Smart Grid Energy Management Staff Exchange

D3.3 Zero energy buildings and integration with smart grids: Components, Services, Systems & Controls

Marie Skłodowska-Curie Actions (MSCA)
Research and Innovation Staff Exchange (RISE)
H2020-MSCA-RISE-2014

Revision History

Revision date	Previous revision date	Summary of Changes	Changes marked
20/09/2016	14/09/2016	Improvement of introduction and conclusions.	Yes

Approvals

This document requires the following approvals:

Name	Partner	Date	Approval (y/n)
Prof. Denia Kolokotsa (Project Coordinator)	TUC	20/9/2016	y
Prof. Mattheos Santamouris	UOA	20/9/2016	y
Prof. Diofantos Hadjimitsis	CUT	20/9/2016	y
Prof. Costas Papanicolas	CyI	20/9/2016	y
Prof. Maria Kolokotroni	UBRUN	20/9/2016	y
Dr. Cristina Cristalli	AEA	20/9/2016	y
Fabio Montagnino	IDEA	20/9/2016	y
Dr. Nerijus Kruopis	EGM	20/9/2016	y
Federica Fuligni	EXERGY	20/9/2016	y
Dr. Siew Eang	NUS	20/9/2016	y

Distribution

This document has been distributed to:

Name	Partner	Date
Prof. Denia Kolokotsa (Project Coordinator)	TUC	14/09/2016
Prof. Kostas Kalaitzakis	TUC	14/09/2016
Kostas Gobakis	TUC	14/09/2016
Nikos Kampelis	TUC	14/09/2016
Vagias Vagias	TUC	14/09/2016
Aggeliki Mavrigiannaki	TUC	14/09/2016
Prof. Mattheos Santamouris	UOA	14/09/2016
Theoni Karlesi	UOA	14/09/2016
Prof. Margarita N. Assimakopoulos	UOA	14/09/2016
Dr. Niki Gaitani	UOA	14/09/2016
Marina Laskari	UOA	14/09/2016
Vassilis Lontorfos	UOA	14/09/2016
Georgios Kyriakodis	UOA	14/09/2016
Ioannis Kousis	UOA	14/09/2016
Prof. Diofantos Hatzimitsis	CUT	14/09/2016
Chrysso Chatzinikola	CUT	14/09/2016

Prof. Costas Papanicolas	CyI	14/09/2016
Dr. Nicolas Jarraud	CyI	14/09/2016
Alex Lupion Romero	CyI	14/09/2016
Marios Demetriades	CyI	14/09/2016
Marina Kyprianou	CyI	14/09/2016
Andri Pyrgou	CyI	14/09/2016
Prof. Maria Kolokotroni	UBRUN	14/09/2016
Prof. Tatiana Kalganova	UBRUN	14/09/2016
Thiago Santos	UBRUN	14/09/2016
Dr. Cristina Cristalli	AEA	14/09/2016
Riccardo Paci	AEA	14/09/2016
Dr. Laura Standardi	AEA	14/09/2016
Gino Romiti	AEA	14/09/2016
Daniela Isidori	AEA	14/09/2016
Francesco Carducci	AEA	14/09/2016
Dr. Nerijus Kruopis	EGM	14/09/2016
Karolis Koreiva	EGM	14/09/2016
Gabija Silienė	EGM	14/09/2016
Fabio Montagnino	IDEA	14/09/2016
Filippo Paredes	IDEA	14/09/2016
Luca Venezia	IDEA	14/09/2016
Pietro Muratore	IDEA	14/09/2016
Federica Fuligni	EXERGY	14/09/2016
Fernando Centeno	EXERGY	14/09/2016

Gozde Unkaya	EXERGY	14/09/2016
Felipe Maya	EXERGY	14/09/2016
Sreenivaasa Pamidi	EXERGY	14/09/2016
Kassim Caratella	EXERGY	14/09/2016
Monica Osorio	EXERGY	14/09/2016
Dr. Siew Eang	NUS	14/09/2016

Table of Contents

1 Introduction

The goal of this work is to analyse possible advanced technologies for the integration of Zero Energy Building (ZEBs), and Nearly ZEBs (NZEB), in smart grids. The importance of such an integration is due to the fact that innovative electrical grids are going to play a key role in the future energy sector development where multiple distributed energy sources are connected and jointly cooperate in an efficient way in the view of satisfying energy consumption.

Clearly, this integration involves many fields such as:

- Interoperability of the various metering, monitoring and control devices
- Energy analysis and continuous performance improvement
- Users active engagement
- Buildings internal comfort optimisation
- Advanced control strategies aimed at satisfying energy consumption in the most economic and efficient way.

Initially, work presented in this report addresses smart metering application and testing as a basic component in present and future electrical grids; in fact, interoperability among meters of various OEMs must be guaranteed as then the control system is enabled to coordinate and control all the energy systems monitored. To do so, a building environment is simulated where the smart meters utilized belong to different firms; then, the interoperability is tested using dedicated protocols.

Secondly, this report focuses on services and systems, which denote all the activities related to the analysis of the energy consumption and users satisfaction through internal comfort and their engagement. The analysis performed is done from an industrial and commercial point of view for both users satisfaction at work via online surveys and at home via questionnaires and focus groups.

Lastly, tailored control strategies are developed in the view of maximizing energy performance from thermal comfort and energy cost perspective for buildings that host departments of universities, one located in Singapore and the other one in Crete.

1.1 Secondments linked to Research Activities

Table 1 provides an overview of the secondments involved in the research activities included in Deliverable 3.3.

Table 1: Seconded personnel and link to research activities in Task 3.3

Seconded Person	Sending Institution	Receiving Institution	Research Field
Arnoldas Čerškus	ELGAMA Elektronika	University of Athens	Advanced Smart Metering
Laura Standardi	AEA - Loccioni Group	University of Athens	Energy Consumption Analysis
Marina Laskari	University of Athens	AEA-Loccioni Group	Evaluation of thermal comfort – Leaf Lab
Niki Gaitani	University of Athens	AEA-Loccioni Group	User engagement
Denia Kolokotsa	Technical University of Crete	National University of Singapore	Evaluation of thermal comfort – NUS
Andrea Ferrante	AEA - Loccioni Group	Technical University of Crete	Demand Response – K1, TUC
Laura Standardi	AEA - Loccioni Group	Technical University of Crete	Smart Metering and Web-based monitoring
Nikos Kampelis	Technical University of Crete	AEA - Loccioni Group	Demand Response – K1, TUC

2 Components

The future integration of buildings with smart grids requires components of various type in order to ensure a reliable service. Among these components, this work focuses on smart meter as a key function component in coordinating and controlling the future smart grids; in fact, users are interested in having their energy needs satisfied and save money through tailored control strategies that handle data coming from smart meters. Nowadays, many firms produce smart meters, thus, interoperability must be guaranteed in order to apply the control strategy to all the energy systems connected. Moreover, once the interoperability is guaranteed, it is crucial to collect and organize measures in ways users can easily exploit them.

