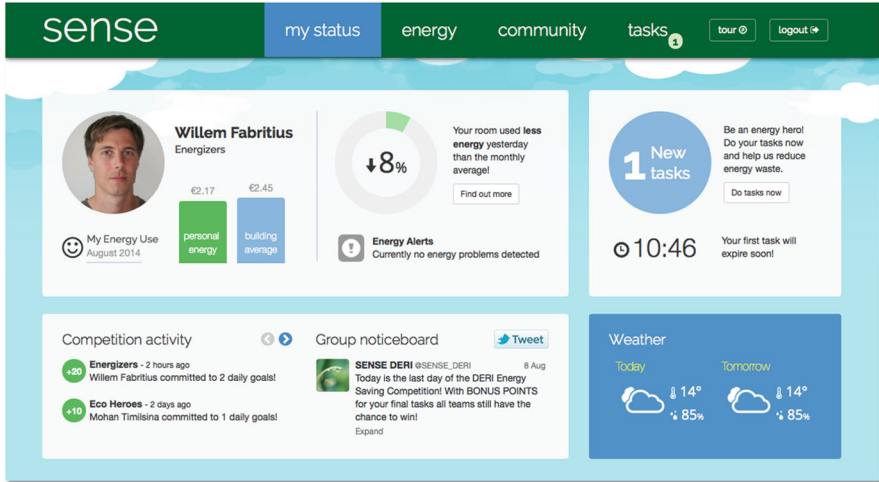


Fig. 17.7 Personal status summary

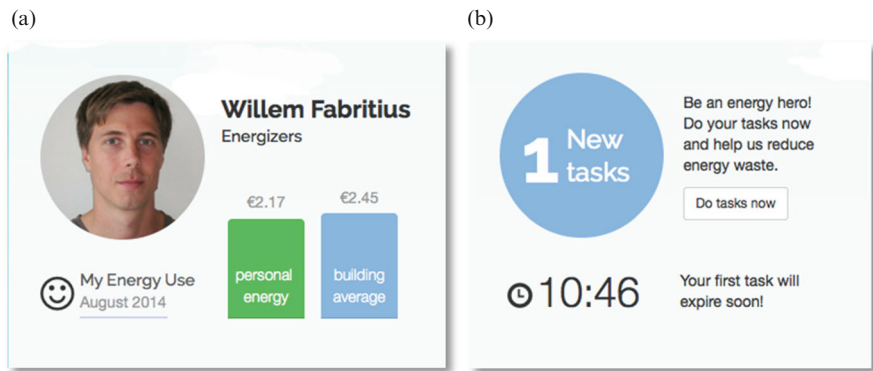


Fig. 17.8 (a) Personal energy consumption panel (b) Task notification panel

[352]. It is important to note that negative facial expression is not used due to observations made by [353] when using this feedback strategy, where complaints were received from customers.

The prominence and proximity of the user’s name and photo aim to highlight that the energy consumption recorded is a personal reflection of themselves within their organisation. This can trigger cognitive dissonance [354] when a user’s personal image of being environmentally conscious does not match with the message portrayed. Also, the prominence of the team name appeals to the user’s sense of relatedness, a strategy for establishing Intrinsic Motivation [355].

The task notification panel in Fig. 17.8b is the most important section of the Personal Status summary. This panel serves as a call to action for users to perform tasks, and it employs a variety of techniques to attract their attention. Firstly, when a

task is available, the panel uses a flashing animation to attract attention. This type of visualisation creates a strong response [356] and should be used sparingly; therefore, after 5 s, the animation ceases. Secondly, the expiry time is highlighted to the user with a countdown clock animation. This indicates the limited window of opportunity for the user to perform the task, employing the strategy of Scarcity [352]. Finally, the use of “labelling” feedback appeals to the user’s sense of identity (“Be an Eco-Hero”) [357] eliciting desirable associations of eco-friendliness (Biospheric values [358]). This message could equally be adapted to elicit associations of being a team player (Altruistic) or money saver (Egoistic), depending on the user’s personal values [358].

