Smart Energy Efficient Buildings
A Living Lab Approach

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Abstract: In this paper we provide an overview of current research trends, challenges and issues in the domain of smart energy efficient buildings. Based on current research and literature we discuss topics like technology integration, semantic interoperability, automation, and the importance of considering user needs. Furthermore, we introduce a living lab approach, which allows us to conduct research on these topics in a real smart building environment. This living lab is a system for enabling smart energy efficient building applications based on a middleware approach. We describe the software design and the real-world deployment of this system in ten rooms of a university and eight rooms of an office building.

1 INTRODUCTION

Smart energy efficient buildings are considered a substantial part of future smart cities. Oftentimes, when talking about smart buildings, what is meant are buildings which have a building management system (BMS) installed. Such a BMS typically controls the lighting and heating, ventilation and air conditioning (HVAC) of larger buildings based on certain control strategies. Furthermore, BMSs are usually proprietary, closed systems provided as whole-in-one solutions by one vendor and normally are installed when a building is designed from scratch.

In the age of Ubiquitous Computing (UbiComp), new technologies are available at an affordable price and can help making buildings smarter than they are now. For example, wireless sensor networks (WSNs) can contribute to a better understanding of a building's behavior by monitoring environmental values. Smart meters (and even sub-meters on device level) can provide additional insights into a building's energy consumption. Even wireless building management systems (W-BMS) are available to retrofit existing buildings. Last but not least, in the vision of the smart grid, buildings are supposed to perform a transformation from energy consumers to prosumers, i.e. producing and exchanging energy with other entities of the smart grid.

From an ICT research perspective we argue that buildings are gradually becoming places of Ambient Intelligence (AmI) where technology works in the background and becomes invisible to the occupants (Sadri, 2011). For example, adaptive control strategies are being researched to improve the prediction of occupant behavior for more accurate heating and lighting control. The exploitation of an ever-increasing amount of information that is becoming available in smart buildings can surely contribute to more efficient automation and control. But, at the same time, an increasing amount of data is captured about occupant behavior and it is important to find the right balance between technology, data collection, automation and the occupants' needs and privacy concerns. A responsible development towards smart energy efficient buildings and cities has to consider both, the technology- as well as the human dimension (cf. (Nam and Pardo, 2011) who conceptualize smart cities by identifying the different dimensions).

From the technology perspective, a major issue is to achieve interoperability between systems and technologies inside the smart buildings themselves. This would be the basis for extensible smart buildings ready for future interaction with smart cities and the smart grid. The second major issue that needs more attention is the role of the end users in such smart buildings (i.e. occupants, building managers, etc.). Even with current BMSs there often is a lack of acceptance from occupants due to a lack of transparency of system behavior. If buildings are becoming even smarter it is inevitable to consider the users

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in the process of moving towards smart energy efficient buildings.

In the first part of this paper we give an overview of relevant research areas and important issues to be considered when talking about future smart buildings. The second part introduces our living lab approach to gain insights into both, technical and user-related challenges, opportunities, and problems. We present our concept of a middleware-based smart building living lab which we deploy in 18 rooms. Ten are located in buildings of a university campus in Italy and eight are in an office building of a research institute in Germany. The living lab deployment demonstrates the integrated deployment of different subsystems. It is designed to be an open, extensible system, that will evolve into an integrated building energy management system, following an iterative, user-centered living lab process. Thus, the findings of this research cover two dimensions: The technology dimension in the sense of the integrated BMS and the human dimension by following an explorative living lab approach. We would like to note that the term smart building in the scope of this paper is limited to commercial, office, or (semi-)public buildings and does not include smart homes.

2 SMART BUILDINGS

In the following we characterize some of the main challenges we see for smart buildings. We mainly consider two areas, which are of course heavily intertwined: The technology dimension, mainly dealing with integration and interoperability and the human dimension, considering the end users. As said before, from the upcoming trend towards integrated smart buildings arise a lot of challenges and concerns that need to be considered when developing ICT systems for such buildings. Based on existing literature and our own research experiences we discuss the different issues that need to be considered.