2.1 Smart Metering in ZEB and Smart Grids

The critical point in operation of smart grids and smart buildings is the interoperability between the different devices that are involved in energy management, as well as the effective compilation and presentation of the data collected (1).

Since energy monitoring and control play an increasingly important role in building energy management, smart meters are crucial for the smart buildings deployment. Smart Meters collect data from devices to databases for analysis and real time monitoring, offering the knowledge of energy consumption in order to control the flow of energy inside a building. In addition, the lack of common standard architectures for telecommunications to ensure interoperability between equipment and systems from different manufacturers makes Smart Meter adaptation practices more difficult (2).

Table 2: Abbreviations List

AMR	Automated Meter Reading
AMM	Advanced Meter Management
AMI	Advanced Metering Infrastructure
DCS	Data Collection System
MDMS	Meter Data Management System
DLMS	Distribution Line Message Specification

DC	Data concentrator
PLC	Power Line Carrier
OFDM	Orthogonal Frequency Division Multiplexing modulation
HAN	Home Area Network
IHD	In-Home Display

The main principles of the smart metering are the following (2) (3) (4):

- **Open standard-based solution**: Provides interoperability and interconnectivity with measuring devices and compatible components (hardware/software) of the AMI systems produced by other manufacturers. Applies open stacks for both the communication and application protocols. Using DLMS/COSEM standards enables manufacturer and communication technology independence.
- **Scalability:** Being flexible and easy scalable metering solution can be seamlessly expanded from small project to large operated system.
- **Easy deployment:** Enables quick and seamless deployment based on "plug & play" connection that essentially decrease installation and maintenance costs. Auto-discovery function makes it easier to manage the newly installed equipment.
- **Security:** Enables the secure access, storage and management of information based on the data encryption and key management.
- **Business oriented solution:** Provides all necessary data for utility needs and billing purposes. Enables optimization of the distribution systems by minimizing the distribution network losses, improving the quality of the electrical power, and eliminating the peak load.
- **Real-time metering:** Permits both scheduled and instantaneous remote metering of electricity/water/gas/heat. Implements a flexible TOU tariffs, which promotes the electricity supply to markets with different customers' capabilities and functional requirements.
- **Tamper-proof**: Allows detecting and ceasing the electricity theft and fraud.
- **Load control:** supporting local load control which can cut off power when the power exceeds the limit value and lasts for a certain time.

Furthermore, smart metering is based on three-level architecture (a simplified diagram is presented in Figure 1).

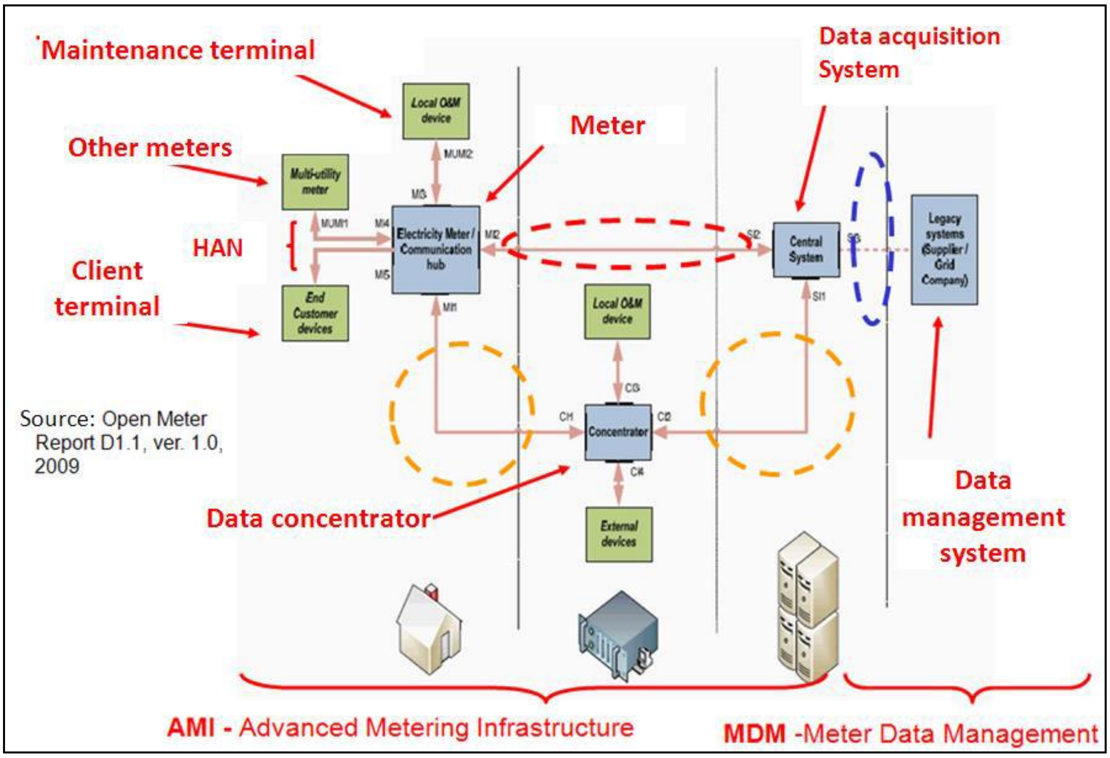


Figure 1: Smart metering solution

- The lower level (on the left) comprises customer devices (smart meters, including HAN equipment), and customer interface units IHD.
- The intermediate level is responsible for managing the communication between end-point equipment and the Master Station, linking all three layers. The main communication technologies are PLC and GPRS/GSM/Ethernet. PLC and GPRS/3G communication are supported communication between a meter and a concentrator. HAN devices communicate with the meters via M-Bus wireless interface.
- The core of the upper level (on the right) is Data Collection System, which provides all necessary data to MDMS, Billing System etc.

2.1.1 Methodology

The work done is within the UOA, where, there is the need of an effective data management in order to better understand billing procedures and apply energy cost reduction measures. The University has adopted a wide range of approaches for energy data management, including manual Excel workbooks, Access databases, software developed “in-house”, or management software.

The aim of ELGAMA work is to:

- Improve integration of the Smart Metering Infrastructure into existing University buildings for the monitoring and control of energy performance;
- Analyse the available communication technologies for smart metering infrastructure;
- Identify the necessary and nice-to-have functionalities and implementation of Smart Metering solutions at the University.
- Improve the interoperability issues of UOA energy utility data.