### 17.4.3.3 Community Participation

The community participation section (see Fig. 17.9) is important for the maintenance stage of the TTM-based user journey as it provides a platform on which to run energy saving competitions among teams in the workplace. The interface uses a “points, badges and leaderboard” system (commonly known as the PBL gamification strategy [359]). By appealing to the user’s sense of competence, autonomy, and relatedness, intrinsic motivation can be increased, encouraging users to participate in an activity for their own inherent pleasure (e.g. the fun factor) [355]. For example, by encouraging users to form teams and engage in friendly competition with their co-workers, a sense of relatedness is created [355].

Extrinsic motivators are also involved, such as a user’s desire for rewards and status [360]. We will now explore three key panels in this section for daily goals, team competitions, and rewards.

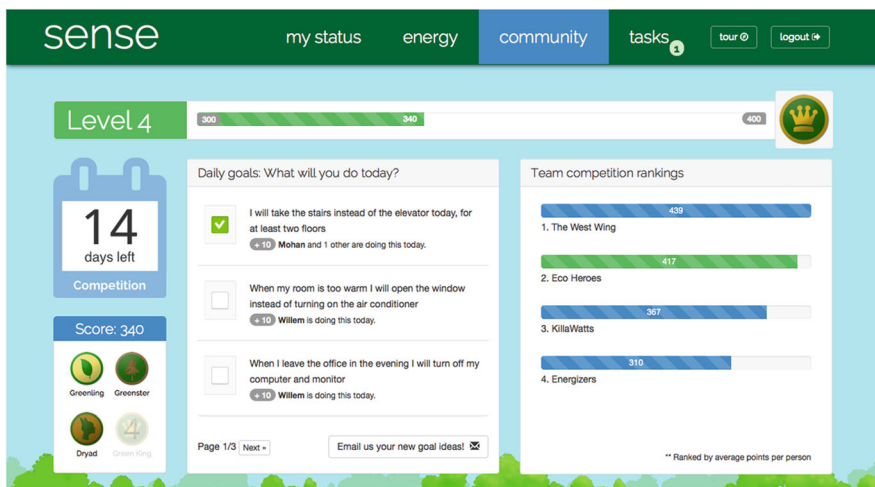
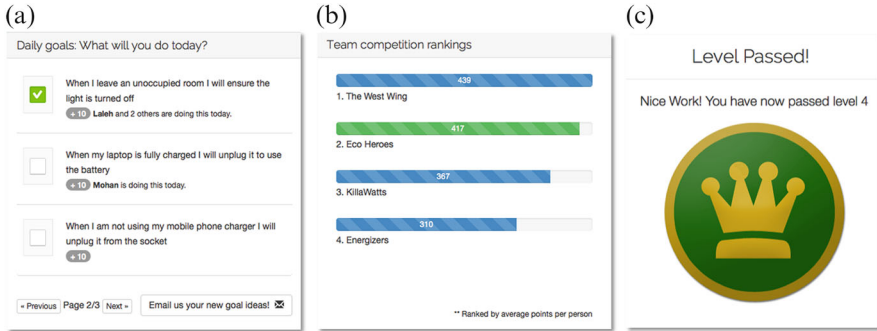


Fig. 17.9 Community participation section



**Fig. 17.10** (a) Daily goals panel, (b) Team competition rankings panel, (c) Rewards panel

**Daily Goals Panel** This panel [see Fig. 17.10a] allows users to publicly commit to energy saving goals, which is shown to be an effective motivation strategy [361–365]. The goals listed address common issues of energy waste in office environments; activities that are generally easy to perform and accepted as “best practices” [366]. By committing to a goal, users earn points which help to improve their personal score and team rankings. Users are required to visit the website daily to make these commitments, helping to drive traffic to the website and serving as a reminder. Participants can submit new goal suggestions via the email link at the bottom-right of the panel. Allowing users to select and suggest their own goals appeals to the users’ sense of autonomy, an essential factor in intrinsic motivations [355]. The goals’ written format utilises the Implementation Intentions strategy [367], whereby anticipated situational cues are used as an anchor to trigger the desired behaviour [368] (e.g. “When I leave the office I will turn off my computer and monitor”).