Technology Integration. Dealing with heterogeneous devices, technologies, and systems is a typical issue for AmI systems and a problem that also exists in the smart energy efficient buildings domain. E.g. BMSs from different vendors use different technologies and protocols; a lot of existing hardware is already installed and working; new hardware may be installed with new communication protocols such as wireless BMS like EnOcean[1]; experimental technology like Arduino[2] allowing to develop custom sensor networks may also be considered. To address these problems of heterogeneity, systems need to be open and extensible to new kinds of technologies. In the domain of building management an approach to overcome these problems is the OPC unified architecture specification[3]. Another approach from the research domains of UbiComp and AmI is middleware. The middleware concept is more general and not restricted to building management, thus providing greater flexibility with regards to integration of other technologies (e.g. smart phones, WSNs) and extensibility. Of course greater flexibility does not come for free but usually with greater complexity. Examples of relevant middleware solutions are (Kirkham et al., 2008), (Capone et al., 2009), and (Eisenhauer et al., 2009).

Monitoring, Control, and Automation. To increase energy efficiency in buildings a basic requirement is to have access to environmental data, otherwise it would be impossible to evaluate any kinds of energy savings. Therefore, a monitoring infrastructure is necessary and of course if not already installed it should be cheap and easy to deploy. With the rise of WSNs and smart metering, fine-grained monitoring of almost every kind of environmental information is possible. Of course, control strategies for lighting and HVAC would benefit from additional data sources but it is not trivial to integrate new devices into existing systems. It would be a major advantage if new data sources could be exploited seamlessly by an existing monitoring and control system. This would give us the opportunity to develop really flexible and advanced control strategies. For example, a simple WSN might significantly increase occupancy detection algorithms. Again, this example stresses the need for open, integrated systems which allow for extensibility both, software- and hardware-wise.

Semantic Interoperability. While technology integration as described above refers to the term syntactic interoperability, semantic interoperability resides on a higher layer. Semantic interoperability should allow developers to use different technologies transparently. A semantic layer should abstract from any concrete technology. The issue of semantic abstraction is often tried to be solved by ontologies, which should help to find common concepts for different implementations. There are several approaches that try to define semantic knowledge for smart buildings (Wicaksono et al., 2010), (Dibowski and Kabitzsch, 2011).

[1] http://www.enocean.com

[2] http://www.arduino.cc/

[3] http://www.opcfoundation.org

End Users. End users are an important, yet often neglected factor contributing to the success of smart buildings as they are heavily affected by any kind of automated system. In the domain of building automation, standards and key figures to measure occupant comfort exist (ANSI/ASHRAE, 2004). However, occupants are often unhappy with automated systems for many reasons. Usually occupants don't know why an automated system behaves like it does. If people need to start waving at sensors to make the light or heating work, the system simply does not fulfill its basic requirements of automation. Besides trying to increase the accuracy of presence detection, another option would be to give the people back some control over their environment. Studies have indicated that occupants are happy with personal control over lighting (Galasiu and Newsham, 2009) and current research efforts of personal building controls for occupants indicate that this can be an opportunity (Krioukov and Culler, 2012), (Krioukov et al., 2011). It is still an open issue how to increase the occupants' acceptance of automated systems and further research in this direction is highly encouraged. User control and/or transparency of system decisions might be possible ways to go. Besides the issue of acceptance, we also believe that the opposite communication channel needs further investigation: If occupants could provide feedback (to the building manager or the system directly) about the system, its behavior, or their own comfort, this might improve both, the system itself and its acceptance.

Furthermore, researchers from the field of Human Computer Interaction and Psychology deal with questions of motivating energy efficient behavior. They investigate different kinds of interventions ranging from feedback on energy consumption (Darby, 2006) to energy saving competitions (e.g. (Brewer et al., 2011)). (Froehlich et al., 2010) provides a good overview of both research areas and analyses what they could learn from each other to effectively foster energy efficient behavior. Although, most of the research in that area tackles the domestic domain, we think it is worth identifying promising approaches and transfer them to the domain of office and (semi-)public buildings.

Last but not least, occupants are not the only stakeholders in a smart building and one major player which should not be forgotten is the building manager. When designing energy management systems, building and/or energy managers and facility staff need to be involved in the process because they are the main expert users. Efforts to understand the needs of building managers have already been undertaken by (Lehrer and Vasudev, 2010) and should be continued, especially in real deployments and field trials.

Security and Privacy. Another important issue when talking about future smart buildings, integration, data collection, feedback, etc. is privacy. We believe that the best smart building system will fail if it is not able to deal with occupants' privacy concerns. Therefore, it is of the utmost importance to include all relevant stakeholders right from the start.