In this context, a series of testing activities are performed in order to identify possible interoperability problems among the tested devices. The implemented testing activities include:

✓ Testing of integration and interoperability between different smart meters and data collection including import and export functions
✓ Automatic smart meter registration functionality and alarm handling;
✓ Testing of parameterization and synchronization procedure;
✓ Configuration of tariff plan and load control
✓ IHD (In-Home Display) tests
✓ Remote firmware update

2.1.2 The UOA smart metering testing environment

In order to test the UOA utility data collection and interoperability with smart metering, a multi apartment building conditions have been created in a testing laboratory. The interoperability is tested between the ELGAMA smart meter and the ADD (Addax) smart meter. A simplified diagram of the testing environment and its components is depicted in Figure 2. The testing environment consists of:

- Smart meters with GSM/GPRS/3G or PLC and Wireless MBus communication modules,
- Data Concentrator (DC),
- In-Home Displays (IHD),
- Operational and maintenance software where data can be collected and saved.

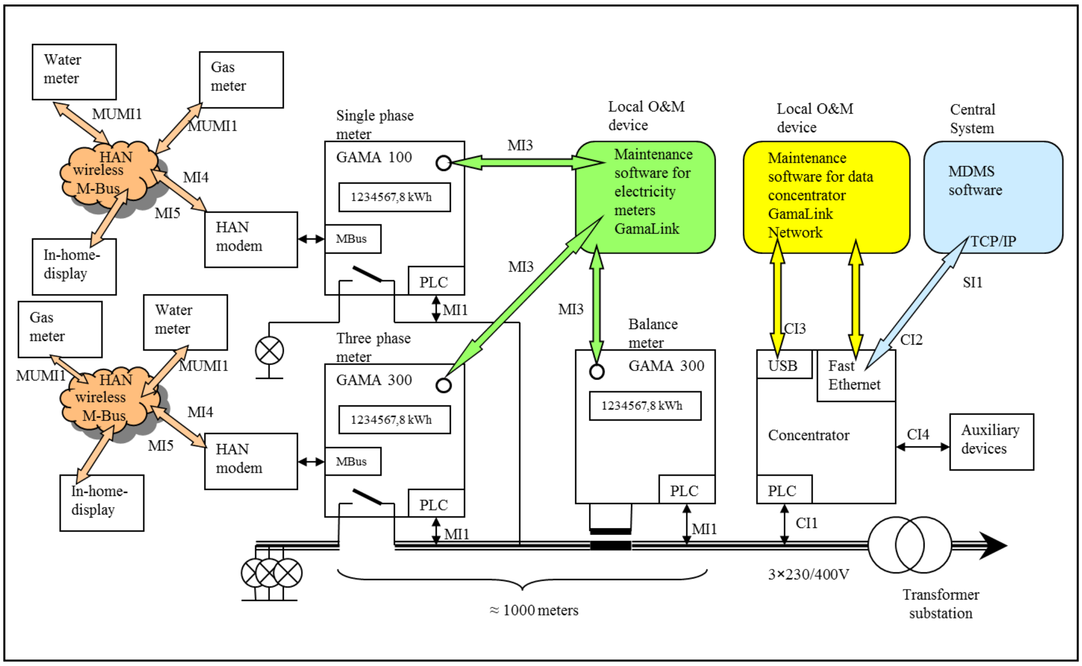


Figure 2: "Elgama-Elektronika" Smart metering solution

For the specific testing environment, Open Meter interfaces are chosen as explained in detail below.

Table 3 Communication interfaces

Interface	System components	Communication
CI2 – SI1	Concentrator – Central System	Ethernet/GPRS/3G/4G
MI2 – SI2	E-meter/Comm Hub – Central System	GPRS/3G/4G
SI3	Central System – Legacy Systems	
MI1 – CI1	E-meter/Comm Hub – Concentrator	Prime PLC/GPRS/3G/4G
CI3	Concentrator – Local O&M device	Ethernet/USB
CI4	Concentrator – External devices	RS485
MI3	E-meter/Comm Hub – Local O&M device	Optical interface/RS485
MUMI1 – MI4	Multi-utility meter – E-meter/Comm Hub	Wireless MBus
MI5	E-meter/Comm Hub – End Customer device	Wireless MBus
MUMI2	Multi-utility meter – Local O&M device	

Prime PLC communication

A basic communication technology of EGM (Elgama-Elektronika) solution is shown in Figure 3, which uses existing communication lines, and thus provides a low-cost transmission of data in the system. Furthermore, any device with PLC-modem can operate as a repeater on the long network distances and can retranslate up to eight levels. To sum up, the main characteristics of this structure are:

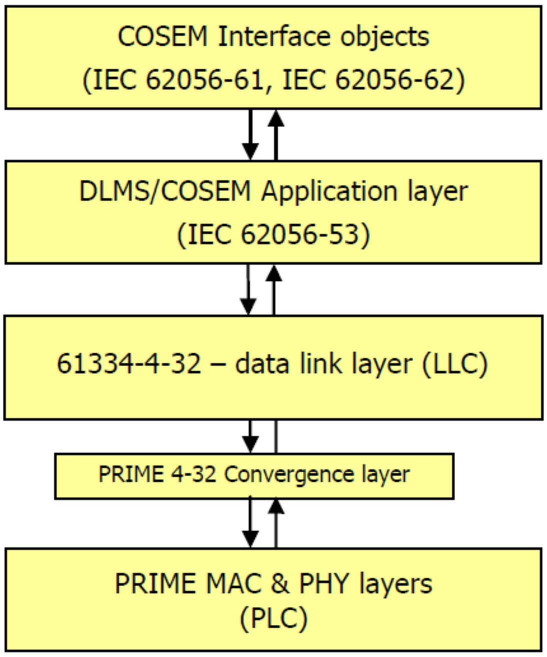


Figure 3: The prime PLC communication

- Open protocol (http://www.prime-alliance.org),
- OFDM (Orthogonal Frequency Division Multiplexing) modulation,
- CENELEC 50065-1 Band A frequency band 41-89 kHz,
- Communication data rate 21…64 kbps,
- Dynamic routing,
- Retranslation,
- Encryption AES128.

