Events Processing and Device Interoperability in a Smart Office IoT Application

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Abstract. *The paper presents the Smart Office concept, which was proposed as a pilot application in the FP7 project ELLIOT. The solution is based on the LinkSmart semantic middleware that provides an Internet of Things platform for interoperable functional connection of devices, sensors, services, and software systems. The means of processing low-level events generated by devices are discussed together with an extension of the middleware on business rules and process workflows.*

Co-creative development and adaptation of the application is supported by the Living Lab environment. Interactions of users with the Smart Office are evaluated according to the knowledge, social, and business aspects. The feedback obtained from users can then be used to adjust the business processes of the application. The structure of devices and processes supporting this approach is presented for the office room where the Smart Office prototype was installed and is operating in the first trial of the pilot application.

Keywords. Interoperability of devices, Internet of Things, Ambient Intelligence, Living Lab, Smart Office application, events processing

1 Introduction

The concept of Ambient Intelligence (AmI) is usually connected with applications requiring proactive, but sensible interactions between various devices, sensors, software systems, and involved users; i.e. with the solutions that are capable to "support people in their daily lives" [4]. It includes the features of device networking, sensitivity, adaptivity, transparency, ubiquity and intelligence embedded in various devices employed in everyday life activities of people, which leads to the infrastructure that is nowadays referenced as the Internet of Things (IoT) approach [3]. A list of alternative definitions of AmI, together with the respective features and the distinctions of AmI with the related research and development fields such as pervasive computing, ubiquitous computing, and artificial intelligence, is provided, for example, in [6].

Typically, the paradigm of AmI specifies the main characteristics of systems and technologies possessing the ambient intelligence as follows [2]:

- *Embedding*: services are integrated directly into the devices, while the devices are networked and integrated into a common environment;
- *Context awareness*: devices can recognize the user and his/her situational context;
- *Personalisation*: user profiles, needs and preferences are taken into an account, as an extension of the situational context and/or as a frame of the embedded service settings;
- *Adaptivity / adaptability*: devices or set of devices are able to change their behaviour and/or state in a response to user's requests, inputs obtained from another devices in a network, or changes in the situational context;
- *Anicipating*: devices can anticipate user's desires by means of various knowledge models and prediction techniques.

The last four characteristics of this outline address the interfaces between people and devices. Indeed, the interactivity is considered as one of the most an important aspects of AmI [4], targeting the reduction of explicit human-computer interaction by an intelligent inference of situations and user needs from the observed human activities. Moreover, to ensure a desired level of adjusting an AmI/IoT solution to the user's needs, the interactivity between people and devices should be reflected during the design phase already; in an ideal case, users could be involved directly into the design, implementation, testing, and continual improvement of the application. The so-called people-centric design [1] is an underlying principle of the co-creative Living Lab environment [17], which can be applied to facilitate the involvement of relevant stakeholders in the design, development, and testing of AmI/IoT applications towards innovative solutions that can be potentially accepted by a wide community of users. This approach was adopted in the FP7 project ELLIOT (`http://www.elliot-project.eu`) targeting the development of an experimentation and co-creation platform for AmI/IoT applications, where the user iteraction and experience is measured and evaluated by means of knowledge, social, and business characteristics [5]. The ELLIOT platform is built on the LinkSmart middleware [18], which is an IoT-enabling technology originally developed in the FP6 project Hydra (http://www.hydramiddleware.eu) and its futher enhancements are ongoing within the FP7 project EBBITS (http://www.ebbits-project.eu). Host institutions of the authors were/are participating as development partners in all three mentioned projects and the authors are actively involved in the development of the respective solutions.

In the following sections, the Smart Office is presented as one of the pilot applications of ELLIOT. The focus is given on the processing of events and interoperability of sensors, achieved by employing semantic web service interface provided by the LinkSmart infrastructure.

2 Related research

The concept of Smart Office is still rather new and, in comparison to the well-established Smart House, can be considered as mostly a research topic [16]. However, in the last few years this topic is addressed in literature as a separate research domain namely as a specific type of AmI applications [7],[14]. Key features of a Smart Office application include continuous monitoring of business environment, prediction, autonomy, and adaptation.