The names of other users who have committed to a goal are displayed within the goals panel, encouraging influence through the social proof strategy [352]. Also, the knowledge that the users’ own commitments will be made public, increases the likelihood of compliance with the stated goals, by appealing to their desire to show the consistency of character within their peer group [352].

**Team Competition Rankings Panel** The team rankings panel [see Fig. 17.10b] allows users to receive feedback on their team’s status within the energy saving competition, appealing to a user’s competitive nature and desire for status [360]. By focusing on team level rankings, users are not singled out by their peers in terms of performance, which was a significant concern highlighted in the user research conducted by Foster et al. [369]. Comparative feedback among teams has been shown to be effective in previous research on workplace energy consumption reduction [370]. Displaying a set time limit for the competition using a calendar utilises the Scarcity principle [352] for user motivation.

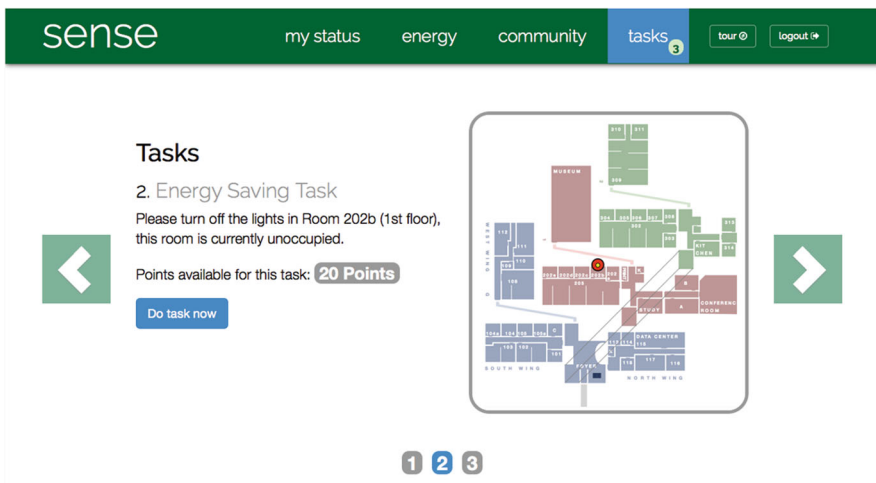


**Rewards Panel** Competitions are shown to appeal more strongly to certain personality types as well as personal achievements to others (e.g. using Bartle’s Character Theory this maps to Killers and Achievers, respectively [371]). Providing rewards such as points and badges [see Fig. 17.10c] can appeal to these types, with a sense of achievement coming from level progression as opposed to outperforming other players [360]. The level progress bar [see Fig. 17.10c] allows users to receive immediate feedback on their progress, appealing to a user’s sense of competence [355] and providing positive re-enforcement [372] (Fogg’s Conditioning principle [373]).

### 17.4.3.4 Tasks

Two types of tasks are available in the smart office pilot: (1) data management tasks and (2) citizen actuation tasks for energy savings. These tasks are implemented using the human task service of the RLD. Further details on this service are available in Chap. 9, and an example of an energy saving task is provided later in this chapter and also in Chap. 16.

The tasks interface is arguably the most important section in the dashboard, helping to guide user actions to solve energy waste problems directly as part of the action stage of the user journey. The interface utilises Fogg’s Suggestion and Tunnelling principles [373], by prompting users and providing task instructions to guide them through the task. The task instructions include a building map for identifying the location of the task (Fig. 17.11), a task instruction gallery with a step-by-step walk-through of how to perform a task (Fig. 17.12) and form inputs describing the data required for collection (Fig. 17.13).



