Universal Integration of the Internet of Things through an IPv6-based Service Oriented Architecture enabling heterogeneous components interoperability

Grant agreement for: Collaborative project
Grant agreement no.: 288445
Start date of project: October 1st, 2011 (36 months duration)

Deliverable D7.3
Smart IPv6 building deployment, test and recommendation report

<table>
<thead>
<tr>
<th>Contract Due Date</th>
<th>31/07/2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submission Date</td>
<td>13/08/2014</td>
</tr>
<tr>
<td>Version</td>
<td>1.0</td>
</tr>
<tr>
<td>Responsible Partner</td>
<td>Mandat International</td>
</tr>
<tr>
<td>Author List</td>
<td>Sébastien Ziegler, Cédric Crettaz, and additional contributions from IoT6 partners and the Industry Advisory Board</td>
</tr>
<tr>
<td>Dissemination level</td>
<td>PU</td>
</tr>
<tr>
<td>Keywords</td>
<td>Internet of Things, IPv6</td>
</tr>
</tbody>
</table>

Project Coordinator: Mandat International (MI)
Sébastien Ziegler <sziegler@mandint.org>
Table of Contents

1. Introduction .....................................................................................................................................3
   1.1. Project description .....................................................................................................................3
   1.2. Work package objectives ...........................................................................................................3
   1.3. Task T7.2 objectives ..................................................................................................................4
   1.4. Deliverable D7.3 Objectives .....................................................................................................4

2. “Smart IPv6 Building” approach ..................................................................................................5
   2.1. Concept origin ............................................................................................................................5
   2.2. Relevance of improving intelligence and integration of buildings ...........................................6
   2.3. Methodological implications .......................................................................................................7

3. Scenarios and use cases selection ................................................................................................11
   3.1. Functional dimensions and application domains .......................................................................11
   3.2. Technical dimensions to be assessed ......................................................................................11

4. Scenarios and use cases description ............................................................................................13
   4.2. Comfort: “The Smart Office” ..................................................................................................16
   4.3. Energy: “Saving and User Awareness” ...................................................................................19

5. Deployment plan ................................................................................................................................25
   5.1. Deployment requirements ...........................................................................................................25
   5.2. Deployment strategy ....................................................................................................................25
   5.3. Provisional deployment architecture ...........................................................................................26
   5.4. Main actors ................................................................................................................................27
   5.5. Provisional list of components ....................................................................................................28
   5.6. Deployment process .....................................................................................................................32

6. Detailed deployment plan .................................................................................................................33
   6.2. Comfort: The Smart Office .......................................................................................................34
   6.3. Energy: Saving and User Awareness .........................................................................................35
   6.4. Security & Safety: Intrusion and Fire Detection ........................................................................36
   6.5. Selection of deployed components to comply with the heterogeneity requirement .................37
   6.6. Deployment plan devices matrix .................................................................................................41

7. Technical analysis ............................................................................................................................42
   7.1. Ease of deployment .....................................................................................................................42
   7.2. Heterogeneous integration .........................................................................................................43
   7.3. Scalability ...................................................................................................................................45
7.4. Flexibility, modularity.................................................................47
7.5. Security and Reliability...............................................................48
7.6. Cost of deployment....................................................................48
7.7. Energy efficiency .......................................................................49
7.8. Return on investment .............................................................59
7.9. Identified limitations ...............................................................60

8. Conclusion and recommendations .............................................61
8.1. Recommendations for the deployment of smart IPv6 buildings .....61
8.2. Recommendations for further research and development ..........62

9. References .....................................................................................63

Table of Figures
Figure 1: Original Smart IPv6 Building concept ................................5
Figure 2: Using IPv6 to integrate multiple systems in smart buildings ....12
Figure 3: Meeting space and small lounge area in the Mandat International testbed ......26
Figure 4: Disposition of different areas and devices in the Mandat International testbed .....27
Figure 5: Initial provisional deployment planning .........................................................32
Figure 6: Building Maintenance use case deployment plan ..............................................33
Figure 7: Smart office use case deployment plan .........................................................34
Figure 8: Energy use case deployment plan .................................................................35
Figure 9: Security and safety use case deployment plan ..................................................36
Figure 10: Multi-systems integration .............................................................................44
Figure 11: IoT6 and UDG flexibility .............................................................................47
Figure 12: Power needed to reach a desired temperature ..............................................55
Figure 13: Annual energy consumption based on the temperature .................................55
Figure 14: Annual cost for heating .............................................................................56
Figure 15: Energy consumption comparison for heating ..............................................58
Figure 16: Energy costs comparison for heating .........................................................58

Table of Tables
Table 1: Deployment plan devices matrix .............................................41
Table 2: Address scalability of mainstream protocols .................................................45
Table 3: Results in usage for the coffee machine .........................................................51
Table 4: Results of the Measurement without and with IoT6 scenario .........................52
Table 5: Computers electricity consumption ...............................................................54
Table 6: Temperature based on designated room .........................................................56
Table 7: Number of working days for Mandat International staff ..................................57
Table 8: Results based on desired temperature .............................................................57
Table 9: Return on Investment on Mandat International Building .................................59
1. Introduction

1.1. Project description

IoT6 is a European research project exploring the potential of the Internet Protocol version 6 (IPv6) for the Internet of Things (IoT). The IoT6 objectives are:

- Research the potential of IPv6 and related standards to support the future Internet of Things and to overcome its current fragmentation and lack of interoperability;
- Develop a highly scalable IPv6-based Service-Oriented Architecture to achieve interoperability, mobility, cloud computing integration and intelligence distribution among heterogeneous smart things components, applications and services;
- Explore innovative forms of interactions with multi-protocol integration, mobile and cellular networks, cloud computing services (SaaS), RFID and Smart Things Information Service, information and intelligence distribution.

1.2. Work package objectives

Work package 7 covers the various tests that ensure the applicability of the IoT6 approach. It started with the development of test plans for the components and the fully integrated IoT6 system. These test plans comprised several test cases that in turn described the implementation of a test purpose for particular test architecture. Thus, a complete specification of the actions required to achieve a specific test purpose has provided. The information needed for the specification of test cases. This included, for example:

- The collection of relevant system interfaces via which the system is tested;
- The structure and configuration of the test system;
- The concrete data values to be exchanged when testing a system implementation;
- The sequences of interaction with which the correctness of a system implementation is evaluated;
- Pre- and post-conditions for testing a system implementation.

Furthermore, a validation of the potential of the system architecture and its novel use cases (in particular concerning business processes) has been pursued. For the purpose of generalizing the gathered results, a specific testbed was built composed of different hardware and software systems. IoT6 is exploring a distributed testbed approach by enabling remote interactions between various components located by the various members of the consortium, and members of the industry support group too.

The main objectives of WP7 are to:

- Test and validate the complete interoperability among the various components of the architecture developed in the previous WP and the related subsystems of the Internet of Things;
- Test and validate the complete multi-protocol interoperability of the system by testing the interaction with real devices through all the possible different couplings of protocols (among the selected standards), as well as with a scenario requiring interactions among the standards together;
- Test and demonstrate various innovative Internet-based application scenarios related to the Internet of Things, including business processes related scenarios;
• Test and demonstrate the potential of the multi-protocol card to enable distribution of intelligence with real cases scenarios;
• Test and estimate the potential scalability of the system;
• Test and demonstrate the IPv6 virtual proxy function for non-IP devices;
• Deploy and validate the system in a real testbed environment with real end users in order to test the various scenarios.

1.3. Task T7.2 objectives
The Task T7.2 “Smart IPv6 building deployment, tests and recommendation report” is testing and demonstrating the potential of IPv6 and IoT6 in a building environment. This Task is exploring innovative forms of interactions among heterogeneous “smart things” that traditionally use different communication protocols. The focus is placed on the interaction of established protocols used in building automation such as ZigBee, KNX, and BACnet. The following validation steps demonstrate that the integration of heterogeneous devices and smart things into smarter and interoperable environments allows the execution of novel, innovative use case scenarios that are enabled only by the integration of multiple systems. Prominent examples are energy saving, security, increased comfort and also the tight integration of novel business processes such as demand-side management or remote maintenance. The main deliverable of this task is a report on the applicability and an assessment of the suitability of IPv6 and IoT6 enabling a more holistic control of the building environment.

1.4. Deliverable D7.3 Objectives
The deliverable D7.3 “Smart IPv6 building deployment, test and recommendation report” includes the results of the deployment and tests of IoT6 architecture and components in a smart building environment. It presents tested use cases and proposes some recommendations on the potential application of IPv6 and IoT6 architecture for future smart buildings. It identifies key applications and potential developments for smart buildings.
2. “Smart IPv6 Building” approach

2.1. Concept origin

IoT6 took as a reference the original concept of a “Smart IPv6 Building”, which was initially coined by Mandat International in the frame of a previous project\(^1\). The Smart IPv6 Building concept is characterized by the attempt to use IPv6 as a universal integrator enabling all sorts of cross-domain and cross-application interactions. As illustrated in Figure 1, the model uses IPv6 as an integrator for innovative interactions with and between:

- Building environment and heterogeneous building systems;
- Information and services, including web and cloud-based services;
- Users and human interactions;

![Figure 1: Original Smart IPv6 Building concept](image)

The initial objectives of the Smart IPv6 Building model were as follows:

**Building automation**

- Reduce energy consumption by at least 25%;
- Ease the deployment and integration of building automation systems;
- Manage access control and to improve security;
- Provide innovative tools for meeting and conference rooms;
D7.3: Smart IPv6 building deployment, test and recommendation report

- Develop innovative interfaces within the building (virtual assistant, etc.);
- Enable individual environment customization by the users (temperature, light, music, etc.).

**Information & services**

- Display real time information on the state of the world: key figures (population, surface of forest, etc.), satellite images, global temperature, etc.;
- Provide innovative services, including contextualized services;
- Enable building infrastructure booking (meeting rooms, etc.);
- Ease resource identification and orientation for the delegates attending international conferences;
- Test innovative semantic and multilingual services;

**Human beings**

- Provide telepresence solutions (in particular for people living in developing countries);
- Facilitate the networking among delegates;
- Develop a global network of delegates and experts, with new forms of decentralized cooperation and collective intelligence;
- Test on-line collaborative tools;
- Organise social activities during the conferences.

While some of those objectives are very specific and linked to a specific project, in the present deliverable we took the option to use them as an overall vision of a potential IPv6-controlled building. Without being formally bound by those objectives, the task effort has tried to use them as a benchmark and a guiding vision.