The approach adopted in ELLIOT emphasizes the adaptation feature, which can be achieved by means of co-creation and collaborative development of the Smart Office in an experimental environment of Living Lab [15]. Moreover, it is proposed to integrate social, cognitive, economical, legal and ethical aspects related to IoT technologies and services into a holistic meta-model covering knowledge, social, and business aspects of interactions between people, services, and devices [5].

Another relevant research area is related to the LinkSmart middleware, which is employed as the main AmI/IoT building block for the Smart Office application. The Internet of Things, with an extension to people and services, is innovative and rapidly evolving research and application domain that addresses effective and adaptable, so-called intelligent, communication and information exchange between various devices, sensors, services, information systems, and resources. In the European context, the IoT(SP) research is supported, for example, by the CERP-IoT cluster [19], which helps to co-ordinate the research efforts in the involved FP6/FP7 projects, including Hydra and EBBITS. Investigations on the IoT(SP)-enabling middleware are in focus of such projects as, for example, ASPIRE, BRIDGE, CoBIs, CuteLoop, etc. A more detailed survey of relevant projects and approaches can be found, for example, in [12]. Trends in the IoT(SP) domain include efficiency and practical applicability of the solutions, shift towards business processes, event-driven architectures, adaptability and autonomy of “things”, advanced user interfaces and means of maintenance, usage of semantic technologies for more intelligent communication and information exchange, etc. Some of these features are also addressed by the LinkSmart extensions that are ongoing in EBBITS, as it is presented in section 4.

3 The Smart Office Living Lab

The Smart Office is a type of AmI/IoT application that is similar to the well-known Smart House concept, but is applied in an industrial or business environment [16]. It implies that, besides the networking and interoperability of various devices, sensors, and business information systems, the Smart Office is focused on facilitating user interactions driven by business processes or workflow sequences established in such an environment. Expected benefits on business process optimisation, improvement of working conditions for employees, or overall increase of work effectiveness can be achieved by adjusting the Smart Office application in a co-creative environment of Living Lab that enables measuring and evaluating interactions between people and devices during the work.

3.1 KSB model

The ELLIOT platform provides the KSB (Knowledge-Social-Business) experience model [5] as a mechanism for investigation, measurement, and evaluation of the quality of user interactions in an AmI/IoT application. The model is implemented as a taxonomy, a hierarchical structure of semantic concepts that represent particular knowledge, social, and business characteristics of an application. The taxonomy is connected onto a multimedia ontology, where the concepts are instantiated into a textual and audio/video content representing speeches, gestures, movements, face expressions that can be interpreted as manifestations of a KSB experience.

The KSB experience model captures the social, business, and knowledge aspects of user interactions and this way it is capable to represent a human behavior in the presence of IoT scenarios. The aspects of interactions can be seen as space dimensions that form a triangle of knowledge, social, and business characteristics, as it is depicted in Figure 1. The target can be set up in the middle of the triangle, if it is required to balance all three KSB aspects equally; or it can be placed near to any dimension that needs to be emphasized in the evaluated AmI/IoT application.

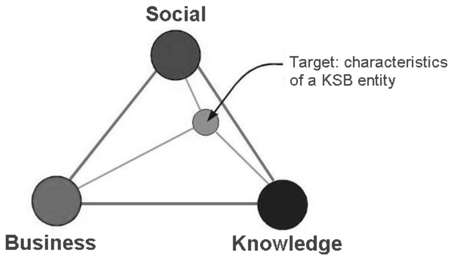

Figure 1. The KSB experience model [5].

The knowledge, social, and business characteristics in the KSB experience model typically correspond to a set of quantitative KPIs (key performance indicators), which are specified for particular AmI/IoT application. During the application run time, the KPIs are regularly calculated and the distance from the target is evaluated in the KSB model by means of semantic matching. The information on the difference between the target and the actual KSB value is then provided as a feedback and may be used to adjust the AmI/IoT application towards a desired level of balanced KSB aspects.