GSM/GPRS/3G communication

GSM radio network with CSD/GPRS/EGDE/3G technology and TRANSPARENT DATA TCP/IP protocols is used for data transmission to dispatcher offices. Controller supports two-direction data exchange (data reading, parameterization and firmware update) with communication protocols IEC 62056-21 or DLMS/COSEM, as shown in Figure **4**. The main features of such a structure are:

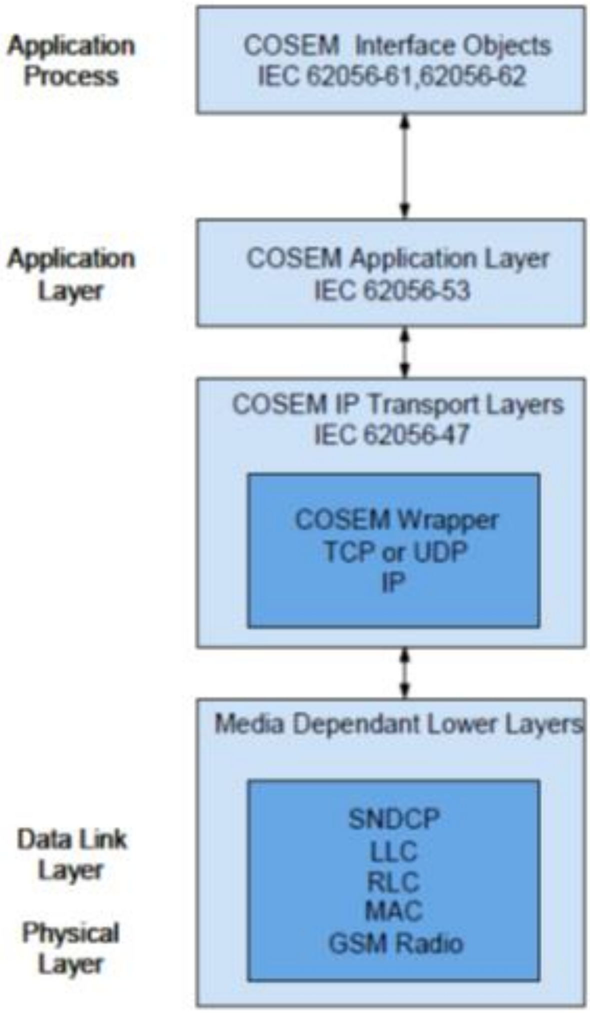


Figure 4: **The various layers of the communication**

- No need for additional wires
- Open architecture
- Consistent IP services
- Potential fast data rates
- Potential high bandwidths
- Mobility

Wireless MBus communication

Home appliances access to the network via the smart meters by standard MBus wireless interface. Moreover, the meter operates as a master and the multi utility meters as slaves. The readout of HAN meters is performed periodically by the meter, which stores the consumption data of HAN meters and makes it available for the Master Station via PLC or GPRS/GSM. Moreover, there is no direct access from the Master Station to HAN meters. Furthermore, M-Bus wireless channel allows transmission frequency ranges from 169 to 868 MHz in compliance with EN 13757-4 and, for the UOA testing, frequency range - 868 MHz has been chosen as shown in Figure **5.**

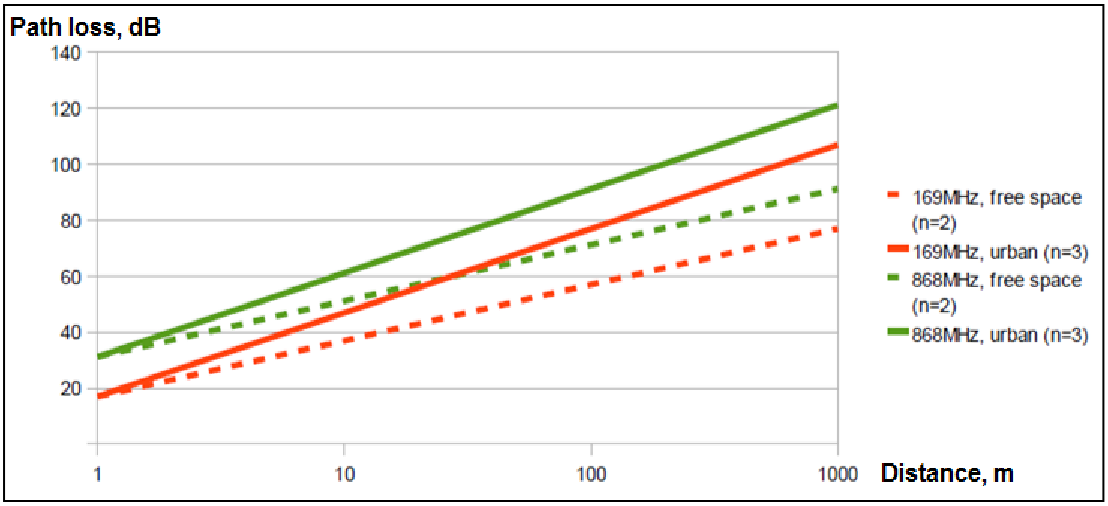


Figure 5: Frequency ranges

RS485 communication

Meters have electrical communication interface - RS485. Communication protocols supports two-direction data exchange (data reading, parameterization and firmware update) with communication protocols DLMS/COSEM and the maximum data rate is 19200 Baud. Moreover, interface supports multidrop configurations, thus, it enables the connection of multiple meters to a single bus or few meters to one GPRS/3G modem.

Optical communication

Interface meets the requirements of the standards DLMS/COSEM and it is used to download data locally into PC or hand held terminal by means of optical head. Furthermore, interface is also used for local parameterization of a meter. Data transmission speed up to 19200 Baud.

Figure 6 represents the structure of the optical communication:

- Object modelling Layer - Cosem interface objects (EN 62056-61, EN 62056-62)
- Application Layer - DLMS/COSEM application Layer (EN 62056-53)
- Data Link Layer - HDLC based data link layer (EN 62056-46)
- Physical Layer - Optical interface (EN 62056-21)