### 2.2. Relevance of improving intelligence and integration of buildings

Buildings are critical. Buildings are responsible for 40% of total EU energy consumption and generate 36% of GHG$^2$. This highlights the importance and the need to achieve a higher level of energy-efficiency in buildings, as well as to reduce their greenhouse gas emissions. There are three complementary strategies:

- Improving the envelop and insulation of the buildings, which is easily implementable for new constructions, but difficult to apply to existing ones;
- Optimizing the energy efficiency of individual subsystems, for instance by replacing traditional lighting by LED lights;
- Improving the intelligence and the “behaviour” of the building, by adapting the use of energy to the effective needs of the users.

The first strategy is difficult to apply to existing buildings. The second one is already largely exploited. It is anticipated that the latter strategy may bring substantial energy savings, but is still under exploited. However, it can contribute to reducing the building energy consumption and its greenhouse gas emissions through a more integrated and smarter building management.
There is an important parameter to take into account for a successful implementation of such a strategy: Building environment directly affects the quality of life and work of its users and inhabitants. The user acceptance is hence of crucial importance. Buildings must be capable of not only providing mechanisms to minimize their energy consumption (even integrating their own energy sources to ensure their energy sustainability), but also of improving occupant experience, acceptance and eventually their productivity.

The integration and development of systems based on ICT and, more specifically, the IoT are important enablers of a broad range of applications, both for industries and the general population, helping to make smart buildings a reality. IoT permits the interaction between smart things and the effective integration of real world information and knowledge in the digital world. Smart (mobile) things endowed with sensing and interaction capabilities or identification technologies (such as RFID) provide the means to capture information about the real world in much more detail than ever before. Nevertheless, challenges related with: (1) the management of huge amount of data provided in real-time by a large number of IoT devices deployed, (2) the interoperability among different ICT, and (3) the integration of many proprietary protocols and communication standards that coexist in the ICT market applicable to buildings (such as heating, cooling and air conditioning machines), need to be faced before flexible and scalable solutions based on the IoT paradigm can be offered.

2.3. Methodological implications

We took as a reference the energy performance model for buildings proposed by the CEN Standard EN15251. It proposes criteria for dimensioning the energy management of buildings, while indoor environmental requirements are maintained at acceptable levels. According to this standard, there are static and dynamic conditions that affect the energy consumption of buildings. Given that each building has a different static model according to its design, we try to provide a solution for energy efficiency focusing on analysing how dynamic conditions affect the energy consumed in buildings. Thus, we need to identify the main drivers of energy use in buildings. After monitoring these parameters and analysing the associated energy consumed, we can model their impact on energy consumption, and then, propose control strategies to save energy. The main idea of this approach is to provide anticipated responses to ensure energy efficiency in buildings.

Bearing in mind all these concerns, we enumerate below the stages that must be carried out to achieve efficiency building energy management:

1. **Monitoring.** During the monitoring phase, information from heterogeneous sources is collected and analysed before concrete actions are proposed to minimize energy consumption, bearing in mind the specific context of a given building. Since buildings with different functionalities have different energy use profiles, it is necessary to carry out an initial characterization of the main contributors to their energy use. For instance, in residential buildings the energy consumed is mainly due to the indoor services provided to their occupants (associated to comfort), whereas in industrial buildings energy consumption is associated mostly with the operation of industrial machinery and infrastructures dedicated to production processes. Considering this, and taking into account the models for predicting the comfort response of buildings occupants given by the ASHRAE, we describe below the main parameters that must be monitored and analysed before implementing optimum building energy
management systems. In this way, from this set of parameters affecting energy consumption in buildings, we can extract the input data to be included in the proposal of building management.

A. Electrical devices always connected to the electrical network. In buildings, it is necessary to characterize the minimum value of energy consumption due to electrical devices that are always connected to the electrical network, since they represent a constant contribution to the total energy consumption of the building. For this, it is necessary to monitor over a period of time the energy consumed in the building when there is no other contributor to the total energy being consumed. This value will be included as an input to the final system responsible for estimating the daily electrical consumption of the building.

B. Electrical devices occasionally connected to the electrical network. Depending on the kind of building under analysis, different electrical devices may be used for different purposes. For instance, for productive aims in a company, or for providing comfort in a home, etc. On the other hand, the operation of such devices could be independent of the participation and behaviour of the occupants; for example, in the context of a factory or an office where there are timetables and rules. Whatever the case, recognition of the operation pattern of devices must be included in the final system responsible for estimating the daily electrical consumption of the building. To obtain these patterns it is necessary to monitor previously the associated energy consumption of every device or appliance. To monitor each component separately in the total power consumption in a household or an industrial site over time, cost effective and readily available solutions include Non-Intrusive Load Monitoring (NILM) techniques.

C. Occupants' behaviour. Energy consumption of buildings, due to the behaviour of their occupants, is one of the most critical points in every building energy management system. This is mainly because occupant behaviour is difficult to characterize and control due to its uncertain dynamic. First of all, it is necessary to have solved the occupants' localization before behaviour models associated to them can be provided. Depending on the building context, the impact of occupant's behaviour on total energy consumption is different. For example, in residential buildings the impact of the behaviour in the energy consumed is one of the biggest, followed by environmental conditions. However, in buildings with productive goals, the electricity consumed by the appliances and devices working for such goals is usually the main contributor to the total energy consumed in the building. Therefore, it is necessary to monitor and analyse this issue in order to provide behaviour patterns that will be included in the final estimation of the daily energy consumption of the building. Occupants' behaviour can be characterized for features such as:

- Occupants localization data
- Activity level of occupants
- Comfort preferences of occupants

D. Environmental conditions. Parameters like temperature, humidity, pressure, natural lighting, etc. have a direct impact on the energy consumption of buildings. Nevertheless, depending on the specific context of the building and its requirements, this impact will differ and be greatest in the case of indoor comfort.
services (like thermal and visual comfort). Therefore, forecasts of the environmental condition should also be considered as input for the final estimation of energy consumption of the building.

E. Information about the energy generated in the building. Sometimes, alternative energy sources can be used to balance the energy consumption of the building. Information about the amount of daily energy generated and its associated contextual features can be used to estimate the total energy generated in the future. This information allows us to design optimal energy distribution or/and strategies of consumption to ensure the energy-efficient performance of the building.

F. Information about total energy consumption. Knowing the real value of the energy consumed hourly or even daily permits the performance and accuracy of the building energy management program to be evaluated, and make it possible to identify and adjust the system in case of any deviation between the consumption predicted and the real value. In addition, providing occupants with this information is crucial to make them aware of the energy that they are using at any time, and encourage them to make their behaviour more responsible.

In IoT6 project we decided to take into account both comfort and energy efficiency. As regards the comfort provided in buildings, we focus on thermal and visual comfort.

2. Information Management. An intelligent management system must provide proper adaptation countermeasures for both automated devices and users with the aim of providing the most important services in buildings (comfort) and satisfying energy efficiency requirements. Therefore, energy savings needs to be addressed by establishing a trade-off between the quality of services provided in buildings and the energy resources required for the same, as well as the associated cost.

3. Automation. Automation systems in buildings take inputs from the sensors installed in corridors and rooms (light, temperature, humidity, etc.), and use these data to control certain subsystems such as HVAC, lighting or security. These and more extended services can be offered intelligently to save energy, taking into account environmental parameters and the location of occupants. Therefore, automation systems are essential to answer the needs for monitoring and controlling energy efficiency requirements. At this respect, the 1888-2011 IEEE Standard for Ubiquitous Green Community Control Network Protocol describes remote control architecture of digital community, intelligent building groups, and digital metropolitan networks; specifies interactive data format between devices and systems; and gives a standardized generalization of equipment, data communication interface, and interactive message in this digital community network.

4. Feedback and user involvement. Feedback on consumption is necessary for energy savings and should be used as a learning tool. Analysis of smart metering, which provides real-time feedback on domestic energy consumption, shows that energy monitoring technologies can help reduce energy consumption by 5% to 15%. As can be deduced, a set of subsystems should be able to provide consumption information in an effective way. The main subsystems are:
D7.3: Smart IPv6 building deployment, test and recommendation report

  a. Electric lighting
  b. Boilers
  c. Heating and cooling systems
  d. Electrical panels

On the other hand, to date, information in real-time about building energy consumption has been largely invisible to millions of users, who had to settle with traditional energy bills. In this, there is a huge opportunity to improve the offer of cost-effective, user-friendly, healthy and safe products for smart buildings, which increase the awareness of users (mainly concerning the energy they consume), and permit them to be an input of the underlying processes of the system. Therefore, an essential part of any intelligent management system is user involvement through their interactions and their associated data (identity, location and activity), so that customized services can be provided.

The project voluntarily adopted an iterative and incremental approach, motivated by the potential to:

  • Take into account technological evolution by integrating new products and solutions when made available, including emerging IPv6-based products;
  • Associate industrial partners, including IoT6 Advisory Board members, and remain open to new products and/or partners;
  • Optimize the learning curve with an agile process benefitting from the on-going experience and accordingly fine-tuned.
3. **Scenarios and use cases selection**

This chapter presents the different use case scenarios for the deployment plan. These have been built around both functionality from the point of view of the end-user and the building administration, and the technical implications of their implementation.

3.1. **Functional dimensions and application domains**

The evaluation has focused on four main functional and application domains. These have been identified by analysing the needs of both the end-users of a Smart IPv6 Building, and the administrators of the different automation systems involved. Each of the functional dimensions has been tested through a specific use case implementation.

**Maintenance**

The implementation of the Smart IPv6 Building must incorporate serviceability facilitating features that will result in more efficient hardware or software maintenance and reduced operational costs, by automatically identifying dysfunctions or faults and root cause analysis.

**Comfort**

The implementation of the Smart IPv6 Building must enhance the level of comfort in the everyday life of employees and building administrators by assisting them in repetitive simple tasks and creating an easy to control and more welcoming environments and interfaces.

**Energy**

Through smarter, built-in energy management solutions and automation procedures, the implementation of the Smart IPv6 Building must contribute to reduce energy consumption and improve energy efficiency.

**Security and safety**

The Smart IPv6 Building must have an increased level of protection from both external threats and from its internal structural and equipment failures. Different safety mechanisms must be put in place to guarantee the safety of the building and its occupants, and particular care must be given to consider the privacy issue from an end user perspective.

3.2. **Technical dimensions to be assessed**

In order to assess the impact of the IoT6 technology, each use case has been assessed through five main technical parameters:

**Interoperability**

IoT6 aims to provide an open IPv6 based service oriented architecture for the IoT, with multi-protocol interoperability among heterogeneous smart things and systems. It is important to enable new forms of interaction among heterogeneous devices from different suppliers using different communication protocols.