The KSB experience model is embedded in the ELLIOT platform and is applied by project partners on several use cases in the logistics, health care, green services, smart sensors, and retail domains. The here-presented Smart Office pilot application addresses the optimization of energy consumption in an office, together with a desired improvement of working conditions for employees. A set of the corresponding KPIs designed for this pilot in accordance with the KSB model is described in the next subsection.

3.2 The concept of an energy efficient Smart Office in ELLIOT

The Smart Office pilot application of the ELLIOT project tries to employ the Smart House paradigm in a business environment, focusing namely on an optimisation of business processes in offices with respect to the energy consumption and improvement of working conditions for employees. Interactions of employees in the office are monitored by a set of dedicated sensors and devices, processed by the semantic AmI middleware in accordance with specified business processes (cf. section 4), and transformed to the KPIs compatible with the above-described KSB experience model. The ELLIOT platform evaluates the KSB aspects and provides a feedback for both system users and semantic middleware, where the obtained information can be used to update the underlying processes accordingly. The Smart Office pilot application is designed in ELLIOT as a Living Lab that enables co-creation and experimenting with settings of sensors, devices, business rules, KPIs, personal preferences of users, and other system parameters. The structure of the Smart Office pilot is presented in Figure 2.

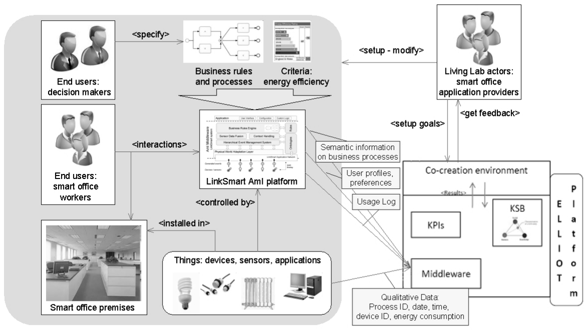

Figure 2. The Smart Office structure.

To evaluate the knowledge, social, and business aspects of the Smart Office application in a Living Lab environment of ELLIOT, we have designed a set of respective high-level KPIs as follows:

Knowledge KPIs:

- Business process models created for various scenarios of workflow in the office (i.e., Meeting Room, Working Units, or Collaboration scenario, cf. section 4.4);
- Semantic structures (ontologies) specifying metadata for complex events, input and output characteristics of services, business rules, etc.;
- Awareness of energy consumption (and possible energy savings) for particular tasks and employees in a given workflow.

Social KPIs:

- Level (frequency, efficiency, etc.) of interactions between employees collaboratively working in a workflow scenario;
- Acceptance level of proposed workflow modifications, both from employees and decision makers;
- Personal preferences of particular employees on the working environment (i.e., level of adaptability for a team work, acceptance of requirements or preferences of colleagues on light, heating, air conditioning, etc.);
- Proposals for modifying the workflow scenarios, based on the evaluation of KSB aspects and measured sensor data.

Business KPIs:

- User satisfaction, level of adaptation of working environment to personal preferences of employees (in a relation to the working performance of employees);
- Effectiveness of collaborative goal-oriented work of employees in the office;
- Appropriateness of the underlying business process(es) for achieving defined business goals.
- Energy efficiency; for example, overall or average energy consumption (per device or globally for the whole office);
- Usage of devices for particular tasks (i.e. frequently / rarely used; may include an indication of errors in device functionality).

The presented high-level KPIs were specified as expected benefits of the Smart Office pilot, targeting the energy efficiency, satisfaction of employees with their working environment, and optimization of business processes that scaffold the working scenarios in the office. More detailed specification and instantiation of KPIs is assumed for each particular Smart Office application, in accordance with the applied operational scenario (cf. section 5).

The Smart Office pilot and the respective Living Lab environment was installed in premises of RWE IT Slovakia, s.r.o., a subsidiary of the RWE Group. The installation itself is maintained by the InterSoft, a.s., an application user partner of the ELLIOT project. Both companies collaborate closely on the pilot specification, design, and installation.