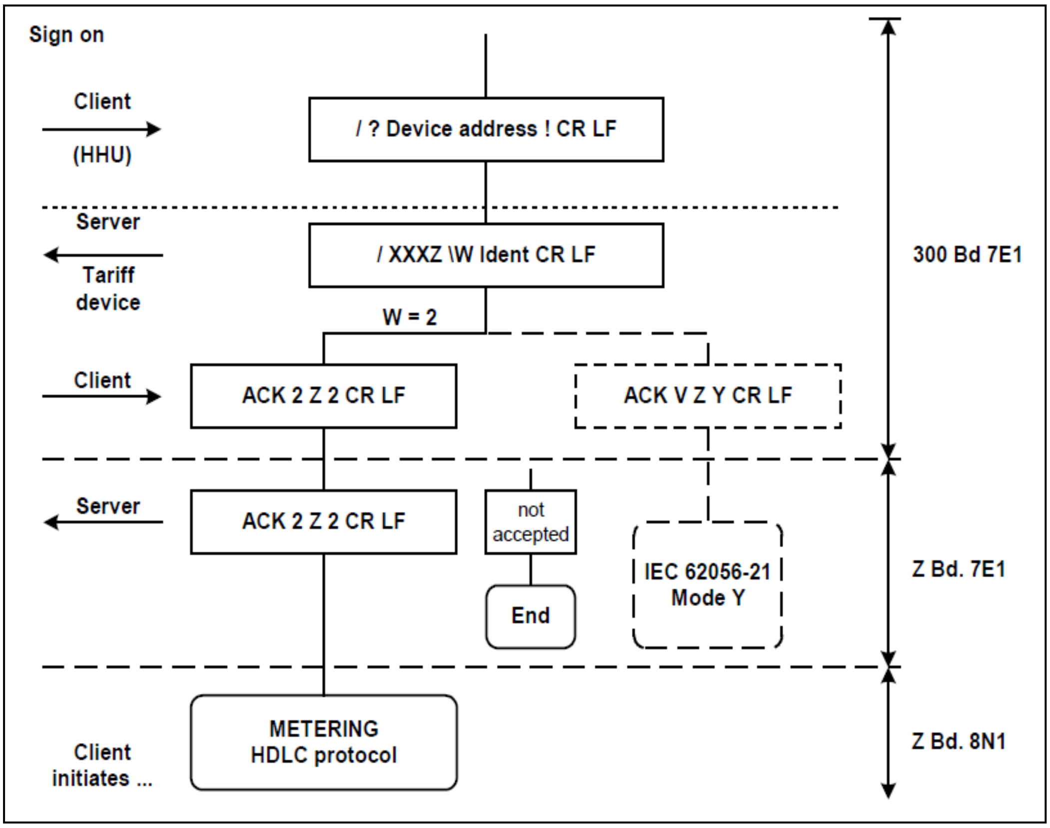


Figure 6: Optical Communication

2.1.3 Smart meter

The main components of the metering system are the smart meters that can be wire direct connected (with the maximum allowed current up to 100 A) or transformer connected (balance) meters with the maximum allowed current up to 10A and nominal voltages 3x57.7/3x120/3x230 V.

Optionally, different communication interfaces can be integrated (M-Bus wired/wireless, USB, Ethernet, GSM/GPRS etc.). The meters are high accurate devices suitable for residential and industrial metering. Accuracy class for direct connected meters: 1 (active energy) and 2 (reactive energy); for transformer connected meters: 0.5s (active energy) and 1 (reactive energy).

Moreover, smart meters are capable of two-way communication; each meter is equipped with internal PLC modem or GSM/GPRS/3G modules placed under the terminal cover that provide the communication interface to the Data Collection System: via Data concentrator for PLC Prime or directly via GSM/GPRS/3G. For the testing environment of UOA the following meters have been chosen:

1. Single phase (Gama100) and three phase meters (Gama300) with internal PLC Prime and Wireless MBus communication modules from “Elgama-Elektronika” company;
2. Single phase (NP71E) and three phase (NP73E) meters with PLC Prime and Wireless MBus communication modules from “Addax”;
3. Single phase (Gama100) and three phase meters (Gama300) with external GSM/GPRS/3G controllers and Wireless MBus communication modules from “Elgama-Elektronika” company;
4. Single phase (NP71E) and three phase (NP73E) meters with GSM/GPRS/3Gand Wireless MBus communication modules from “Addax” company;
5. Balance meter (Gama300) with external GSM/GPRS/3G communication controllers from “Elgama-Elektronika” company.

The main smart meters features tested are:

- Measurement of active [kWh] and reactive [kVarh] energy
- Communication interfaces
- Open standard protocol (DLMS/COSEM)
- Time-of-use metering
- Data profiles (load, billing, event log)
- Tampering detection
- Load management (internal mains relay)
- Self-diagnostics
- Security: authentication and encryption (AES 128)
- Plug & Play (self-registration on communication network)
- Alarming (immediate messages about extraordinary events)
- Remote firmware update
- Readout and profiling of water and gas consumption data
- Messages to/from In-Home Display
- Power quality monitoring

2.1.4 Data Concentrator

Data concentrator with LAN/PLC/GPRS communication modules from “Addax” company have been installed in the testing laboratories at UOA.The Data

Concentrator (DC) provides communication via different channels ensuring data exchange between the end-point devices and DCS (Data Collecting System) and long-term data storage. Moreover, DC supports communication by PLC Prime, Ethernet or GPRS/3G and it ensures data collection by scheduler or on request.

The key features of the data concentrator are:

- Transmitting metering data and alerts to the DCS via Ethernet or 3G
- Transmitting commands from the DCS to the Smart Meters
- Automatic detection, registration and support of the end-point devices within the network
- Synchronization of Smart meter's clock with the DCS system time
- Support of up to 1000 end-point devices.

2.1.5 In-Home Display (IHD)

IHD is intended to visualize metering data, when the meter is installed at an out-of-reach place or if the direct reading-out of the metering data is inconvenient. IHD displays user information on the LCD and it comprises metering data from electricity / water / heat meters. As a result, a customer can be informed or warned by text messages which are sent to the IHD from the Central System. Wireless MBus communication to IHD includes:

- Frequency band 868 MHz;
- Output power 14dBm (25mW);
- Mode T2: Transmit only with short data bursts typically 3.8 ms every 25 seconds and establish two way link if acknowledgement is received;
- Mode R2 (optionally with gateways): Transmit regularly and wait for a wakeup message which establish a two way communication. Multichannel support.

The pairing process of the smart meter with the IHD is showed below (Figure 7).

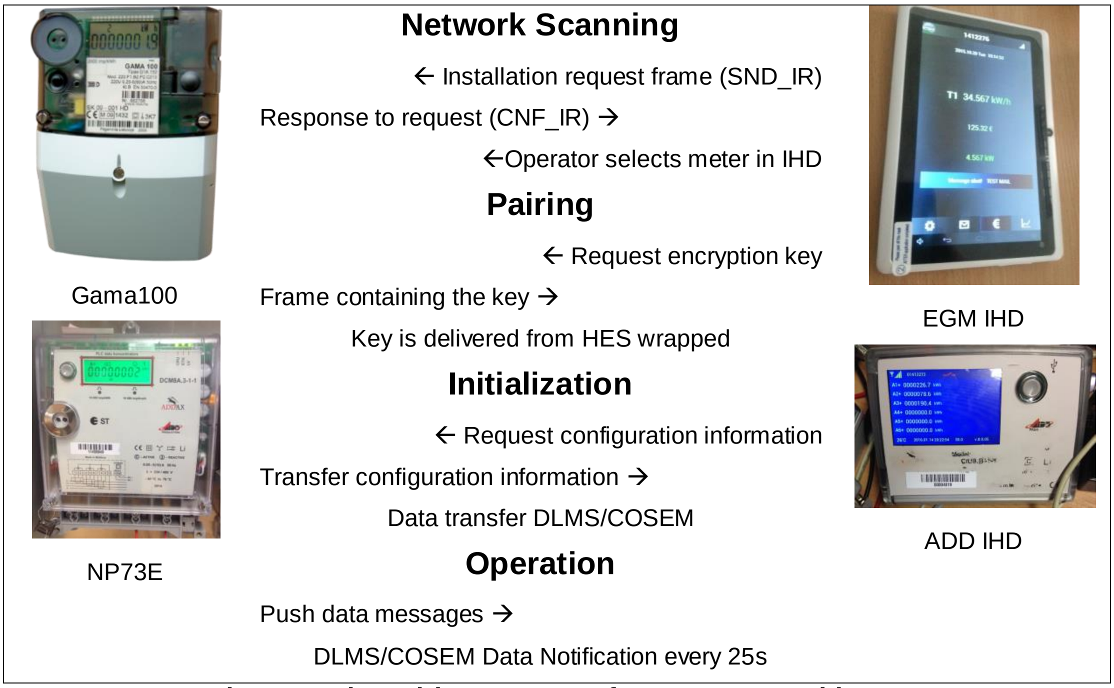


Figure 7: The pairing process of smart meters with IHD

2.1.6 Data reading, Configuration and Data management software

Metering provides the raw material for energy profiling, but data collection is only the front end of the process. In fact, the raw data is then imported into software and manipulated for cost allocation, billing, load shedding, rate negotiations, and other possible and various applications.