3 LIVING LAB APPROACH

To gain deeper knowledge and develop solutions to the challenges discussed above, we propose a living lab approach to provide a real-world experimental environment. We hope to gain experiences from deployments and a user-centered development process that go far beyond what is possible in a controlled lab environment or simulations. Our aim is to create a flexible software infrastructure for smart energy efficient buildings, allowing easy integration of different technologies and rapid development of applications, so we can quickly react to user needs. To put it in a nutshell, we develop a living lab to gain knowledge about smart building technologies, deployment and user interaction. This living lab relies on a middleware-based software infrastructure and can be seen as a smart energy efficient building system in the making. In the following we describe the test sites, system design and implementation, and the developed and planned end user applications.

3.1 Test Sites

We currently have two field deployments in a research campus in Germany and a university campus in Italy. The deployment in Germany is located in one office building and comprises 8 rooms on the same floor: four single-person offices, two two-person offices and two student labs with eight and four work places. The two-person offices and two of the single-person offices are equipped with EnOcean technology for lighting and heating control and for monitoring of presence, temperature, window states, and energy consumption of appliances and lights. Two of the single-person offices are equipped with monitoring devices only. In the student labs we have deployed an experimental setup of Arduino sensors for measuring presence and window states and Plugwise[4] smart plugs for measuring energy consumption of appliances.

The Italy deployment is spread over three different buildings, each with different requirements for integrated monitoring and control systems. This deployment comprises 10 rooms in total with each two

[4] http://www.plugwise.com

rooms forming a test and reference room. A test room is equipped with hardware to control lighting and HVAC while a reference room only hosts monitoring devices. Each pair of test and reference rooms are situated next to each other and share similar characteristics with regards to size, number of maximum occupants, orientation in the building, etc. This setup has been chosen to achieve a high degree of comparability. Four rooms are located in a castle which hosts several offices and secretariats. This castle was built in the 17th century and thus has very strict requirements regarding any kinds of refurbishments. The offices and secretaries are two-person rooms. Deployment-wise the castle has special requirements with regards to BMS installation so it is not possible to install anything wired in the walls because it is a historic building. Consequently, a wireless monitoring and control system based on EnOcean and Plugwise technologies has been installed. The remaining 6 rooms are located in two buildings of the main campus of the university. These rooms are two two-person offices, two single-person offices and two student labs with 20 workplaces. The buildings in that part of the campus are partially equipped with a Siemens Desigo BMS. Furthermore, TelosB WSNs and Plugwise smart plugs have been deployed in these rooms to gather additional data about environmental conditions and power consumption of devices.

3.2 Implementation

The implementation of the smart building living lab is based on a middleware approach. We use middleware to integrate different technologies and make use of an abstraction layer to allow unified access to these technologies. To not reinvent the wheel we employ the LinkSmart middleware[5], which is an open source middleware for developing AmI applications on top of heterogeneous technologies (Eisenhauer et al., 2009). It is available under LGPL license and has been applied among others in the areas of energy efficient smart homes (Jahn et al., 2010) and office environments (Jahn et al., 2011).

3.2.1 LinkSmart Middleware

LinkSmart implements a service-oriented architecture providing to software developers a set of components (called managers) they can select from, depending on their specific requirements. Each manager encapsulates a set of operations and data that realize a well-defined functionality. Some of these managers are essential (e.g. Network Manager) while others provide optional functionality (e.g. Event Manager). Each manager has a clearly defined role, offering a set of services to be used by other managers or application level components. The main features of the LinkSmart middleware with respect to the smart building living lab are as follows:

Network Management. A LinkSmart Network is formed by distributed Network Managers that take care of the communication among devices and managers. Every service can register itself at a Network Manager and thus take advantage of communicating inside the LinkSmart network. The Network Manager enables network communication by creating an overlay P2P network that implements SOAP Tunneling as transport mechanism for Web Service calls (Milagro et al., 2008). This concept allows direct communication among all devices inside a LinkSmart network, no matter if they appear behind a firewall or NAT (Network Address Translator). The LinkSmart addressing scheme allows devices to transparently publish and use services anytime anywhere regardless of network boundaries or fixed service endpoints.

Event Management. For smart building applications it is essential to be modular, extensible and provide low coupling of components, as set-ups can change when devices are removed or new devices are added to the environment. The Event Manager addresses these requirements, implementing a publish/subscribe mechanism for LinkSmart services. Thus, we are able to develop loosely coupled applications, which are flexible enough to face the requirements of dynamic AmI environments. The Event Manager handles all subscriptions and is responsible for publishing events via a Network Manager, compliant to the LinkSmart communication model.