The pilot application is located in the office of open space room type, occupied by eight employees. The room is equipped by computers and monitors for each employee, together with a shared printer and scanner. The office room has connected to a central heating system, air conditioning is controlled individually for the room. For the purposes of the Smart Office application, additional sensors and AmI-enabled devices were installed upon this infrastructure (see Figure 5 in section 4.3), integrated by a control unit consisting of a semantic AmI/IoT middleware and the ELLIOT platform. The underlying technology and device structure of the Smart Office pilot is described in the following section.

4 A middleware for IoT applications

Both the ELLIOT platform, as well as the Smart Office system itself, are built on the same semantic infrastructure of the LinkSmart middleware [18], which provides means for inclusion of heterogeneous devices into an AmI/IoT application. By wrapping a low-level API of devices, sensors, or various software systems with a defined web service extension, LinkSmart enables the interoperability of devices and provides an uniform access to their functionality [13].

The LinkSmart middleware was originally developed in the FP6 project Hydra and is currently available on the SourceForge.net as an open source project [18]. However, the development of LinkSmart is still ongoing, for example, within the FP7 project EBBITS, where both host institutions of the authors are involved as development partners. The LinkSmart updates in EBBITS are namely focused on an extension of the events processing, inclusion of business rules and process workflow structures [12], as well as on scalability and performance improvements of semantic repositories. Since these enhancements are fully in line with the requirements of Smart Office, the LinkSmart middleware was taken in ELLIOT as the core platform for this AmI/IoT application.

4.1 The LinkSmart architecture

A high-level architecture of the LinkSmart middleware is presented in Figure 3, including an outline of interactions with the ELLIOT platform in the Smart Office application. LinkSmart is build on semantic technologies, which are combined with web services and service oriented architectures [9]. The LinkSmart ontologies provide a meta-data specification for combining low-level sensor data into more complex hierarchical events, which are enhanced by a contextual information resolved from the underlying semantic structures. The fused events are further wrapped by a web service interfaces, where the input and output characteristics are semantically described as well. This way, the semantic interoperability of event-based web services is enabled and services can be dynamically included in business rules and workflow sequences exposed to the interface of front-end applications.

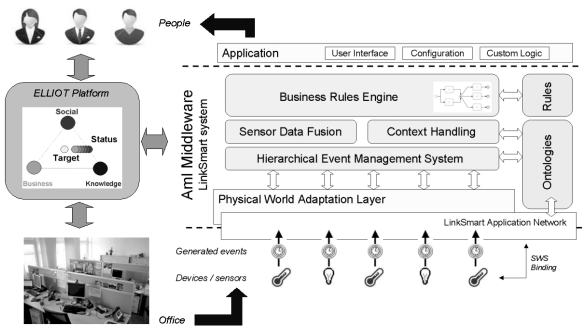

Figure 3. The LinkSmart middleware included in the Smart Office application.

The Physical World Adaptation Layer (PWAL) is implemented as a set of supported protocols for object oriented (CIP, Common Industrial Protocol) or wireless (6LoWPAN) communication with devices. In addition, several network connections like ZigBee, Bluetooth, or WLAN are provided as well. The API of a device, exposed by some of the supported communication protocols, is then transformed to a web service interface of the OSGi framework (`http://www.osgi.org`). Properties and input/output parameters of the web service are semantically modeled in LinkSmart as instances of concepts in the *Device.owl* ontology [13].

The inner middleware components for sensor data fusion, hierarchical events processing, context handling, and business rules processing are enclosed in the business logic layer of LinkSmart. Updates proposed for LinkSmart in FP7 projects EBBITS and ELLIOT are mostly focused on these components, as it is described in the next subsections. The events processing currently uses the publish/subscribe model, together with significantly enhanced semantic representation of events and event types [12]. The components for business rules and workflow maintenance, which were added to the LinkSmart infrastructure in EBBITS, are especially important for the Smart Office AmI/IoT application, since they enable a connection with KPIs as well as the means for visualization and management of user interaction processes in the office.