**Ease of deployment**

IoT6 will make it easy to develop holistic control and monitoring systems by integrating in a single semantic framework all kinds of sub-systems of smart things. This will ease the transition towards IPv6 by proposing different schemes of IPv6 proxy services for heterogeneous devices, including non-IP compliant devices and legacy devices.
Reliability
IoT6 deployment must result in reliable systems and components, able to perform their required functions under any conditions as good as or better than in the absence of such technology. Consistent performance and security of data and systems against attacks are also important aspects.

Cost of deployment
IoT6 deployment should be cost effective by providing more functionality and performance at lower cost. By enabling the combination of heterogeneous devices, IoT6 will increase the choice for the end-user, enabling him to combine different games, types and brands of products to optimize the price of the system to be deployed. Being a fully flexible programmable solution, IoT6 can make available more services at a lower cost.

Scalability
IoT6 deployment in the Smart IPv6 Building must be highly scalable and easily extendable to other sectors of the Internet of Things. The open service-oriented architecture of IoT6 will enable the integration and interoperability of heterogeneous communicating things, with intelligence distribution, mobile network integration, business processes and cloud computing integration.

In order to cover the four application domains and to assess their respective technical dimension, it has been decided to implement one use case per application domain.
4. Scenarios and use cases description


The first scenario addresses the maintenance process of building automation components through the cross-domain IoT6 architecture. It intends to demonstrate the benefits of the IoT6 architecture to ease the integration of the IoT (with a focus on building automation components) with mobile phones, as well as with virtual resources, such as STIS, SaaS and business management application.

This scenario presents a situation within a building automation system, where spurious behaviour of an automation component is observed. IoT functionality is then used to investigate the malfunction, order a replacement part, guide the replacement process, and finally confirm the replacement and resume normal operation.

1. The building control and monitoring system detects a malfunctioning device, through either regular monitoring or device notifications. The CMS sends an alert to an Online Maintenance Service (OMS).

2. The OMS searches for and retrieves information on the device through, among others, the Smart Things Information Service (STIS). First of all, the maintenance tool does a query to the resource directory to obtain the IPv6 address of the STIS. The OMS then opens a maintenance ticket and sends an alert to a maintenance officer through the smartphone Maintenance App.

3. The maintenance officer launches some tests through the Maintenance App and collects data from local sensors, including non-IP based sensors, to make a diagnostic of the problem. The maintenance officer uses the Maintenance App from his mobile phone to order the spare parts.

4. The parts arrive on site. A local maintenance employee scans the device ID from his smartphone with the Maintenance App. The information is sent to the OMS. The local employee receives instruction on how to replace the device. The employee validates the replacement once it is done.

5. The remote maintenance officer tests remotely and validates the installation of the new device. Then he closes the maintenance ticket of the maintenance process in the OMS.

Sequence diagrams

Step 1.

[Diagram showing the interaction between Temperature Sensor, Non IP Based Protocols Proxy, Control and Monitoring System, and Online Maintenance Service.]
Step 2.

Online Maintenance Service → Smart Things Information Service → Resource Directory → Maintenance App

1. get STiS IPv6 address
2. get device information
3. generate maintenance ticket
4. notify maintenance officer

Step 3.

Maintenance App → Online Maintenance Service → Non IP Based Protocols Proxy → Sensor(s)

1. launch diagnostics
2. start tests
3. get data from sensors
4. send results
5. display results
6. order spare parts
D7.3: Smart IPv6 building deployment, test and recommendation report

Step 4.

Step 5.
4.2. Comfort: “The Smart Office”

This scenario is directly inspired by the IIAB proposals. It intends to demonstrate the ability of the IoT6 architecture to interact with heterogeneous devices, including non-IP based protocols, with a focus on energy efficiency and user comfort.

1. An employee arrives at the office building. He identifies himself with his mobile phone through an interface, such as NFC. A terminal reads the tag included in the mobile phone and notifies the Control and Monitoring System (CMS) of the user presence.

2. At his office, the lights, the blinds and the HVAC system are adapted to create a comfortable and welcoming ambiance for him at his workstation, by taking his preferences into account.

3. The employee updates his custom preferences through the Smart Office App on his mobile phone.

4. A visitor arrives, signs in to the visitors’ list with his mobile phone, and is guided to the waiting lounge. The CMS notifies the employee that his visitor has arrived and his current location.

5. A presence sensor installed in the waiting lounge detects the arrival of the visitor. Video and music are launched, together with lighting adaptation to create a welcoming atmosphere.

6. The employee leaves his office. The lights, windows and HVAC systems around the workstation are automatically adapted in order to save energy. A presence sensor placed in the office detects that nobody is in this room and the different actions to save energy can be initiated.

7. After their meeting, the employee and visitor leave the building. The employee receives a farewell message. A request to the resource directory is realized to retrieve the address of the mobile phone.

Sequence diagrams

Step 1.
Step 2.

D7.3: Smart IPv6 building deployment, test and recommendation report

Step 3.

Step 4.

Visitor's Phone  NFC Terminal  Non IP Based Protocols Proxy  Control and Monitoring System  Smart Office App

read tag

send tag information

register visitor

notify visitor's arrival
Step 5.

Step 6.

Step 7.
4.3. Energy: “Saving and User Awareness”

This scenario intends to illustrate the use of the IoT6 architecture for building automation with a focus on energy management and user awareness. The use case further includes user interaction through a building automation component.

1. An employee enters an office. His presence is detected, the Control and Monitoring System (CMS) automatically turns on the lights, blinds, and HVAC for best comfort and energy efficiency.

2. A touch screen with the Smart Office app turns on and displays information such as the time and date, messages from the reception, current room temperature, humidity and energy consumption. One can browse more detailed statistics at different levels (room, floor, building,) like energy consumption graphs over time.

3. The employee uses the app to manually modify the HVAC and lights settings. The app alerts him of the energy consumption increase generated by these modifications (ecological footprint).

4. The Smart Office app suggests more efficient settings for optimal energy consumption, which the employee validates.

5. When the employee leaves his office, the lights, windows and HVAC systems around the workstation are automatically adapted in order to save energy. A presence sensor placed in the office detects that nobody is in this room and the different actions to save energy can be initiated.

Sequence diagrams

Step 1.
D7.3: Smart IPv6 building deployment, test and recommendation report

Step 2.

Step 3.
D7.3: Smart IPv6 building deployment, test and recommendation report

Step 4.

Step 5.

The scope of this scenario is focused on the detection of an abnormal situation, notifying a responsible authority, and live monitoring through IPv6 connected sensors. This use case is but a sub-scenario of a broader surveillance system.

We consider two triggering situations. The first is the case of intrusion in a secured zone, like an office building at night time. The second is triggered as a reaction to hazardous environmental conditions, in this case the detection of a fire.

1. Intrusion detection: A presence sensor detects movement in a room meant to be empty, or a magnetic sensor placed on a door/window meant to remain closed senses it has been opened.

2. Fire detection: A sensor captures abnormal temperature values and/or detects the presence of smoke.

3. The sensor data is sent to the Control and Monitoring System (CMS) which is able to recognize the abnormal measures in the received packet and tags the data with a “priority/safety alert” tag.

4. The CMS looks up the IP addresses of the closest security server and possible back-ups. The resource directory contains all IPv6 addresses needed by the local data server. It sends the data by anycast with QoS and priority routing to a first group of security servers. If it does not receive a reply in a given time, it sends again the duplicate data to another group of security server. The security server confirms the reception of the data received.

5. An alert ticket is generated on the Security & Safety Service (SSS). The SSMS collects information from local sensors, including a picture taken by a security camera.

6. The SSMS sends an alert message to a security agent (by email, SMS, and through the Security & Safety App) including the information collected by the sensors.

7. The staff member accesses the live feed of the security cameras through the SSA on his smartphone.

Sequence diagrams

Step 1.
Step 2.

Step 3.
Step 4.

Step 5.
5. Deployment plan

This chapter describes the deployment plan in the Mandat International testbed for the final validation.

5.1. Deployment requirements

The proposed use-case scenarios imply the following specific requirements:

1. **Smart routing**: Content-based routing is required to implement the different scenarios;

2. **QoS with priority routing**: The transmission of data should be reliable, especially for critical data;

3. **Reliability and self-healing architecture**: The system should automatically return from errors to a normal state;

4. **Re-routing of packets**: The packets should be re-routed across the different kinds of IoT6 servers;

5. **Ubiquitous end-to-end communication between components**: The devices should be accessible from any place in the world;

6. **Privacy and security**: The privacy and the security should be guaranteed in all cases;

7. **Addressing**: Multicast and anycast addressing should be supported in the scenarios implementation;

5.2. Deployment strategy

The testbed deployment was designed in order to enable the selected use cases and to encompass the various communication protocols integrated by T4.2, including:

- 6LoWPAN
- ZigBee
- KNX
- RFID/NFC reader
- BACnet
- EnOcean
- Wireless Metering Bus

For each scenario, the deployment has been explored and planned with the following considerations:

- The chosen places/rooms must provide realistic environment for the corresponding scenario to take place;

- The deployment should minimize its impact on the existing building infrastructure, such as wiring, in order to decrease deployment cost and time;

- Synergies should be exploited, as several scenarios can share similar equipment;

- Relevant coverage: The test should be performed in a real environment, with reasonable quantity of equipment, such as WSN motes, to provide connectivity to all the emplacements involved in tests;
• Taking into account heterogeneity: the use cases deployment should consider, where relevant, heterogeneity of solutions.

The deployment intended to achieve a good balance between the researched features, the ease of deployment and the costs:

• The building automation components should be easy to deploy in the testbed. Hardware should have suitable analogical/digital input/output interface and good specification for eventual adaptation.
• Wireless products are preferred because they can be deployed and relocated easily. However, actuators will mostly require wiring for both power and connectivity. Wired hardware should be chosen carefully to avoid additional work on the existing infrastructure. This is a particularly relevant constraint for an effective deployment in retrofitted buildings.
• The hardware should be affordable for normal user. Wide range of features and effortless installation usually mean expensive product.

5.3. Provisional deployment architecture

In order to test and validate the IoT6 use case scenarios, the evaluation of the integrated research output have been performed in an end-user environment provided by Mandat International at their Champ-Baron office. It comprises:

• A meeting space with several workstations
• A small waiting lounge
• A water-closet
• A tiny kitchen
• A server rack

This testbed is a typical office in which we can perform various IoT6 use cases with a real end-user approach as a “smart office” testbed. The testbed is used by a regular staff coordinating various activities related to the United Nations and international cooperation. The following pictures provide some views of the “smart office” testbed at Champ-Baron:

![Meeting space and small lounge area in the Mandat International testbed](image)

The following figure displays the Mandat International smart office testbed. The different devices displayed are for reference and have been adapted according to the targeted use cases.
5.4. Main actors

In the context of the testbed, several roles and stakeholders have been identified:

1. **Office employee**
   
   A local office employee with an NFC enabled smartphone appears for the comfort scenario. Identification is used for personal workspace preferences. In practice, the identification could be carried through multiple other solutions including RFID identity cards.