Proxies. A proxy is a software component that enables basic syntactic interoperability between different technologies; it is responsible for integrating a certain kind of technology, device, or subsystem into a LinkSmart network. A proxy acts as a bridge between the LinkSmart network and the underlying technology. It translates whatever kind of language the low-level technology speaks into LinkSmart Web Services so the low-level technology can be used transparently by any other LinkSmart component. For example, our EnOcean proxy internally can handle EnOcean telegrams and offers a Web Service interface to be used by components on the middleware layer. This concept allows us to use each low-level technology transparently inside the LinkSmart network.

[5]http://sourceforge.net/projects/linksmart/

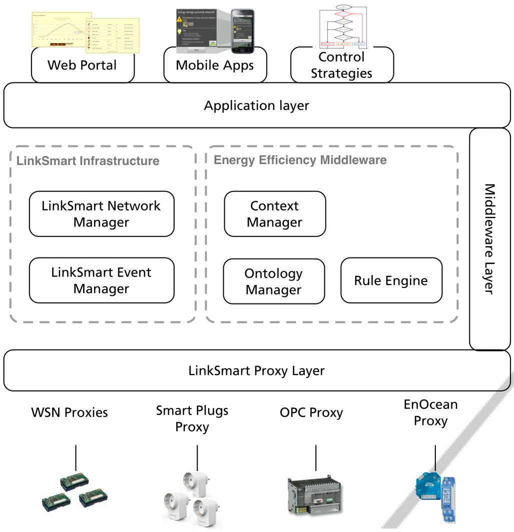

Figure 1: 3-Layered Software Architecture.

3.2.2 Smart Building Living Lab

The software architecture of our smart building living lab is based on three layers (cf. Figure 1), adhering to the principles of the LinkSmart middleware: On the lowest level the proxy layer is responsible for syntactic interoperability between the different low-level technologies. We currently have proxies for EnOcean, Arduino WSN, TelosB WSN, Plugwise smart plugs, and a proxy based on OPC for accessing the Siemens Desigo BMS. On top of this, the middleware layer provides components specifically designed for the energy efficient smart building applications, which should support the management of reoccurring tasks. We currently have three main components on this layer: The Ontology- and Context Manager, which manage semantic knowledge about the smart buildings. This includes information about sensors and other devices, buildings, and rooms. The Rule Engine, which is the basis for developing custom control strategies. It allows us not only to implement control strategies for lighting and HVAC accross the different technologies but also to quickly react to user needs or other lessons learned from the deployments. For example, if there is a gap between simulation and real behavior of a control strategy, we are able to quickly tweak parameters or to even exploit information from additional sensors. The topmost layer is the application layer. On this layer reside all kinds of applications that make use of the integrated system and information that is available. For example, the aforementioned control strategies reside on this layer, as well as end-user applications for feedback and control, which will be described in the next chapter.

3.3 End User Applications

As one of our goals is to strengthen the role of end users in smart buildings we are highly interested in the needs and wishes of the different end users. We mainly consider two categories of users in our buildings: expert users (i.e. the building managers) and occupants (i.e. students and employees). Based on existing studies and semi-structured interviews we conducted with users (cf. (Jahn et al., 2011)) we implement a first set of applications. As a first approach we implement a web portal that allows building managers to monitor environmental values such as temperature, humidity, or power consumption. As reported in (Lehrer and Vasudev, 2010), the analysis of such data is still not an easy task. The web portal allows expert users to browse data by different categories and view information per room or device and in a certain period of time. Figure 2 is an excerpt from

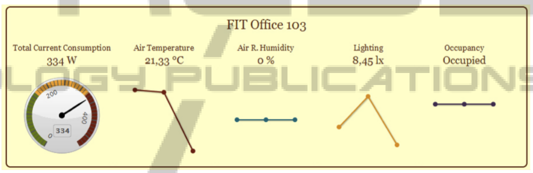

Figure 2: Web Portal Screenshot.

the web portal showing the recent trends for environmental values in one office. Regarding occupants we aim at investigating new concepts of user-building interaction. First, of course we want to increase the acceptance of smart buildings by providing feedback and enabling transparency. One goal is to find out the right types of information to show to the occupants or the degree of transparency that is feasible. The second concept we want to investigate is if it makes sense to let occupants provide feedback to the system and if it is possible to give them a certain amount of control over the system. Previous research indicates that such concepts are fruitful and well recognized by occupants ((Krioukov et al., 2011) and (Krioukov and Culler, 2012)).