4.2 Events processing model

The events generated by physical devices and sensors are transformed in PWAL to web services, normalized and annotated by semantic characteristics that were resolved from the *Events.owl* ontology. In early versions of LinkSmart, the events were represented in a simple attribute-value format. It was, however, redesigned in EBBITS to a more complex semantic representation, which enables employing advanced clustering, sensor data fusion, semantic search, mediation, and reasoning mechanisms that are supported by applied RDF triple store framework and related reasoning engines [10]. This approach makes the representation of events compatible with other semantically expressed or annotated data such as object models of devices, services, or business rules. Consequently, it allows an inclusion of both low-level and complex events into process models, where they may act as triggers of particular tasks or business rules.

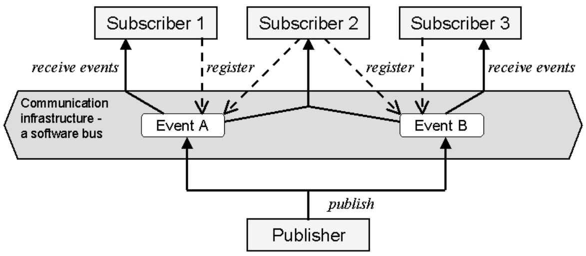

Figure 4. Publisher-subscriber schema of eventing.

To support the role of triggers for events, the Publisher/Subscriber model was adopted for events processing in EBBITS [11]. The publish/subscribe schema provides two principal players, the publisher (an information producer) and the subscriber (an information consumer). The publisher entity publishes the events on a software bus, while the subscriber expresses his/her interest in a specific part of information (an event or a pattern of events), submitting related subscription. The subscriber is notified when the submitted subscription matches an occurred event or a pattern of events. This communication model, schematically depicted in Figure 4, provides simple and efficient methods for distributing information and guarantees decoupling in terms of time, space and synchronization, between publisher and subscriber [8].

The LinkSmart system is typically installed in a peer-to-peer network, where each device is connected to a separate LinkSmart instance that represents a network node. It implies that the above-presented concept of publish/subscribe schema needs a slight modification. The service bus can be replaced by distributed network infrastructure of peer-to-peer nodes that communicate on the subscription and publishing principle. The information exchange between devices is managed by a control unit, which is again a LinkSmart instance with a registry of devices, their semantic descriptions, and business processes that specify the functionality of the application on an upper level of user interface.

The control flow of complex events from sensors or devices (i.e., publishers) to semantically described web services (subscribers) can be handled by a business process infrastructure, which determines a sequence of tasks for particular application. In both EBBITS and ELLIOT projects it was decided to employ the jBPM, `http://www.jboss.org/jbpm`, as a visualization and modeling interface for maintenance, monitoring, and control of the business processes. The business rules environment was proposed to be built on Drools, `http://www.jboss.org/drools`, a powerful business logic integration platform of JBoss community. These technologies were selected due to their compatibility with the LinkSmart platform and its envisioned extensions on handling the semantic context of devices and processing of low-level as well as complex events.

4.3 Smart Office sensors and devices

The Smart Office pilot application of the ELLIOT project builds on all the updates that were proposed for the LinkSmart platform. We have designed a set of devices for the Smart Office pilot with respect to the APIs and drivers that can be wrapped by the dedicated web service interface and can be configured in accordance with the events processing model. Of course, the devices and sensors were selected in accordance with the pilot focus on optimizing the energy consumption and increasing the quality of working environment for employees in the office.

The structure of sensors and devices, which was designed for the experimental Living Lab in the office of RWE IT Slovakia, is presented in Figure 5. A set of Plugwise devices (`http://www.plugwise.com`) is proposed for energy measurement, namely circle plugs, switches, thermometers, temperature and air humidity sensors. The Arduino-based devices (`http://www.arduino.cc`) such as infra red motion sensors and/or RFID readers can be used for monitoring a presence of employees in the office, XBee modules can support wireless communication, etc. All the proposed devices can be divided into four logical groups as follows:

- *Plugwise Home Automation solution*: devices to control and measure electricity consumption in buildings (smart houses, offices). Measurement results are available for both actual and historical consumption data. Devices (circles - wireless electrical sockets, switches; sensors - temperature, humidity) communicate together via

ZigBee network. The main communication entry point between the controlling software and the Plugwise components is provided by a stick - a device emulating serial port on a controlling computer.