2. **Office visitor**
   
   Person with no permanent relationship to the office and no identification mechanism appears in the comfort scenario. His smartphone is used for temporary identification.

3. **Local maintenance employee**
   
   Member of (or somehow affiliated with) the local staff. They are assigned an individual ID associated with certain access privileges, one of which is the ability to carry maintenance processes (in this case, device installation) within the building automation.

4. **Maintenance officer**
   
   Member of (or somehow affiliated with) the local staff. They are assigned an individual ID associated with certain access privileges and responsibilities including monitoring devices and managing different maintenance tasks locally and remotely, as it’s the case in the maintenance scenario.
5. Security officer

A person responsible for handling a specific alarm, registered via an IPv6-enabled mobile phone and a Security & Safety App at the Security & Safety Service component.

5.5. Provisional list of components

Services

Control and Monitoring System (CMS)

The Control and Monitoring System is responsible for controlling and monitoring the building automation system, including devices using heterogeneous communication protocol, either directly or through a legacy protocols proxy with an IoT6 gateway. It contains a (usually large) set of rules describing each and every control loop in the system.

Note that while we are referring to ‘the’ CMS, it could – and in most cases will – be not just one centralized component, but rather a hierarchically structured set of CMSs, each with control over a specific local neighbourhood within the automation system.

In the maintenance scenario the CMS is only marginally involved: The maintenance is carried out by the Online Maintenance Service, which subsequently notifies the CMS of the various state changes for the component in question.

For the comfort and energy scenarios, energy management is built into the CMS for simplicity, though it could be carried by a separate Building Energy Management System, responsible for monitoring temperature and energy consumption in the building.

Online Maintenance Service (OMS)

A Software as a Service, or probably the UDG with a web interface: This is the central component in the maintenance scenario, accepting the maintenance request and utilizing the other components to carry out the maintenance process.

In the scenario, inventory management is also carried out by the OMS, though it could very well be a separate component that provides an interface to the infrastructure management (in particular, to handle the order process for the replacement part).

Security & Safety Service (SSS) and Security Servers

The Security & Safety Service accepts incoming alarm messages and relays them to mobile devices according to their vicinity to the alarm location. It keeps track of the generated alarm via a ticketing mechanism and also informs the mobile clients as soon as the alarm has ceased.

Multiple Safety Servers: are in charge of managing safety alerts and can interact with a number of components and devices connected to the IoT6 architecture. To avoid unnecessary developments, a UDG control and monitoring system will be adapted to work as a safety server.

Smart Things Information Service (STIS)

Radio Frequency Identification (RFID) technology enables tagging of everyday objects with a unique smart thing Identifier (STID). Smart Thing Information Service (STIS) have been developed to ease the management, the sharing and the access to tags related information. The STIS serves as a global infrastructure, providing information about smart thing metadata (e.g., product class or description), traces of location and time, as well as status of smart things. The STIS encompasses information systems, communication protocols, and data types that support capturing, storage, and exchange of smart thing-related data.
Resource directory and discovery (Digrectory, Digcovery)

Digcovery is a global IoT6 discovery system that can be used to search and discover devices based on certain criteria on resource type and interface.

Digrectory is used to locate services accessible within the (local) IoT. It is a local DNS based resource directory providing IPv6 addresses and servicing descriptions for devices. It is handed a service description together with a set of parameters, and it responds with the IPv6-address of a node that has registered itself to provide this service. These records are uploaded to the global Digcovery system.

Front-end applications

In the different use cases, different applications are used to interact with the interconnected services:

Smartphones
In the scenarios described above, the employees use their smartphones to interface with the different building automation systems. This is, of course, not mandatory, and is merely used here to demonstrate the integration of smartphone applications into the IoT6-environment as rich and compact interfaces. In an actual system, a nearby local terminal could be used instead, for example. Note that the sequence diagrams show the different smartphone apps rather than the smartphones running them.

Touchscreens or tablets
Like smartphones, touchscreen terminals or rather tablets can act as human-machine interfaces to both control and monitor the different tasks of building automation.

Maintenance App
This application program runs on a smartphone, handling user interaction with the maintenance environment and services. It is expected to be configured with the ID of the maintenance employee in order to allow proper authorization towards the maintenance environment.

Smart Office App
This is the application program running on the smartphone of an employee in the comfort scenario, where it adjusts personal workspace settings (light, temperature, etc.)

Security & Safety App
A smartphone application running on the mobile phone of security officers, acting as an interface for and handling communication with the Security & Safety Service.
Network Proxy

Non-IP Based Protocols Proxy

For legacy devices and devices communicating through non IPv6 based protocols, a proxy is required, and is a central component to an IoT6-system. This is accomplished through the use of the following software and hardware, complementary solution.

A CoAP/oBIX Gateway is used to interface the IoT6-enabled part of the automation system with non-IPv6-enabled components. In particular, it will be a CoAP/oBIX Gateway, providing access to BACnet and KNX subsystems.

A Smart Board with IoT6 Gateway is used to distribute the intelligence and the multi-protocol integration. It will work in complementarity with the multi-protocol control and monitoring system. It will provide an IoT6 (CoAP/JSON/oBIX) Gateway to some BACnet and KNX subsystems.

Sensors

Temperature sensors

These will be used to monitor the current temperature in the different rooms and areas of the deployment testbed.

Presence sensors

Used to monitor the presence of people in the different rooms and areas in order to adapt energy consumption accordingly by, for example, turning the lights off in the absence of people.

Energy meters

In order to assess the efficiency of the deployed energy management solutions, energy meters are used to measure energy consumption at different levels (building/floor/room/appliance.)

CO and CO₂ detectors

CO and CO₂ detectors are standard safety hardware in office environments. Here, they are integrated into the deployed security solution.

Magnetic sensors

Placed on doors and windows, these are used to monitor the state of security-sensitive rooms and areas like windows outside office hours, or the door of a secure off-limit room.

For the interaction with the lighting and temperature sensors two BACnet controllers are used, which are non-IPv6-enabled automation devices. Other legacy protocol devices will be considered too.

In the case of the maintenance scenario, the sensor will be disabled (by disconnecting the PTC measurement resistor inside it) to trigger the maintenance process, and re-enabled (by reconnecting the PTC) to simulate the replacement of the device.

For the security scenario, the temperature sensor will be heated to a certain temperature to trigger the fire detection. Likewise, the presence sensor or magnetic sensor (placed on a door/window) can be used for the same result.
**Actuators**

**Lamps and lights**
ZigBee enabled light bulbs capable of reproducing different colours and of varying light intensity are used on floor, desk, and ceiling lamps.

**Switches**
Smart switches are used to control different devices like lights and blinds through the deployed Smart IPv6 solution.

**Motorized blinds**
Motorized windows blinds are placed on several windows.

**HVAC (heating, ventilation, and air conditioning)**
The HVAC can be controlled for a desired temperature/humidity. It consists of multiple actuators including the building’s built-in hardware like radiators and ventilation systems as well as other actuators like standalone fans.

For the interaction with the HVAC system BACnet controllers are used, which are non-IPv6 – enabled automation devices. Other legacy protocol devices will be considered too.

**Multimedia devices**
Multimedia devices like televisions, screens and speakers are also used as IoT enabled devices, notably directly accessible through UPnP/DLNA.
5.6. Deployment process

The deployment plan was adapted to the overall IoT6 work plan and schedule and was dependent on the other work package deliverables. The deployment was planned as follows, with an initial deployment by the end of December 2013. Tests and fine tuning started in February 2014. However, benchmark energy consumption data was collected since early 2013.

<table>
<thead>
<tr>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption of the deployment plan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ad hoc developments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-site deployment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test and technical fine tuning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiments with end-users and data collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deliverable TOC and initial draft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing the deliverable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proof reading and finalizing the deliverable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Initial provisional deployment planning

Despite its appearing linear development, the experimentation process adopted an iterative cycle of tests and experiments.

The experimentation will continue and will be extended to address complementary and future deployments, including the deployment of a new air ventilation system provided by CIAT, one of the IoT6 Industry Advisory Board members, to be deployed by the end of August 2014.
6. Detailed deployment plan

The following section describes the specific deployments used for each use case:

### 6.1. Maintenance: Building Maintenance Process

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and Monitoring System (CMS)</td>
<td>IoTSys module</td>
</tr>
<tr>
<td>Smart Board</td>
<td>IoT6 (CoAP/JSON/oBIX) Gateway</td>
</tr>
<tr>
<td>Temperature sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-EM1000 using CoAP interface.</td>
</tr>
<tr>
<td>Online Maintenance Service (OMS)</td>
<td>Software as a Service (SaaS)</td>
</tr>
<tr>
<td>Maintenance App</td>
<td>Smartphone interface for OMS</td>
</tr>
<tr>
<td>Smart Things Information System (STIS)</td>
<td></td>
</tr>
<tr>
<td>Resource Directory and Discovery</td>
<td>Digrectory, Digcovery</td>
</tr>
</tbody>
</table>

![Figure 6: Building Maintenance use case deployment plan](image-url)
6.2. **Comfort: The Smart Office**

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and Monitoring System (CMS)</td>
<td>IoTSys module</td>
</tr>
<tr>
<td>Smart Board</td>
<td>IoT6 (CoAP/JSON/oBIX) Gateway</td>
</tr>
<tr>
<td>Smart Office App</td>
<td>Smartphone interface for CMS</td>
</tr>
<tr>
<td>Resource Directory and Discovery</td>
<td>Digrectory, Digcovery</td>
</tr>
<tr>
<td>Authentication terminal</td>
<td>RFID/NFC terminal</td>
</tr>
<tr>
<td>Light bulbs + gateway</td>
<td>Philips HUE ZigBee enabled bulbs</td>
</tr>
<tr>
<td>Blinds + gateway</td>
<td>Somfy</td>
</tr>
<tr>
<td>HVAC</td>
<td>Adhoco radiator valves, Z-Wave enabled fan</td>
</tr>
<tr>
<td>Presence sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-SE1000.</td>
</tr>
<tr>
<td>Audio and video display</td>
<td>TV (screen and loudspeakers)</td>
</tr>
</tbody>
</table>