4 CONCLUSIONS

We provided an overview of current research efforts in the domain of smart energy efficient buildings and described our living lab approach to foster user-centered research in such buildings. One goal of this paper is to raise awareness for important issues in smart building research. The main benefit of our living lab approach is that we are able to tackle technical issues and user-related questions at the same time. By following this approach our vision is to develop smart buildings that are both, efficient in the way they work and well accepted by end users. The current state of the system is this: All hard- and software components for integration, monitoring, and control has been deployed. Now we are in the phase of validating sensor measurements and adapting the control strategies to the peculiarities of deployed sensors. Once the basic monitoring and control (HVAC and lighting) is running smoothly, we will start the deployment of the first end user applications and start the next iteration of the user-centered development process.

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REFERENCES

ANSI/ASHRAE (2004). *Thermal environmental conditions for human occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Brewer, R. S., Lee, G. E., and Johnson, P. M. (2011). The kukui cup: A dorm energy competition focused on sustainable behavior change and energy literacy. In *Proceedings of the 2011 44th Hawaii International Conference on System Sciences*, HICSS '11, pages 1–10, Washington, DC, USA. IEEE Computer Society.

Capone, A., Barros, M., Hrasnica, H., and Tompros, S. (2009). A New Architecture for Reduction of Energy Consumption of Home Appliances. In *TOWARDS eENVIRONMENT, European conference of the Czech Presidency of the Council of the EU*.

Darby, S. (2006). The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays. Technical report, Environmental Change Institute, University of Oxford.

Dibowski, H. and Kabitzsch, K. (2011). Ontology-based device descriptions and device repository for building automation devices. *EURASIP J. Embedded Syst.*, 2011:3:1–3:17.

Eisenhauer, M., Rosengren, P., and Antolin, P. (2009). A development platform for integrating wireless devices and sensors into ambient intelligence systems. In *Sensor, Mesh and Ad Hoc Communications and Networks Workshops, 2009. SECON Workshops '09. 6th Annual IEEE Communications Society Conference on*, pages 1 –3.

Froehlich, J., Findlater, L., and Landay, J. (2010). The design of eco-feedback technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, pages 1999–2008, New York, NY, USA. ACM.

Galasiu, A. and Newsham, G. (2009). Energy savings due to occupancy sensors and personal controls: a pilot field study. *Lux Europa 2009*, pages 745–752.

Jahn, M., Jentsch, M., Prause, C., Pramudianto, F., Al-Akkad, A., and Reiners, R. (2010). The energy aware smart home. In *Future Information Technology (FutureTech), 2010 5th International Conference on*, pages 1 –8.

Jahn, M., Schwartz, T., Simon, J., and Jentsch, M. (2011). Energypulse: tracking sustainable behavior in office environments. In *Proceedings of the 2nd International Conference on Energy-Efficient Computing and Networking*, e-Energy '11, pages 87–96, New York, NY, USA. ACM.

Kirkham, T., Savio, D., Smit, H., Harrison, R., Monfared, R., and Phaithoonbuathong, P. (2008). Soa middleware and automation: Services, applications and architectures. In *Industrial Informatics, 2008. INDIN 2008. 6th IEEE International Conference on*, pages 1419 –1424.

Krioukov, A. and Culler, D. (2012). Personal building controls. In *Proceedings of the 11th international conference on Information Processing in Sensor Networks*, IPSN '12, pages 157–158, New York, NY, USA. ACM.

Krioukov, A., Dawson-Haggerty, S., Lee, L., Rehmane, O., and Culler, D. (2011). A Living Laboratory Study in Personalized Automated Lighting Controls. In *3rd ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings*, Seattle, WA.

Lehrer, D. and Vasudev, J. (2010). Visualizing Information to Improve Building Performance : A Study of Expert Users. In *Proceedings, ACEEE Summer Study on Energy Efficiency in Buildings*, pages 141–153.

Milagro, F., Antolin, P., Kool, P., Rosengren, P., and Ahlsén, M. (2008). SOAP tunnel through a P2P network of physical devices. In *Internet of Things Workshop, Sophia Antopolis, Sep*.

Nam, T. and Pardo, T. A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In *Proceedings of the 12th Annual International Digital Government Research Conference: Digital Government Innovation in Challenging Times*, dg.o '11, pages 282–291, New York, NY, USA. ACM.

Sadri, F. (2011). Ambient intelligence: A survey. *ACM Comput. Surv.*, 43(4):36:1–36:66.

Wicaksono, H., Rogalski, S., and Kusnady, E. (2010). Knowledge-based intelligent energy management using building automation system. In *IPEC, 2010 Conference Proceedings*, pages 1140 –1145.