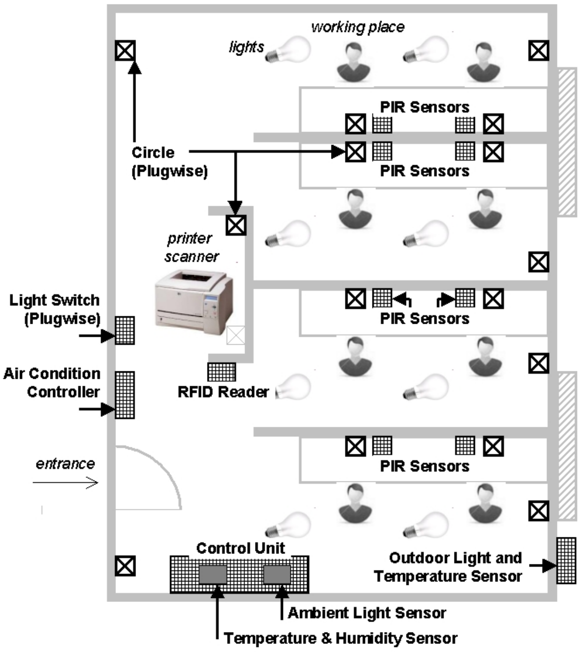

Figure 5. Distribution of sensors and devices in the RWE IT office room.

- *Indoor ambient light sensor*, which is based on the BH1750FVI chip. The Arduino Uno Rev3 is used as a controller. The indoor light sensor is connected to the SmartOffice system wirelessly via XBee Z2 module.
- *Outdoor ambient light and temperature sensor*: the light sensor is based on the BH1750FVI chip. For temperature measurements, the TMP102 of Texas Instruments is used. Both the sensors are controlled by an Arduino Fio controller. The communication is handled by the XBee module. The device is powered by 2000mAh LiPo battery, permanently charged by a 1W solar panel.
- *People presence sensors*, which are used for detecting a presence of people in the office to enable personalized settings of environment. The alternatives include RFID-based ID cards, passive infrared sensors (PIR), etc.

After installing all the devices in accordance with the scheme in Figure 5, it was necessary to specify usage scenarios that enable an investigation of Smart Office features in the experimental Living Lab.

5 Smart Office scenarios

To demonstrate the Smart Office capabilities on modeled types of the office workflow, we have specified three operational scenarios for an office environment in general, namely:

- *Meeting Room scenario*: A project team performs series of working meetings in the office on a regular basis and schedule (e.g. daily, duration 30 minutes, etc.). Personal preferences on light, heating, and software / hardware infrastructure are monitored and adjusted by the platform, with respect to the criteria of minimizing overall energy consumption.
- *Working Units scenario*: Several groups of employees, working on the same or similar task, are monitored in the office. The performance, information exchange, energy consumption, and resources usage are measured. Achieved results are evaluated in a competitive manner.
- *Collaboration scenario*: A set of employees is working collaboratively on a single task or project, according to a specified workflow. Effectiveness of the collaboration can be measured by monitoring the sub-tasks accomplished by individuals, personal settings and preferences for working environment (i.e., both software / hardware infrastructure and light / heating conditions used), by a frequency of information exchange between employees, etc. The results of energy consumption, CO2 footprint, efforts, and work quality can then be evaluated globally for the whole workflow, as well as individually for contributions of particular team members.

These operational scenarios will be subsequently addressed during the Smart Office development. However, the prototype implementation and testing was focused on particular sub-processes required by all the operational scenarios, namely the exploration of a suitable occupancy sensing and awareness of energy consumption.