![Figure 7: Smart office use case deployment plan](image-url)
6.3. **Energy: Saving and User Awareness**

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and Monitoring System</td>
<td>IoT Sys module</td>
</tr>
<tr>
<td>CMS</td>
<td></td>
</tr>
<tr>
<td>Smart Board</td>
<td>IoT6 (CoAP/JSON/oBIX) Gateway</td>
</tr>
<tr>
<td>Smart Office App</td>
<td>Touchscreen interface for CMS</td>
</tr>
<tr>
<td>Resource Directory and Discovery</td>
<td>Directory, Discovery</td>
</tr>
<tr>
<td>Light bulbs + gateway</td>
<td>Philips HUE ZigBee enabled bulbs</td>
</tr>
<tr>
<td>Blinds + gateway</td>
<td>Somfy</td>
</tr>
<tr>
<td>HVAC</td>
<td>Adhoco radiator valves, Z-Wave enabled fan</td>
</tr>
<tr>
<td>Presence sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-SE1000.</td>
</tr>
<tr>
<td>Temperature and humidity sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-EM1000 using CoAP interface.</td>
</tr>
<tr>
<td>Energy meters</td>
<td>Wattics (room consumption) and Pikkerton (appliance consumption)</td>
</tr>
</tbody>
</table>

*Figure 8: Energy use case deployment plan*
6.4. Security & Safety: Intrusion and Fire Detection

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and Monitoring System (CMS)</td>
<td>IoTSys module</td>
</tr>
<tr>
<td>Smart Board</td>
<td>IoT6 (CoAP/JSON/oBIX) Gateway</td>
</tr>
<tr>
<td>Security &amp; Safety Service (SSS) and Security Servers</td>
<td></td>
</tr>
<tr>
<td>Security &amp; Safety App</td>
<td>Smartphone interface for SSS</td>
</tr>
<tr>
<td>Resource Directory and Discovery</td>
<td>Digrectory, Digcovery</td>
</tr>
<tr>
<td>Presence and Magnetic sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-SE1000.</td>
</tr>
<tr>
<td>Temperature sensors</td>
<td>Advantic MTM-CM3000 with Advantic MTS-EM1000 using CoAP interface.</td>
</tr>
<tr>
<td>CO and CO2 sensor</td>
<td>Advantic MTM-CM3000 with Advantic MTS-AR1000.</td>
</tr>
<tr>
<td>Security Camera</td>
<td>Cisco VC220 IP Camera</td>
</tr>
<tr>
<td>Email server</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 9: Security and safety use case deployment plan*
6.5. Selection of deployed components to comply with the heterogeneity requirement

The following list is intended to check the heterogeneity of communication protocols involved in the use cases deployment:

6LoWPAN:
Several wireless sensor motes

Temperature and humidity sensor
Presence sensor

ZigBee:
Energy meter, radiator valves, lightings

Adhoco radiator valve
Philips Hue lamp

Pikkerton energy meter
KNX:
Universal dimmer, temperature sensor, radiator valve

Universal dimmer, temperature sensor, power supply and KNX/IP router

Radiator valve
RFID/NFC:
RFID/NFC reader from Arygon

EnOcean:
Wireless buttons

Wireless Metering Bus:
Water meter
D7.3: Smart IPv6 building deployment, test and recommendation report

Z-Wave:
Fan, multi-sensor

Module to control the fan

Motion, temperature and light sensor

Nexa/Chacon:
Magnetic sensors

Magnetic sensor for a door
### 6.6. Deployment plan devices matrix

The following table illustrates the complementarity of the deployed devices:

<table>
<thead>
<tr>
<th>Devices</th>
<th>Use cases</th>
<th>Communication protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maintenance</td>
<td>IP</td>
</tr>
<tr>
<td>Temperature and humidity sensors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authentication terminal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light bulbs + gateway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blinds + gateway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Audio and video display</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence and Magnetic sensors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO and CO2 sensor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security Camera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Button</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Email server</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1: Deployment plan devices matrix*
7. Technical analysis

7.1. Ease of deployment

Traditional solutions

Traditional Building Management Systems (BMS) deployments are often based on specialized protocols such as BACnet, KNX and LON. Most deployments require important retrofitting works to deploy the required communication buses, and are therefore uneasy to implement in existing structures.

The use of wireless sensor networks to audit buildings and control equipment represents a viable and more flexible solution. Solutions based on WSN (Wireless Sensor Network) for monitoring buildings and controlling equipment, such as electrical devices, heating, ventilation and cooling (HVAC), can be installed in existing structures with minimal effort. Traditional WSN solutions are based on specific protocol stacks, such as ZigBee, Z-Wave, or EnOcean. The deployment is easier than with wired bus, but their integration with other systems is still difficult.

Impact of deploying an IoT6/IPv6-based solution

The IoT6/IPv6 approach can be declined in two subgroups of deployments:

A. IPv6/6LoWPAN based deployment with native IPv6 environment.
B. Heterogeneous protocols integrated through IPv6.

For the wireless deployment, we focused on 6LoWPAN for the former subgroup and on legacy protocols, such as ZigBee, Z-Wave and EnOcean for the latter. 6LoWPAN standard share the same physical layer as ZigBee: both are based on IEEE 802.15.4 and both standards are quite similar in terms of energy efficiency (with some minor differences) and radio accessibility.

Wireless sensors compliant with 6LoWPAN and CoAP are quite easy to deploy, due to the IoT6 architecture which is natively 6LoWPAN and CoAP compliant. The address translation with full IPv6 addresses is implicit and automatic, enabling a sort of plug and play solution. It provides a competitive advantage in terms of ease of deployment for 6LoWPAN sensors and actuators.

Another advantage of 6LoWPAN and CoAP is that all the sensors are transparently connected to the IPv6 network and there is no need of a proxy or a gateway. This permits a direct IPv6 connection between the sensors and the applications receiving the sensors data. If the wireless sensors communicate by a protocol like ZigBee or Z-Wave, or by a proprietary protocol, a gateway is required and the role of the gateway is played by the CMS (Control and Monitoring System).

Finally, the natively IPv6 components could benefit from the Stateless Address Autoconfiguration mechanism (SLAAC): By enabling the devices themselves to automatically define their own address, it simplifies the deployment in terms of human intervention with a positive impact in terms of time and cost savings.

At the planning stage, the most relevant impacts identified with the IoT6/IPv6 deployment were:

- The possibility to make abstraction of the specificities of each and every component. The IoT6/IPv6 deployment can be agnostic of any specific protocol.
- The possibility to choose products and solutions by focussing on their sensing and actuating qualities (rather than interfacing specifications).
- The possibility to freely predefined the address allocation regardless of the specific components communication protocols.
The possibility to mix wireless, wired and PLC technologies for the system deployment.
The absence of size constraints, which is often the case with communication protocols with a limited number of address allocation (such as X10) or constrained address structure in predetermined groups and subgroups architecture (such as KNX).

During the operational phase, a few additional benefits were identified:

- The possibility to easily reconfigure the architecture.
- The possibility to add new components and/or systems to the initial deployment.

Globally, the IoT6/IPv6 option had a positive impact in terms of ease of deployment.

### 7.2. Heterogeneous integration

#### Traditional solutions

Traditional solutions for both building automation and Internet of Things implementations are either mono-protocol based or with a limited integration with other protocols. It strongly limits the interoperability, as each subsystem is isolated and uses its own protocol(s), including many non-IP protocols.

IoT6 enables various models of heterogeneous protocols integration. Whether it is by using the UDG model or a distributed half-gateway model, the various subsystems can be integrated together. It enables the smart building deployment to move from a system composed of several independent verticals and silos towards a more integrated system, enabling various components to work together, as illustrated in the figure on the next page.

Another important limitation is related to the difficulty to interconnect the platform with on-line services and web-based applications.

#### Impact of deploying an IoT6/IPv6-based solution

IPv6 provides an almost unlimited number of addresses enabling to interconnect and address an almost unlimited number of heterogeneous devices. IPv6 per se is not sufficient to enable interoperability.

IoT6 provides an open framework to integrate different systems together, including various Internet of Things components, as well as different types of applications. It enables the integration through different mechanisms enabling heterogeneous integration at various levels, from the physical layer up to the application (and semantic) layer. The various protocols are integrated into IPv6 and the IoT6 architecture with solutions such as UDG multi-protocol control and monitoring system or by providing bridges and gateways between specific protocols and the IoT6 stack.

Another interesting IoT6 features is related to the use of CoAP (Constrained Application Protocol). It turns all sorts of legacy devices into RESTful resources with a common interface.

IoT6 service oriented architecture provides a framework enabling end-to-end interactions among heterogeneous systems and solutions, supporting interactions between all sorts of smart things, applications and services, including:

- Cross systems integration and interactions;
- Remote and distant integration and interactions;
- Multi-protocol integration and interactions;
- Mobile networks integration and interactions with ubiquitous access;
- Smart Things Information Service or EPCIS integration and interactions;
Business process applications integration and interactions.

**Traditional model**

![Diagram of a traditional model](image)

**IPv6-integrated model**

![Diagram of an IPv6-integrated model](image)

The most relevant impacts identified with the IoT6/IPv6 deployment were:

- The possibility to combine all kinds of devices together and to be agnostic of any specific protocol.
- The possibility to enable cross-systems and cross-domains interactions.
- The possibility to freely combine components from various manufacturers together.
- The possibility to enable new business models, more decentralized, in which various companies can focus on their expertise in order to propose integrated solutions based on components coming from a larger set of companies, with new forms of ecosystems.
- The possibility to optimize each subsystem individually and to mix them in order to optimize the whole system deployment.
- The possibility to increases the number of possible interactions between different kinds of devices or services.
- The possibility to design new applications or scenarios offering new user experience.
7.3. Scalability

The Internet of things is heading towards a huge number of communicating devices, of which many will be deployed in buildings. Scalability can be defined as the capacity of a solution to cope and handle a very high number of devices and data. It can be differentiated in at least four specific dimensions:

A. Addressing scalability: The capacity to address a large number of devices.
B. Geographic scalability: The capacity to cover a very large space.
C. Data process scalability: The capacity to handle a high volume of data.
D. Functional scalability: The capacity of the framework to include a high number of features and services.