The data software installed provide the necessary detailed information on energy usage and highlight areas for improvements (and can measure the benefits). Looking at all areas, we can see where savings can be made quickly and easily. Also we work towards and improve the less straightforward areas.

Local configuration software GamaLink

Reading and configuration software Gamalink, shown in Figure **8**, is used for local meter data reading and parameterization. GamaLink software was developed tailored to Elgama-Elektronika Ltd electricity meters. It is also capable to communicate with meters from other manufacturers that comply with DLMS standards, in this case with “Addax” company meters. Communication with meter is supported through optical interface and electrical interfaces RS485, TCP/IP, etc. GamaLink supports following functions:

- Data and parameter reading
- Billing data reading and preview
- Meter parameterization

- Generation of parameter templates, export/import of parameter templates
- Storing of read data in database and preview of stored data
- Export and import of stored data in .txt, .CSV, .XML formats.

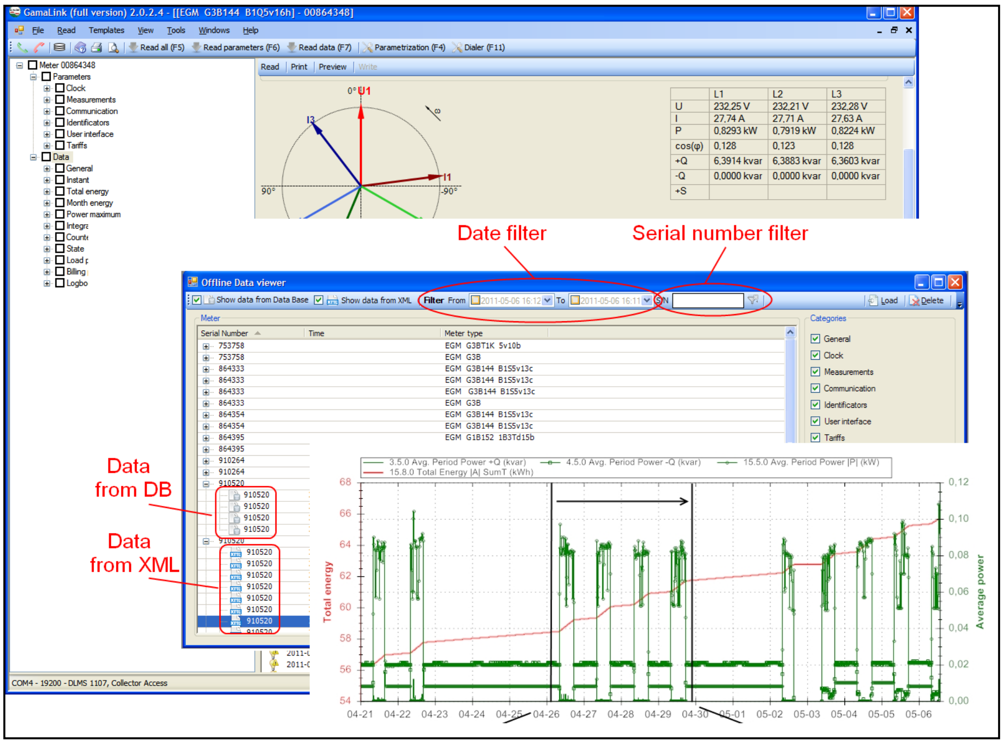


Figure 8: **Local configuration software "Gamalink"**

2.1.7 Data Concentrator application

Application "ADDAX Client" (see Figure **9**) supports remote data exchange between the Head-end system and end-point devices, data acquisition automatically and on-demand.

Base communication capabilities over Power Line Communication (PLC) based on PRIME communication solution also Ethernet interface and optionally additional communication channels using USB interface.

Software is designated for the following functionality:

- On-site configuration of data concentrator
- Readout of data, stored in the data base of data concentrator
- On-demand data readout of meters, connected to data concentrator
- Diagnostics of status and performance
- Firmware upgrade

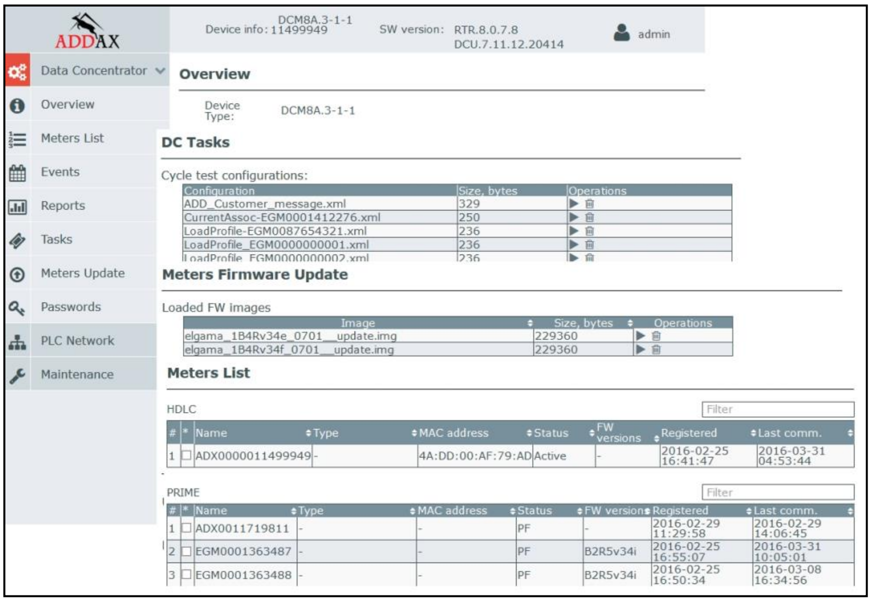


Figure 9: Application "Addax Client"

2.1.8 Maintenance software GamaLinkNet

GamaLinkNet illustrated in Figure 10 is an operation and maintenance (O&M) software of data concentrators that supports XML/Web Services-based communication profile, as it is described in Open meter specification of OSI layers and multi-metering networking interfaces (http://www.openmeter.com/files/deliverables/D3.2_v2.0.pdf, page 97) for the CI2-SI1 interface between the Concentrator and the Central System. Such an O&M software communicates to the Web Services server running on the Concentrator, so, it can be applied to any data concentrator that works with Open meter XML/Web Services-based communication profile.