5.1 Prototype experiments

The monitoring of a presence of employees on their working places is necessary for adjusting the environment settings to personal preferences of individual employees, as well as for evaluating the energy consumption and CO2 footprint for each of them. For this purpose, people presence / occupancy sensors of RFID and PIR were installed in the prototype (cf. Figure 5). It is noteworthy to say that a simple motion sensor is not suitable for monitoring the presence in offices, because it evaluates a movement of subjects. According to our experiments with PIR, the precision of a simple motion sensor is only 45-50%. To increase this value, we have explored several alternative solutions in the Smart Office Living Lab. The first one was based on the RFID technology, where each employee has an ID card to check his/her presence at the entrance to the office room. However, additional (potentially disturbing) action is required from employees in this case. The second option is based on PIR capable of sensing motions. From the user experience point of view it is a non-intrusive technology; however, due to the above-mentioned lack of precision, PIR appears much more suitable for detecting motions than monitoring continuous presence. The third option could be to not use any sensor at all, assuming that the office will run solely on a predefined workflow and schedule, i.e., without any personalized settings. Finally, the presence can be indicated by monitoring the energy consumed for a given period on the working place. Each option captures a different aspect of the presence, and thus a combination of the outlined methods can lead to the desired monitoring precision. Indeed, results that we have achieved after a series of experiments indicate that the PIR motion sensors combined with the energy consumption monitoring on working places, implemented as a flow of complex events, increases the precision level on 94%. This option was also preferred by users, since it is much less intrusive as RFID cards.

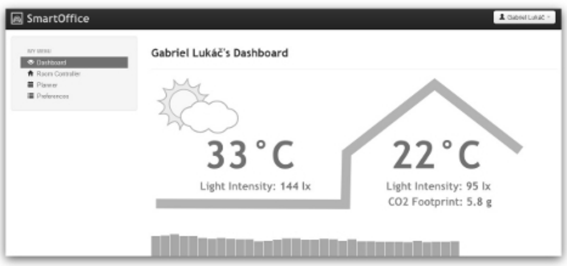

Figure 6. The Smart Office portal, presentation of the monitored data.

All the above-specified operational scenarios require a continuous awareness of employees on their personal consumption of energy, together with an information of monitored characteristics of the working environment such as outdoor and indoor temperature, humidity, light intensity, etc. To provide the monitored values for users, we have developed a web application, so-called Smart Office portal, with the interface depicted in Figure 6. The portal is provided for all employees in the office and in its current version it enables the visualization of measured data for both authorized user and the working team, planning of work time, and maintenance of personalized system settings and preferences. Some data are populated directly form the sensors (e.g., temperature, humidity), while the other data types (e.g., CO2 footprint, average energy consumption of user or group during a period of time) require a more complex event processing.

The portal, functionally connected with the LinkSmart business logic, serves as a communication platform and a system maintenance console for users, but can also be employed as a data source for the Smart Office Living Lab. It allows to gather such data as increase of preferred temperature in a user profile, number of profile changes and room controller actions, number of user profiles with similar settings on temperature and lighting, system logs, etc. These quantitative data can be directly transformed to specific KPIs enabling a calculation of KSB aspects such as knowledge aspects of conation to save energy or sensing affordances, social aspects of attractiveness or community behavior, and business aspects of reliability or performance level.

6 Conclusions

The presented Smart Office pilot application is currently (June 2012) implemented in its first prototype, which was installed in the premises of RWE IT Slovakia. In parallel, the design and implementation of the underlying LinkSmart platform is ongoing in both FP7 projects ELLIOT and EBBITS. The first trial of the prototype testing was already accomplished, as it is briefly presented in previous section. The second interaction, planned for summer 2012, will focus on an experimentation with business processes and rules for specified scenarios in the Living Lab environment.

In general, the goal of the pilot application is to construct the Smart Office as an extensible and scalable service-based AmI/IoT platform, which can be easily adapted to various use cases and office scenarios in a business environment. In addition, we would like to promote the idea of co-creation and experimentation on AmI/IoT solutions by establishing a wider consortium of companies, universities, research institutions, and software houses in Košice and in broader area of Eastern Slovakia around the Smart Office Living Lab.

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