Traditional solutions

In terms of addressing scalability, traditional models are often limited by the specific properties of a given communication protocol. The following Table 2 highlights the inherent limitations of some mainstream protocols:

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Nb of subnets</th>
<th>Nb of host ID per subnet</th>
<th>Total number of addresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>X10</td>
<td>16</td>
<td>16</td>
<td>256</td>
</tr>
<tr>
<td>KNX</td>
<td>16</td>
<td>16 x 256</td>
<td>Theoretical 65,536, but effective 61,455</td>
</tr>
<tr>
<td>LON</td>
<td>127</td>
<td>127</td>
<td>$2^{48}$ Neuron ID</td>
</tr>
<tr>
<td>ZigBee</td>
<td></td>
<td></td>
<td>64,000 nodes per network</td>
</tr>
<tr>
<td>Z-Wave</td>
<td></td>
<td></td>
<td>232</td>
</tr>
<tr>
<td>BACnet</td>
<td>Non-limited</td>
<td>Non-limited</td>
<td>Non-limited</td>
</tr>
<tr>
<td>6LoWPAN</td>
<td>$10^{19}$</td>
<td>$10^{19}$</td>
<td>$10^{38}$ for the data link layer; network layer: $10^{38}$</td>
</tr>
<tr>
<td>IPv6</td>
<td>$2^{64} \approx 10^{19}$</td>
<td>$2^{64} \approx 10^{19}$</td>
<td>$2^{128} \approx 10^{38}$</td>
</tr>
</tbody>
</table>

Table 2: Address scalability of mainstream protocols

In terms of geographic scalability, traditional solutions are often deployed locally at the scope of one building or a few buildings in the same city.

In terms of data scalability, traditional solutions are often based on a central controller with all sorts of devices connected to it and controlled by it. This constitutes a bottle neck by design with most likely the presence of a unique point of failure.

In terms of functional scalability, traditional solutions are often closed ones, controlled by a solution provider.
Impact of deploying an IoT6/IPv6-based solution

In terms of address scalability, with $2^{128}$ addresses, IPv6 provides a magnitude jump in terms of address space, with more IPv6 unique addresses than the number of grains of sand on Earth and the number of atoms in each and every human being on earth.

In terms of geographic scalability, the inherent Internet compliance of IPv6 enables the IoT6 architecture to benefit from the global Internet with ubiquitous connectivity. It enables a global scalability with worldwide deployments, including the extension to outer space deployments\(^\text{16}\).

In terms of data process scalability, IoT6 provides several advantages:

- As demonstrated by its deliverable on smart routing (D3.2 “Smart Routing Mechanisms Design”), IoT6 enables intermediary nodes in the network to process events and apply algorithms in order to distribute the intelligence across the architecture.

- The RESTful option adopted by IoT6 with CoAP enables a high number of clients to access a high number of end nodes in line with a “many to many” connexions model. This approach enables several servers and controllers to share the same pool of resources.

Thanks to the above mentioned qualities, it is possible:

- To duplicate and implement redundancies with critical services in order to avoid a unique point of failure.

- To distribute the data processing, as well as the control and monitoring process across the whole architecture.

In terms of functional scalability, IoT6 can rely on two mechanisms:

- Its capacity to integrate heterogeneous systems and components together (as previously described).

- Its RESTful architecture which enables an unlimited number of services to connect to the same pool or resources through a well-defined interface.
7.4. Flexibility, modularity

Traditional solutions

Traditional solutions the systems are usually homogeneous with a predefined structure. The flexibility is often very limited.

Impact of deploying an IoT6/IPv6-based solution

Of course, IoT6 deployment benefit from several characteristics previously mentioned, such as scalability and interoperability. IoT6 architecture enables a quite open and flexible framework with the possibility to adopt and combine different integration and controlling models, such as:

- Direct control and monitoring of heterogeneous devices and systems.
- Interoperability among heterogeneous devices using different communication protocols.
- Letting various systems coexist with their own logics, while enabling meta-interactions to enable those systems to work together.
- Providing IPv6 or CoAP proxy for legacy devices.

In the case of the smart office deployment, such functionalities were mainly enabled by the UDG multi-protocol control and monitoring system.

Another relevant characteristic of IPv6 is related to its ability to provide a dual addressing scheme: The first half of its address space is usually attached to the network subnet address, while the second half is usually attached to the specific host identifier. In other words, it contains two elements of information: where is the node located and who is the node. It enables a very convenient way to handle the addressing of smart buildings components, including mobile ones.

Some key impacts identified with the IoT6/IPv6 deployment were:

- The possibility to easily distribute and decentralize the intelligence.
- The possibility to mix, to organize and to freely design all sorts of architectures for deployment, with the integration of different subsystems in a very flexible way.
- The possibility to provide a unique identifier to any device, including devices using non-IP-based communication protocols.
- The possibility to use the address as a locator and an identifier and to cope with mobile devices.
7.5. Security and Reliability

**Traditional solutions**

Traditional security mechanisms are usually protocol specific and are mainly focused on firewalling the bus and sometimes on encrypting the data stream. Constrained devices are often neglected and remain vulnerable to hackers. Furthermore, Quality of Service (QoS) is often missing, reducing the reliability of critical communication components.

**Impact of deploying an IoT6/IPv6-based solution**

IoT6 brings several benefits to buildings deployments:

- It benefits from strong encryption mechanisms provided by IPv6 at the network layer with IPSec.
- IoT6 has demonstrated the possibility to extend security to constrained devices, with mechanisms such as DTLS.
- The architecture can also benefit from complementary encryption at the application layer with TLS and SSL for example.
- IoT6 can provide identification and authentication by using local or remote resource directories.
- IPv6 provides QoS enablers, improving reliability of critical communications and components.

7.6. Cost of deployment

**Traditional solutions**

Traditional solutions are characterized by:

- A fragmentation in several verticals organized in rather hermetic and independent silos, as illustrated in Figure 5.
- Proprietary solutions in terms of hardware and software, which leads the users to be a prisoner in a locked-in situation.
- Lack of interoperability with third parties solutions or alternatively interoperability limited to a subgroup of devices sharing the same standard.
- Rigidity of the architecture both in hardware and software.

**Impact of deploying an IoT6/IPv6-based solution**

IoT6 enables more flexible and customisable deployments by mixing different systems and products together. The IoT6 service oriented architecture enables to ease the integration with third parties services and applications, including cloud and software as a service.

The use of the Internet Protocol version 6 has a certain number of inherent advantages:

- The large IPv6 address space enables to get rid of the network address translation (NAT), which allows to simplify the network architecture and to reduce the number of gateways.
- The IPv6 Stateless Auto-configuration mechanism enables a simpler deployment. No need to configure the IP address of the device, as it can find and configure its address itself, saving a lot of manpower.
- The use of 6LoPAN and CoAP-compliant sensors and actuators enables to configure and control them directly from the Internet.
• The availability of free and reliable security mechanisms, such as IPSec, reduces the cost for proprietary security solutions.

**Impact on deployment costs**

IoT6 brings several cost benefits to buildings deployments:

• By enabling the combination of various products together, regardless of their specific communication protocol, it enables to select and mix among a larger set of options to choose the most attractive and cost efficient solutions.

• It enables to mix high end solutions for critical components with low costs products for less critical ones.

• It frees the building owner from locked-in situation, by allowing him to adopt products and solutions from the competition.

• By providing an open interface and service oriented architecture, it can extend the offer and increase the competition on price.

• It can replace several controllers and user interfaces by one multifunctional controlling and monitoring system, reducing the acquisition and deployment cost.

**Impact on maintenance costs**

IoT6 brings several cost benefits to the building’s maintenance:

• It can replace several controllers and user interfaces by one multifunctional controlling and monitoring system, simplifying and reducing the maintenance costs.

• Similarly, for solutions which are paid on a monthly basis or yearly basis, the reduction of the number of controlling applications by simplifying the architecture can save recurring licence costs.

• The solution being based on an open Internet-based API, there is no structural cost to integrate new components.

• It enables the systems to progressively evolve by adding new components instead of having to replace the whole system.

• As illustrated below, an integrated deployment can contribute to save energy and related costs.

### 7.7. Energy efficiency

The smart office testbed has been used to explore the potential energy saving provided by an IPv6 and IoT6 based deployment. The experiment has targeted several sources of energy consumption, in order to demonstrate the potential benefits:

• Devices, such as coffee machine

• Lighting system

• HVAC

• ICT infrastructure

• Overall electricity consumption

The energy analytics benefited from a yearly and seasonal data consumption benchmark of the smart office consumption.
Remarks on energy and electricity consumption

The complex nature of the smart office testbed has to be taken into account. It is not a testbed in a laboratory where all the parameters are controlled by the experimenters, but a real environment in which various people are working on various tasks. Therefore, human activities have a great influence on the electricity consumption.

Several points of measures have been used to try to extract indications on the potential electricity saving of the IoT6 deployment. Overall smart office consumption data have been collected since the beginning of 2013 in order to serve as a benchmark. This overall consumption analysis is extended with an electricity signatures recognition system provided by Wattics. In parallel, individual consumption points have been monitored with dedicated energy meters, such as Pikkerton.

However, it is difficult to neutralize all the external factors, such as climatic variation and user behavioural variations from one measure to another. In order to fine tune and consolidate the measures performed during the test period, additional measures will be performed until the end of the project and extended beyond its duration. We invite the reader to take the following measures as initial results to be further refined in the future.

In terms of energy cost, we took the current price of electricity in Geneva paid by the smart office, which corresponds to 0.08 € per kWh.

Coffee machine

A professional coffee machine is made available to the local staff. For the IoT6 project, it was equipped with a Pikkerton ZBS-110 energy meter. The device measures the frequency, the voltage, the current, the actual load and the used energy. The Pikkerton device has a relay to switch on or off the coffee machine to reduce the electricity consumption.

The Pikkerton module was connected to and controlled by the IoT6 enabled UDG multi-protocol control and monitoring system. This component was itself connected to other sensors through the IoT6 interface and was in charge of switching off the coffee machine when the office was closed and when nobody was present in the office. Moreover, a rule was applied to switch off the machine in periods of time, which were unlikely to require the use of a coffee machine, including night and weekends; in these two cases, the coffee machine was automatically turned off.

Being a professional coffee machine, it is keeping the water system at a certain temperature. In order to maintain this temperature, the coffee machine is regularly heating the water with short peaks of energy consumptions. This means that some electricity is always used, nights and days by the coffee machine, even in standby mode. A great potential for energy savings has been realised by better controlling the machine activity and by switching it off in periods of time such as nights and the weekends.