GamaLinkNet software is designated for the following functionality:

- on-site configuration of data concentrator;
- readout of data, stored in the data base of data concentrator;
- on-demand data readout of meters, connected to data concentrator;
- diagnostics of status and performance;
- firmware upgrade.

Present uses include:

- Interval data recording in 60 min time periods;
- TOU (Time Of Use) metering of electricity;
- Cost allocation for tenant and departmental billing (manually analysis);
- Usage analysis and peak demand identification (manually analysis);

Future uses and “nice to have” functions include:

- Automatic common (Full) Area Management;
- Automatic measurement, verification and benchmarking for energy initiatives;
- Automatic load comparisons;
- Automatic threshold alarming and notification;
- Real-time historical monitoring of energy consumption patterns (for negotiating lower energy rates);
- Automatic reports for tenant and departmental billing;

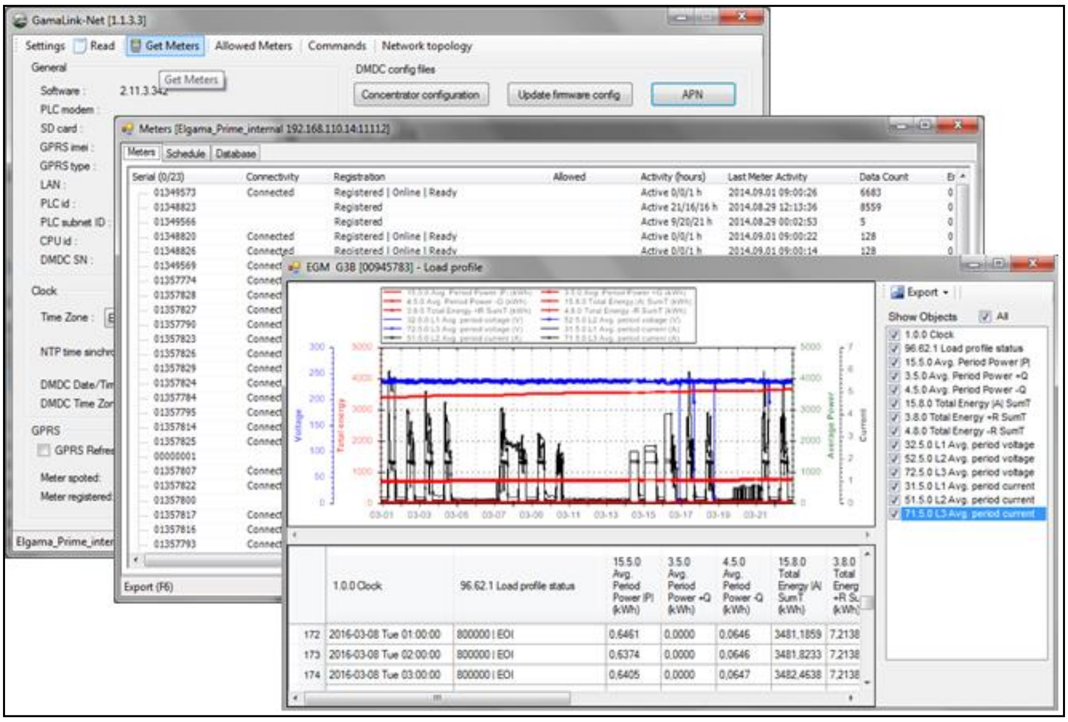


Figure 10: Maintenance software “GamaLinkNet”

2.1.9 Management application

Meter reading data, events and some customer information are aggregated and stored in the DCS (Data Collection system) database. DCS transfers metering information to the external Metering Data Management Systems (MDMS), which enables handling of meter data and consumption events for further use by the various utility applications such as billing, data validation, distribution planning and reliability, revenue assurance, etc. Management application from Poland company “Atende” was chosen.

2.1.10 Testing procedures

An Advanced Metering Infrastructure (AMI) hardware testing prototype for multi-apartment building conditions is created as shown in Figure 11. This configuration consists of smart meters, a balance meter, a data concentrator, an IHD as well as data collecting and management system. This system allows interoperability and interconnectivity with measuring devices and compatible components (hardware/software) of the AMR/AMM/AMI systems produced by other manufacturers. Open stacks for both the communication and application protocols are based on DLMS/COSEM standards.

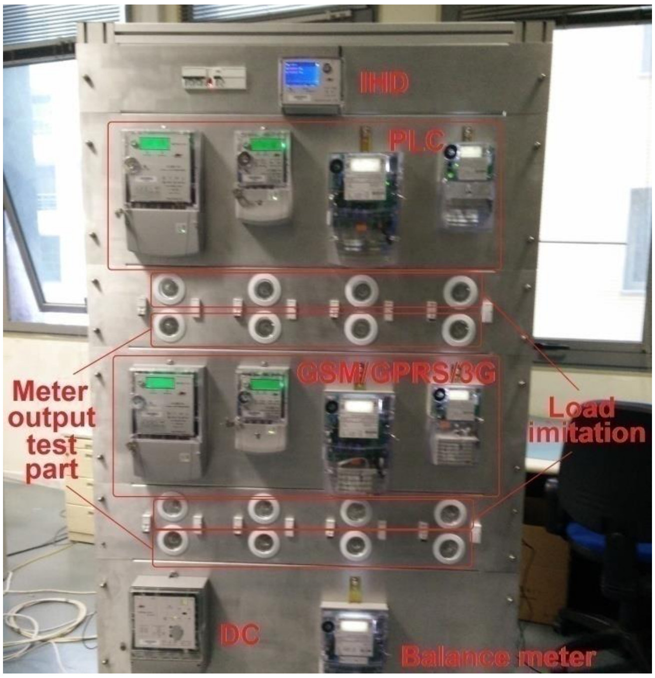


Figure 11: Prototype AMI testing hardware

Testing of integration and interoperability between different smart meters, i.e. EGM (Elgama-Elektronika) and ADD (Addax). The testing environment provides 2-way integration with other systems on two levels:

- The back-end application level-based on WEB-services architecture.
- The concentrator level using protocol of companion standard.

The main tests performed using the testing environment built at UOA are described below:

1. Automatic smart meter registration functionality is tested. In this test the “Plug&Play“ procedure is analysed. Newly installed EGM and ADD meters are automatically discovered and initiated.

2. A remotely parameterization procedure from the Central system and Data concentrator with EGM and ADD meters is successfully tested using available communication channels (Ethernet, PLC, GSM/GPRS/3G).