**Fig. 17.11** Energy saving task description

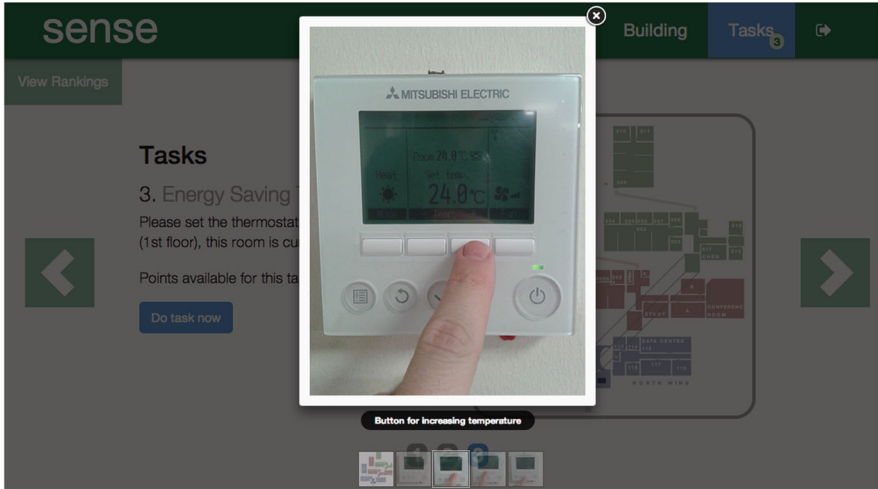


Fig. 17.12 Occupant comfort task instruction gallery

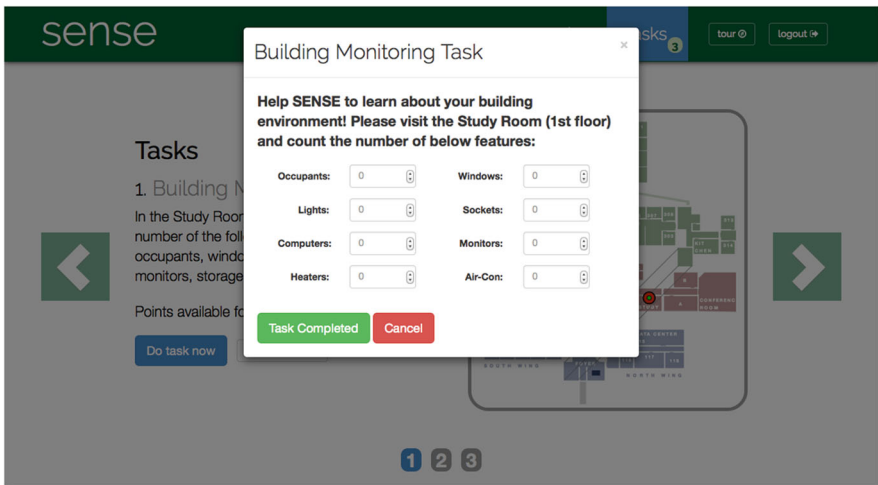


Fig. 17.13 Room inspection task form

## 17.5 User Study

This section presents the results from deploying the model for IoT-enhanced user experience in the smart environments described in Chap. 14. In this section, we detail the methodology used within each pilot, the energy and water savings achieved in the pilots, and the changes in user awareness at the pilots.

### 17.5.1 Methodology

In general, the pilots followed a similar methodology for the design, deployment, and evaluation of the system. The high-level research methodology followed during the evaluation of the deployed intelligent systems is summarised in Table 17.2. During the initial period of the pilots, metering data was collected from existing systems to establish baselines across all pilots. During the control period, the users within the pilots had access to the data generated by the metering infrastructure system through traditional information systems (e.g. Building Management System, and basic public dashboards within the airports, office building, and school). The data collection period for each pilot spanned between 6 and 16 months, which also included a range of user interventions such as pre-surveys, focus groups, interviews,