The energy consumption of the coffee machine is monitored by the Pikkerton module and the Wattics system. Different tests were realised to determine the amount of electricity saved using the IoT6 solution.
The following Table 3 displays the results in usage based on the IoT6 solution to control the coffee machine:

<table>
<thead>
<tr>
<th></th>
<th>Without IoT6 solution</th>
<th>With IoT6 solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily consumption average [kWh]</td>
<td>2.44 kWh</td>
<td>1.37 kWh</td>
</tr>
<tr>
<td>Monthly consumption [kWh]</td>
<td>73.2 kWh</td>
<td>41.04 kWh</td>
</tr>
<tr>
<td>Yearly consumption [kWh]</td>
<td>891.05 kWh</td>
<td>499.61 kWh</td>
</tr>
<tr>
<td>Costs for one year [€]</td>
<td>71.28 €</td>
<td>39.97 €</td>
</tr>
</tbody>
</table>

Table 3: Results in usage for the coffee machine

The previous array shows that the electricity consumption was reduced by 43.9 %.

Lighting

Philips Hue lightings are installed in the testbed. These lightings replace old light spots which consume more energy. The power used by a set of the Philips Hue bulb is 1.35 W in standby mode and 19.5 W with the maximal load.

Right after their installation, the Philips Hue lamps have been interfaced to the IoT6 enabled Control and Monitoring System. This permits the actuation of the lamps based on the different data provided by the sensors already deployed into the smart office.

Different scenarios have been put in place to evaluate the possible lighting energy savings which is in general a large electricity consumer.

Scenario 1

A first scenario was to determine the presence or the absence of people inside the smart office using five presence sensors; these sensors covered the entire room and if all sensors detected no one in the room, all Philips Hue lamps would automatically turn off. If one of the presence sensors detected someone in the room, all lamps are automatically switched on by the IoT6 CMS.

Scenario 2

A second scenario afterwards was implemented using the same presence sensors but with a different approach. Indeed, the smart office was cut in three distinct areas: the meeting area, the desks for the Mandat International staff and the waiting lounge. Each area was equipped by one or two presence sensors and by a Philips Hue lamp. If a presence sensor detected one person in its area, only the corresponding lamp was turned on; if no one was detected by the same sensor, only the area where the sensor was installed was no longer lit. This scenario is interesting for a big room with many lamps which are controlled individually to reduce the energy consumption.

Scenario 3

Finally, a third scenario was also tested using the idea of the first scenario as a basis. A smart phone was added in the testbed as a light sensor. When the light sensor integrated into the smart phone sent that there was not enough light in the office, the IoT6 enabled CMS automatically turns on the Philips Hue lamps.

Since the Philips Hue lamps are connected in a series with the button on the wall, the users have priority and can override the IoT6 enabled CMS, so it is not only the CMS actions, but also the behavior of the users which are measured.
The following Table 4 shows the results of the measurements realized based on the scenario functions described previously:

<table>
<thead>
<tr>
<th></th>
<th>Without IoT6 scenario</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daily consumption average [kWh]</strong></td>
<td>0.26</td>
<td>0.23</td>
<td>0.2</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Monthly consumption [kWh]</strong></td>
<td>7.8</td>
<td>6.9</td>
<td>6</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Yearly consumption [kWh]</strong></td>
<td>93.6</td>
<td>82.8</td>
<td>72</td>
<td>64.8</td>
</tr>
<tr>
<td><strong>Costs for one year [€]</strong></td>
<td>7.49</td>
<td>6.62</td>
<td>5.76</td>
<td>5.18</td>
</tr>
<tr>
<td><strong>Energy saving [%]</strong></td>
<td>11.5%</td>
<td>23.0%</td>
<td>30.7%</td>
<td></td>
</tr>
</tbody>
</table>

*Table 4: Results of the Measurement without and with IoT6 scenario*

**Ventilator**

A fan was installed in the smart office and it is controlled by a Z-Wave module. The model of this module is Everspring AN158-6 and has a relay to turn on or off the ventilator. In the same time, the Z-Wave module measures the energy and the power used by the fan. The typical value for the fan load is 30 W when it is running normally. The ventilator is now remotely controlled based on the presence sensor and the room temperature. Since its power is rather low, its energy consumption has little influence on the global consumption of all devices currently deployed in the smart office. The goal of the ventilator is to increase the comfort of the local staff, but it is controlled by the IoT6 solution to try to make the fan energy efficient. For example, when no one is in the office, the ventilator is automatically switched off in order to avoid the waste of electricity consumption, in the case when someone has forgotten to turn the fan off before leaving the smart office.

The experiments results were not meaningful enough. This seems to be due to several factors:

- The ventilator is used, only during very warm days in summer.
- The users seem to automatically switch off the fan before leaving. This good behaviour makes the smart system unnecessary.

A HVAC fan coil unit from CIAT will be installed in the testbed by September to handle the air conditioning into the office. This HVAC system will be integrated in the IoT6 enabled CMS and several scenarios are planned in order to obtain an energy efficient HVAC system:

**Scenario 1**

The first scenario is to program the start-up and the shutdown of the fan coil unit during working hours.

**Scenario 2**

The second scenario will adapt the air ventilation to the CO2 and particle levels in the room.

Complementary measures will be provided, in a future updated version of this deliverable.
Computers

Two computers were equipped with Cisco EnergyWise clients. The EnergyWise protocol permits to shut down or to wake up computers remotely using the network infrastructure. Each computer was connected to a power supply able to provide 265 W; by comparison the standard notebooks are using standard 90 W power supplies.

Cisco EnergyWise permits shutting down automatically a computer inside the network when the user has forgotten to do it himself. Another feature from Cisco EnergyWise is to power on a computer remotely and this feature can be interesting when some remote maintenance on the machine is required or when the user is entering into the office at the beginning of the workday. In order to deploy EnergyWise clients, the computers must be Energy Star 5 compliant\(^{18}\) and the operating system (Microsoft Windows, Apple Mac OS X and Linux) must be configured with the power management features\(^{19}\).

Different use cases have been tested in the smart office testbed concerning the computers equipped with EnergyWise: for example, if no one was detected near the computers, they were automatically shut down to reduce the electricity consumption. Another scenario was to detect the arrival of a Mandat International employee using his or her smart phone: when the IoT6 solution determined that this employee was arriving in the office, his or her computer was switched on automatically to gain a little time. Correspondingly, when the Mandat International employee left the office, the computer was automatically turned off; if the employee forgot to switch off his or her computer, the IoT6 solution did this and prevented the computer from being on all the night.

Using the Wattics system and the technical specifications for each computer installed inside the Mandat International smart office, the gain in terms of energy savings and money has been determined in function of different scenarios. Basically, three scenarios has been evaluated: the first one was the old situation without Cisco EnergyWise deployed in the Mandat International network infrastructure, the second one was the automatic computers shutdown during the nights and the third one was the automatic computers shutdown during the nights and the entire weekends. The Cisco EnergyWise protocol was integrated into the IoT6 solution using the Control and Monitoring System (CMS). As mentioned previously, this protocol was used to turn on or off the computers remotely: of course, a specific EnergyWise client was required on each computer controlled by the IoT6 solution. In the second scenario, the computers were only switched off during all the nights; these computers could be turned on during the weekends for maintenance tasks like operating system and software updates, deep antivirus and antispyware analysis, data and system backups, etc. In the late scenario, the computers were turned off all the nights and the entire weekends: a major consequence was to program the maintenance tasks during the working days without any disagreements for the users. The maintenance tasks could be realised during the lunch break, when the users were out of the office to eat, and after the work time. In this case, the users didn’t need to turn off the computers before to leave the office; when the required maintenance tasks were finished, the computers were switched off automatically.
The following Table 5 shows the differences between the computers electricity consumption with and without the IoT6 solution:

<table>
<thead>
<tr>
<th></th>
<th>Without IoT6</th>
<th>With IoT6 automatic nights switch off</th>
<th>With IoT6 automatic nights and weekends switch off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily consumption average [kWh]</td>
<td>3.68 kWh</td>
<td>3.38 kWh</td>
<td>3.04 kWh</td>
</tr>
<tr>
<td>Monthly consumption [kWh]</td>
<td>110.42 kWh</td>
<td>101.25 kWh</td>
<td>91.2 kWh</td>
</tr>
<tr>
<td>Yearly consumption [kWh]</td>
<td>1'325 kWh</td>
<td>1'215 kWh</td>
<td>1095 kWh</td>
</tr>
<tr>
<td>Costs for one year [€]</td>
<td>106 €</td>
<td>97.2 €</td>
<td>87.6 €</td>
</tr>
</tbody>
</table>

*Table 5: Computers electricity consumption*

According to our measures and calculations, a computer which is Energy Star 5 compliant, EnergyWise enabled and controlled by the system appears to save about 490 kWh per year, which represents about 39 € on the annual electricity bill, in comparison with a standard and passive computer.

**Heating**

The radiators in the smart office have been equipped with motorised actuators during the IoT6 deployment. Previously, the radiators were fitted with thermostatic valves. The motorised valves permits to better manage the temperature of the smart office: two models are used currently inside the office, one based on the wireless ZigBee protocol and the other based on the KNX protocol.

As it is difficult to precisely measure the hot water flow passing through the valve, several calculations have been made to model and quantify how much energy is necessary to heat the room in order to reach a determined temperature. Based on our calculations, we determined the nominal power of the radiators and how much energy they consume during a 24 hours period.

Basically, the radiators installed in the smart office testbed provide about 3.9 kW during a full day of heating and the daily energy consumption is about 93 kWh.
Based on these calculations, the following graph shows the necessary power to reach a specific temperature in the office:

![Graph showing power needed to reach a desired temperature](image1)

*Figure 12: Power needed to reach a desired temperature*

The following picture displays the energy consumption during a full year:

![Graph showing annual energy consumption based on temperature](image2)

*Figure 13: Annual energy consumption based on the temperature*
The last graph shows the annual cost based on the determined temperature:

![Graph showing annual cost vs. temperature]

**Figure 14: Annual cost for heating**

Of course, the ideal temperature of a given room is related to its use and function. Different uses require different temperature levels. Based on the previous computations, the following Table 6 summarises this fact, considering rooms of similar size for the comparison. Of course those figures are also specific to the climatic environment of the testbed and may vary from one year to another according to climatic and energy cost variations.

<table>
<thead>
<tr>
<th>Room Type</th>
<th>Recommended temperature</th>
<th>Power</th>
<th>Annual consumption</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unoccupied room</td>
<td>11 °C</td>
<td>0.07 kW</td>
<td>374 kWh</td>
<td>30 €</td>
</tr>
<tr>
<td>Sleeping room</td>
<td>17 °C</td>
<td>0.57 kW</td>
<td>3'181 kWh</td>
<td>255 €</td>
</tr>
<tr>
<td>Kitchen</td>
<td>18 °C</td>
<td>0.66 kW</td>
<td>3'649 kWh</td>
<td>292 €</td>
</tr>
<tr>
<td>Sleeping room for kids</td>
<td>19 °C</td>
<td>0.74 kW</td>
<td>4'117 kWh</td>
<td>329 €</td>
</tr>
<tr>
<td>Living room</td>
<td>20 °C</td>
<td>0.82 kW</td>
<td>4'585 kWh</td>
<td>367 €</td>
</tr>
<tr>
<td>Bathroom</td>
<td>21 °C</td>
<td>0.91 kW</td>
<td>5'053 kWh</td>
<td>404 €</td>
</tr>
</tbody>
</table>

**Table 6: Temperature based on designated room**

Currently, the IoT6 solution monitors the room temperature and adjusts the radiator according to targeted temperatures and to the user presence, in order to obtain a good compromise between the users' comfort and the energy efficiency.