**Table 17.2** Research methodology for pilot sites. Adapted from [16]

Pilot Site	Location	Users	Study period	Baseline	Method
Smart Airport	Linate Airport, Italy	Corporate users Passengers	10 months	Pre-study water and energy usage	Passenger survey User trials Staff questionnaires
Smart Office	Insight, Ireland	150 Office workers	6 months	Average energy usage	User study (11 participants) Field study (6 participants) User trials (4–6 participants)
Smart Homes	Thermi, Greece	Domestic users Utility providers	16 months	Manually recorded monthly water usage	Preliminary questionnaires (8 participants) Focus groups Interviews
Mixed Use	National University of Ireland Galway, Ireland	University students Staff & management Public	16 months	Pre-study water and energy usage	Pre-intervention survey (110 participants) User trials and feedback cycles Post-intervention survey (110 participants)
Smart School	Coláiste na Coiribe, Galway, Ireland	School students Staff & management Public	12 months	Pre-study water and energy usage	Awareness questionnaire (150 participants) User trials and feedback cycles Post-intervention survey (70 participants)

and feedback cycles. The user experience evaluation included usability testing, usability field study, and user trials.

### 17.5.2 Impact

The RLD supported the development of more than 25 intelligent applications following the model for IoT-enhanced user experience to serve diverse user groups in five smart environments and provided relevant data for effective data analytics to raise awareness and detect faults. The energy and water saving opportunities identified at the different pilot sites and their estimations in terms of costs and CO<sub>2</sub> emissions (see Table 17.3) were significant and convinced building managers and users to take actions and to further expand the approach to other areas (e.g. expand the smart airport pilot to Malpensa Airport).

In terms of increasing user awareness, the goal of the pilot applications was to provide personalised and actionable information about energy and water consumption and availability to individual users intuitively and effectively at a time scale relevant for decision-making. Access to this information helped increase end-user awareness and improved energy and water consumption. As detailed in Table 17.3, the level of user awareness was increased at four out of five pilot sites. In the mixed-use site where there was no increase in awareness, the pre-intervention surveys indicate that the sample populations exhibited a moderately high level of awareness. Post-intervention awareness surveys were found to be statistically insignificant due to the high baseline level of awareness. Since pre-intervention surveys already indicated a high level of awareness, small differences that might or might not have occurred would have been difficult to capture.

**Table 17.3** Impacts on energy and water saving and user awareness for pilot sites. Adapted from [16]

Pilot Site	Actual savings measured	Estimated annual savings	User awareness
Smart Airport	2954 m <sup>3</sup> 3013 kg CO <sub>2</sub>	54,000 m <sup>3</sup> 55,080 kg CO <sub>2</sub>	Increases awareness of the problem Increase of responsibility and Personal norms
Smart Office	23.86% energy use reduction	–	Increased awareness of usage
Smart Homes	30% water use reduction	–	Increased awareness of usage
Mixed Use	174 m <sup>3</sup> 177 kg CO <sub>2</sub>	8089 m <sup>3</sup> 8251 kg CO <sub>2</sub>	Limited increase (high existing awareness baseline)
Smart School	2179 m <sup>3</sup> 2223 kg CO <sub>2</sub>	9306 m <sup>3</sup> 9492 kg CO <sub>2</sub>	Increased awareness in teachers Increased awareness of junior students Limited increase in senior students (high existing awareness baseline)

## 17.6 Insights and Experience Gained

Based on a reflection of our experience across the pilot sites, the following lessons were identified as key learnings on developing IoT-enhanced user experiences. They can be used to inform the design of the user experience of future intelligent applications within smart environments.

**Minimise Cognitive Overload with Clear and Focused Applications and Visualisations** Within the pilots, it was shown that participants preferred applications and visualisations that had a low cognitive load. Complex applications with full functionality were demanding for users to learn and understand. Users wanted simple (often single purpose) applications over more elaborate multi-purpose ones. We recommended that visualisations and applications be tested early and often to ensure they are easily understood (matching the target users' mental model), and serving the information needs and goals of the target users [374, 375]. Strategies that can be employed to achieve more natural cognition include providing a simplified core message with the ability for users to dig deeper on demand (Progressive Disclosure [374]), harnessing the user's prior experience with design conventions (Consistency [374]) and conceptual knowledge (Priming [374]).