A scenario for the IoT6 solution is to reduce the heating energy consumption by decreasing the time when the different radiator valves are open. The rules and algorithms applied are taking into account thermal inertia. The system was maintaining a minimal temperature of 15°C by night. The IoT6 CMS was configured to open the valves one hour prior to staff and
employees arrival at morning in the smart office. Similarly, one hour prior to the staff leaving the office, the radiator valves were closed by the IoT6 CMS.

The following table displays the number of working days calculated for the office staff, considering that the employees take their vacations at different periods of time, except during the last week of December:

<table>
<thead>
<tr>
<th>Total hours per year</th>
<th>365</th>
<th>24</th>
<th>8'760</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working hours</td>
<td>246</td>
<td>8</td>
<td>1'966</td>
<td>22.44%</td>
</tr>
<tr>
<td>Working hours with lunch break</td>
<td>246</td>
<td>9</td>
<td>2'211</td>
<td>25.24%</td>
</tr>
<tr>
<td>Heating hours with pre-heating</td>
<td>246</td>
<td>10</td>
<td>2'457</td>
<td>28.05%</td>
</tr>
</tbody>
</table>

Table 7: Number of working days for Mandat International staff

With the aforementioned table, the time the heating should be activated can be calculated. The following results and Table 8 shows the desired temperature, the needed energy to reach a given temperature and the period when the heating is on:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>2245.60</td>
<td>179.65</td>
<td>2245.60</td>
<td>179.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2713.43</td>
<td>217.07</td>
<td>2447.25</td>
<td>195.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>3181.27</td>
<td>254.50</td>
<td>2648.91</td>
<td>211.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3649.10</td>
<td>291.93</td>
<td>2850.56</td>
<td>228.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>4116.94</td>
<td>329.35</td>
<td>3052.21</td>
<td>244.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>4584.77</td>
<td>366.78</td>
<td>3253.86</td>
<td>260.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>5052.60</td>
<td>404.21</td>
<td>3455.52</td>
<td>276.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>5520.44</td>
<td>441.63</td>
<td>3657.17</td>
<td>292.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>5988.27</td>
<td>479.06</td>
<td>3858.82</td>
<td>308.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>6456.10</td>
<td>516.49</td>
<td>4060.47</td>
<td>324.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>6923.94</td>
<td>553.91</td>
<td>4262.13</td>
<td>340.97</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Results based on desired temperature
The following graph shows the comparison of the energy consumption for the heating based on the IoT6 solution and without the IoT6 solution:

![Graph showing energy consumption comparison for heating](image)

*Figure 15: Energy consumption comparison for heating*

The following figure displays the costs for the heating within and without the IoT6 solution, based on the current energy cost:

![Graph showing energy costs comparison for heating](image)

*Figure 16: Energy costs comparison for heating*
7.8. Return on investment

The following return on investment figures are based on the current measures. It gives a relevant and interesting indication. However, there are a many parameters to take into account before making any extrapolation or universal conclusion. Many factors are impacting the effective return on investment, including: the type of the building, the age of the building, the actual and the future costs for the electricity, the kind of heating, the size of the deployment. For instance, if the heating is only based on the electricity, the return of investment may be quicker and it may reduce to two or three years a pay back of the required deployment.

Another key parameter is the equipment cost, which is evolving. Cheaper is the equipment, higher will be the return on investment.

The use of the building has a significant importance too: the return on investment for residential buildings tends to take longer than the return of investment for a commercial building or for an office.

The following Table 9 shows current ratio of returns on investments calculated according to the energy saving performed in the smart office, the current energy cost as well as the calculated marginal cost for deploying the IoT6 solution. In the case of the Energy Wise deployment, there is no formal equipment cost. However, we decided to take a flat cost of 20 Euros per PC to cover the deployment and configuration cost, equivalent to about 30 minutes of a maintenance officer hourly cost for the company (employers’ charges included). It summarizes the current estimations in terms of return on investments for an IoT6-enabled building.

<table>
<thead>
<tr>
<th>Device</th>
<th>Marginal cost of device</th>
<th>Energy saving per day [kWh]</th>
<th>Energy saving per year [kWh]</th>
<th>Cost saving per year [€]</th>
<th>ROI [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee machine</td>
<td>270 €</td>
<td>1.07</td>
<td>390.55</td>
<td>35.1495</td>
<td>13.02%</td>
</tr>
<tr>
<td>Lightings</td>
<td>200 €</td>
<td>0.08</td>
<td>29.2</td>
<td>2.628</td>
<td>1.31%</td>
</tr>
<tr>
<td>Computers (if switched off all nights and weekends)</td>
<td>20 € (for installation)</td>
<td>0.64</td>
<td>230</td>
<td>18.4</td>
<td>92%</td>
</tr>
<tr>
<td>Computers (if switched off all nights only)</td>
<td>20 € (for installation)</td>
<td>0.30</td>
<td>110</td>
<td>8.8</td>
<td>44%</td>
</tr>
<tr>
<td>Heating</td>
<td>350 €</td>
<td>0.29</td>
<td>107</td>
<td>8.56</td>
<td>2.45</td>
</tr>
</tbody>
</table>

*Table 9: Return on Investment on Mandat International Building*
7.9. Identified limitations

Despite globally positive impacts of the IPv6 and IoT6 deployment, three main limitations and potential bottlenecks have been identified:

1. Lack of human resources and necessity to train people

   The deployment of IoT6 architecture in a smart building was easy to operate with network engineers. However, the building automation installations are often lead by electricians, and those who are skilled with Internet technologies are not automatically familiar with IPv6. This limitation may delay an adoption process of IPv6-based building automation. On the other hand, it can be anticipated that IPv6 will become mainstream and the potential savings with deployment costs may be sufficiently attractive.

2. Increased exposure to remote attacks

   The use of IPv6 will benefit from its security features, such as IPSec. On the other hand, the integration of all the systems together with the Internet protocol may increase the exposure of the subsystems to remote attacks.

3. Lack of IPv6 and 6LoWPAN commercial products

   While IPv6 is becoming universally deployed and a mainstream protocol for the Internet, it is not the case yet for the IoT adaptations of IPv6. 6LoWPAN and CoAP technologies are just emerging and only a very limited number of devices are currently available. It is however anticipated that the number of IPv6 and 6LoWPAN compliant devices will increase over time.
8. Conclusion and recommendations

The experiments on the smart office testbed have demonstrated the potential of better integrating smart buildings subsystems together. It demonstrates the feasibility of such integration, as well as some potentialities in terms of:

- Ease of deployment
- Heterogeneous integration
- Scalability
- Flexibility, modularity
- Security and Reliability
- Cost of deployment
- Energy efficiency
- Return on investment

It also identified a few limitations to be taken into account.

8.1. Recommendations for the deployment of smart IPv6 buildings

Based on our experiments, this section presents some key recommendations which can be useful for future deployments in smart buildings:

- The Internet Protocol version 6 (IPv6) appears to be a very convenient solution for systems deployments and systems integration in smart buildings. It provides:
  - Highly scalable addressing scheme
  - Self-configuration mechanisms
  - Extended portability on most ICT networks
- IPv6 can support and ease the integration of heterogeneous systems and components together, including heterogeneous communication protocols.
- 6LoWPAN and CoAP provide a stable and flexible solution to integrate constrained devices in smart building environments.
- The IoT6 protocol pile with the use of oBIX in the application layer can ease the integration of IoT6 deployment in building automation systems and applications.
- It is recommended to exploit the use of mobile devices, such as smart phones and tablets, to interact with the building automation infrastructure.
- It is recommended to combine a local autonomous automating solution (not relying on external connectivity) together with on-line services and applications, such as software as a service.
- When a deployment is planned, the first task to accomplish is to enable IPv6 in the local area network (LAN) or alternatively to set up such an IPv6 network.
- It is recommended to exploit the potential of mobile networks and power line communication (PLC) to ease and reduce the deployment costs.
- It is recommended to identify the various subsystems to be interconnected and to pre-allocate specific subnets to each of them.
It is recommended to identify the various sorts of identifiers that will be used in the building (such as barcodes, QR codes and RFID or NFC tags, etc.) and to identify potential web services that could help resolve those identifiers.

It is recommended to isolate the local network from the external network through an ad hoc firewalling and to use by default IPSec for any remote IPv6 connection.

The security should always be a key concern by improving security at the various layers, including by using IPSec and Secure Sockets Layer (SSL) for the communication between the applications or services.

8.2. Recommendations for further research and development

The use and deployment of IPv6 in smart buildings seems to be a promising field of research and development. It may finally solve the fundamental fragmentation and heterogeneity barriers that many companies such as Siemens and ABB are trying to handle since decades.

Some key identified research challenges include:

- Researching and optimizing the communication protocol pile, including the application layer for building automation. In the frame of the IoT6 project, we have already proposed and tested a solution using the following technologies: IPv6, CoAP, JSON and oBIX. Standards such as oBIX are powerful, but still quite verbose. There is room for optimization and for the development of a more global and universal standard with a clearly specified ontology.

- Researching and optimizing energy harvesting in buildings. Wireless deployments are quite attractive in terms of deployment cost and effort. However, many wireless sensors require substantial maintenance effort due to battery replacements.

- Researching and optimizing the combination of wired, power line communication and wireless solutions. Specific research should compare and define the optimal mix of technology from the cost of deployment and energy efficiency perspectives.

- IPv6 features exploitation for smart buildings should be further researched and developed, including in areas requiring a high level of Quality of Service, such as fire alarms.

A complementary deployment of the solution developed in the frame of the IoT6 project is currently in progress in a large building of the University for Applied Sciences Western Switzerland in Geneva (HEPIA). Two floors have been allocated for the first step of the deployment. A large number of sensors and actuators based on different protocols and technologies are being installed and interfaced to the IoT6 architecture. This new testbed will permit to extend the research on smart building environments, notably on energy savings.
9. References

1. More details on www.smartipv6building.com
17. http://www.wattics.com