**Understand Your Users' Needs and Their Journey** When designing intelligent applications, consider users and their stage on the journey. Customising the applications to support a specific task or action helped to capture their interest and increase engagement. Within our pilots, we delivered 100 "personalised" versions of the 25 different intelligent applications to meet the specific needs of users. For example, building managers operate daily in the "Action" phase of the TTM and are interested in applications with concise messages that help them take immediate actions. Technicians were more interested in task-oriented applications with detailed consumption charts for a dedicated analysis and identification of potential issues in the system. At the other extreme, airport passengers, parents, and kids at the "(pre-) contemplation" phase with a more casual interest wanted applications to help them explore the smart environment to learn more about it.

**Social Influence and Interaction are Strong Motivators** Social influence was shown to be a strong motivator, which is consistent with observations found in the environmental psychology literature, particularly in the workplace [376]. The use of gamification with leaderboards and social benchmarking was effective in the pilots with users enjoying the friendly rivalry and social interaction with peers. However, the critical question remains if this strategy can maintain user interest in the long term? One answer may lie in the theory of intrinsic motivation, in which behaviours are performed for their inherent pleasure and are, therefore, more durable [374].

**Close the Feedback Loop with Personalisation** Within the pilots, users had a strong desire to have responsive feedback regarding the impact of their energy and water saving actions, allowing them to track their progress in a closed feedback loop [374]. This strategy appeals to the user's desire for control or mastery, increasing



actuation task that requires a user to change the state of the building for energy saving. First, the tasks are generated based on the observed state of the building (e.g. an empty room with lights turned on, or a window open in a room with AC on) through motion and light sensors. Then, it is routed to an occupant in the building who is within the vicinity of the room. The task is also contextualised to provide the required information for performing the task, as well as the associated rewards.

Based on our experience, tasks with short deadlines need to be pushed to users through real-time communication channels (e.g. instant messages); otherwise, tasks can be presented through an appropriate search and browse interface. While some tasks might get users' attention due to their altruistic nature, proper incentives need to be designed and implemented for sustainable participation of users over time (e.g. leaderboards, badges, rewards).

**Careful Use of Targeted Alerts and Notifications** Information overload in IoT-based systems can overwhelm users. To minimise the search friction between actionable information and users, a well-designed notifications system is needed. Emerging technologies and practices in user experience show that notifications will probably play a much more significant role in IoT-based systems [379]. Within the pilots, we aimed to enable notification to attract users' attention only when necessary—furthermore, the notifications needed to deliver actionable information to users. For example, building managers wanted alerts on faults and optimisation opportunities. They had little interest in exploring charts of usage data, often commenting they do not have time to analyse data to gain any insights. In the pilot evaluations, it was found that the frequency of fault alert notifications must be carefully considered. Overwhelming recipients with notifications of potential faults were found to be counter-productive, leading to a potential disregarding of alert messages.

## 17.7 Summary

Creating a compelling user experience within a smart environment (from smart buildings to smart cities) is an essential factor to success. In this chapter, we introduce a model for Internet of Things (IoT)-enhanced user experience for smart environments. The model is broken down into two parts, one with a focus on *Digitalisation* of the Environment using IoT and Big Data, and the other on *Human–Computer Interaction* (HCI), with a focus on the users' journeys using behavioural models and user experience design. We use the model to develop a journey for users within the context of intelligent energy and water systems using the Transtheoretical Model as a guiding heuristic for the high-level user experience design. Several applications were built following the Transtheoretical Model of behaviour change to guide a user's journey to improve their sustainability. The chapter detailed our experience of developing IoT-based intelligent applications within a smart home, school, office building, university, and airport, where the

goal was to engage a wide range of users (from building managers to business travellers) to increase water and energy awareness, management, and conservation. The Real-time Linked Dataspace simplified the process of developing these personalised applications by supporting the gathering of data from different sources in the smart environment.

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