3. The synchronization process is tested. The data concentrator sends broadcast time synchronization messages to meters. The message transmission is latency-dependant, considering the number of repetition levels to reach the meter. If the time deviation between DC and the meter clock times is larger than configurable synchronization limit, this is logged as the following events: clock adjusted old time and clock adjusted new time. DC time is synchronized automatically with NTP server.

4. Tariff plan is remotely configured from the Central system. Meters provide multi-rate metering of consumed active and reactive energy in single-phase and three-phase power networks. The meter can set time-of-use (TOU) tariffs within predefined intervals during the day.

5. Data collecting procedure is tested. Data can be collected manually via the optical port using PC with specialized software or requested from the Central system or Master Station (ADDAX Client) by on-line commands.

6. Data export and import procedure is implemented in Central System. Data can be exported in different formats like .CSV or .XML. Data import is configured and tested using XML files especially developed for the specific tests. These files contain Load profile, Billing profile, Total energy information and are imported in to Central system.

7. System Alarm handling is also implemented and tested. If an alarm occurs, the proper flag in the alarm register is set and the alarm data are sent to the Central System. The alarm flag in the alarm register remains active until it is cleared from the Central System. The list of events, which are treated as alarms, is configurable (opening the meter cover or the terminal cover, influencing an external magnetic field, etc.).

8. Load control provides the ability to remotely disconnect or reconnect a customer’s load. The basic 100A relay allows remote, local (by a function of the meter, e.g. power over limit, voltage sag/swell, etc.) and manual (by push button) types of control. The remote control can be carried out by address command for a specific meter and by a group command for a group of meters.

9. Remote firmware upgrade functionality from Central System via GPRS/3G communication and via PLC is performed. The ability of remote firmware upgrade of devices allows adding new functionality, optimizations in firmware thus eliminating possible defects.

10. Meter and IHD pairing from Central System is established and tested with two types of IHD Figure 12 and Figure 13: "Addax" IHD screen with user message).

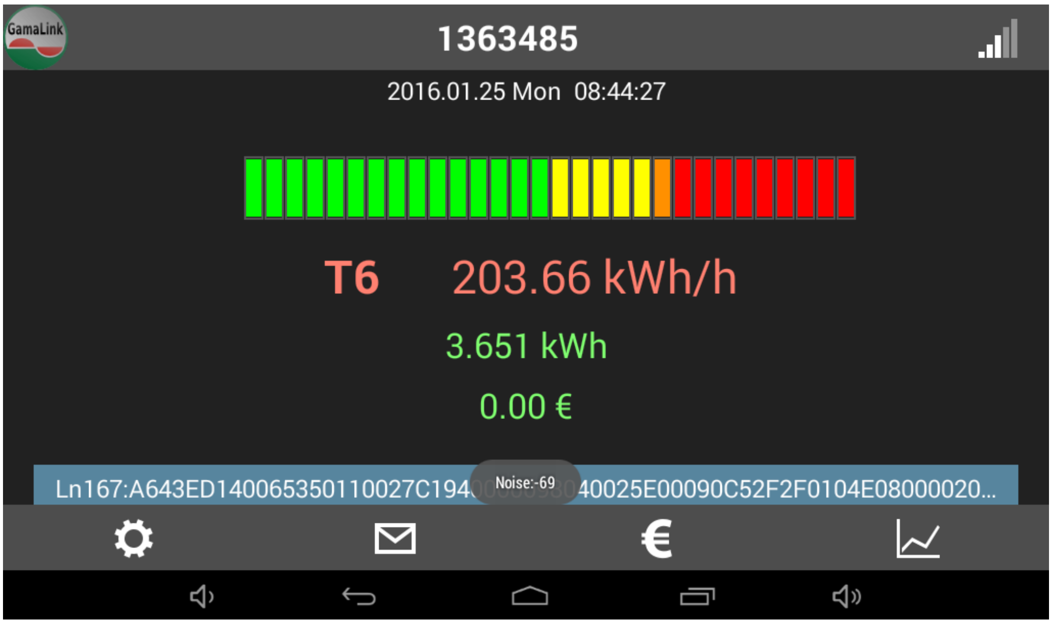


Figure 12: "Elgama-Elektronika" IHD screen with consumption data

Figure 13: "Addax" IHD screen with user message

Finally, the IHD supports the following functions:

- ✓ display simple messages from AMI system
- ✓ secure communication with meter uses using encrypted protocol
- ✓ displays meters enabled to pair with the IHD
- ✓ lost communication detection with the meter
- ✓ notifies consumer when IHD is no longer paired with meter
- ✓ automatic reconnection to the meter after power outage
- ✓ synchronize time from AMI system
- ✓ includes at 6 tariff zones corresponding to the meter
- ✓ informs consumer about consumption per tariff zone
- ✓ informs when consumption exceeds a certain limit
- ✓ displays consumption history
- ✓ displays consumption price in currency for each tariff

2.2 System Integration and Smart Metering

2.2.1 Introduction

As the interoperability between smart meters from various brands has been proofed to be guaranteed, it is essential to guarantee an easy and reliable access to the data monitored both real and off-time. In this view, the one month secondment done by AEA-Gruppo Loccioni to technical University of Crete has been addressed this topic: how to successfully integrate all measures from the smart meters and enable users an easy access to those both real and off time?

2.2.2 Methodology

A significant number of smart meters have been installed in various buildings of Technical University of Crete as reported in Chapter “4.2.5.1. The phases for the Internet based energy management system for SDE” (Table 30). Measures from these sensors have been collected and integrated into a web-based platform developed by Loccioni named myLeaf.

2.2.2.1 myLeaf

Loccioni has internally developed a system that integrates all measures coming from the meters and collects all of those into a web-based platform. Such a system is structured on three levels as shown in Figure 14:

1. Field Level

2. Local EMS
3. Central EMS

Field Level

All measures coming from the switches and the smart meters installed are collected at this level of the system. An important aspect is the connection available: how are measures sent to the local EMS? The site should then be equipped either with LAN or fibre cable or send data via a SIM card or Wi-Fi. This aspect is crucial as well as the interoperability between the hardware from different brands and firms. Another important issue to consider at this stage is the integration with the existing hardware. Often, new devices and/or control systems must cooperate with the existing hardware by refurbishment activities; to do so, data sheets for the existing hardware and electrical layout scheme are needed.

Local EMS

Such an Energy Management System is placed locally on site and enables the coordination and control of all assets connected. Dedicated control strategies and algorithms can be implemented at this level of the system. Since EMS level is located onsite, data security and privacy is of highest level.

Central EMS

The central EMS is a cloud-based platform and users have access to data collected real-time but also to historical data. At this level, dedicated monitoring and control strategies can be implemented as well forecasting techniques. At this level, integration with the energy market platform is possible enabling access to real-time prices. In order to improve the reliability and security of the system, the central EMS can be also installed onsite.

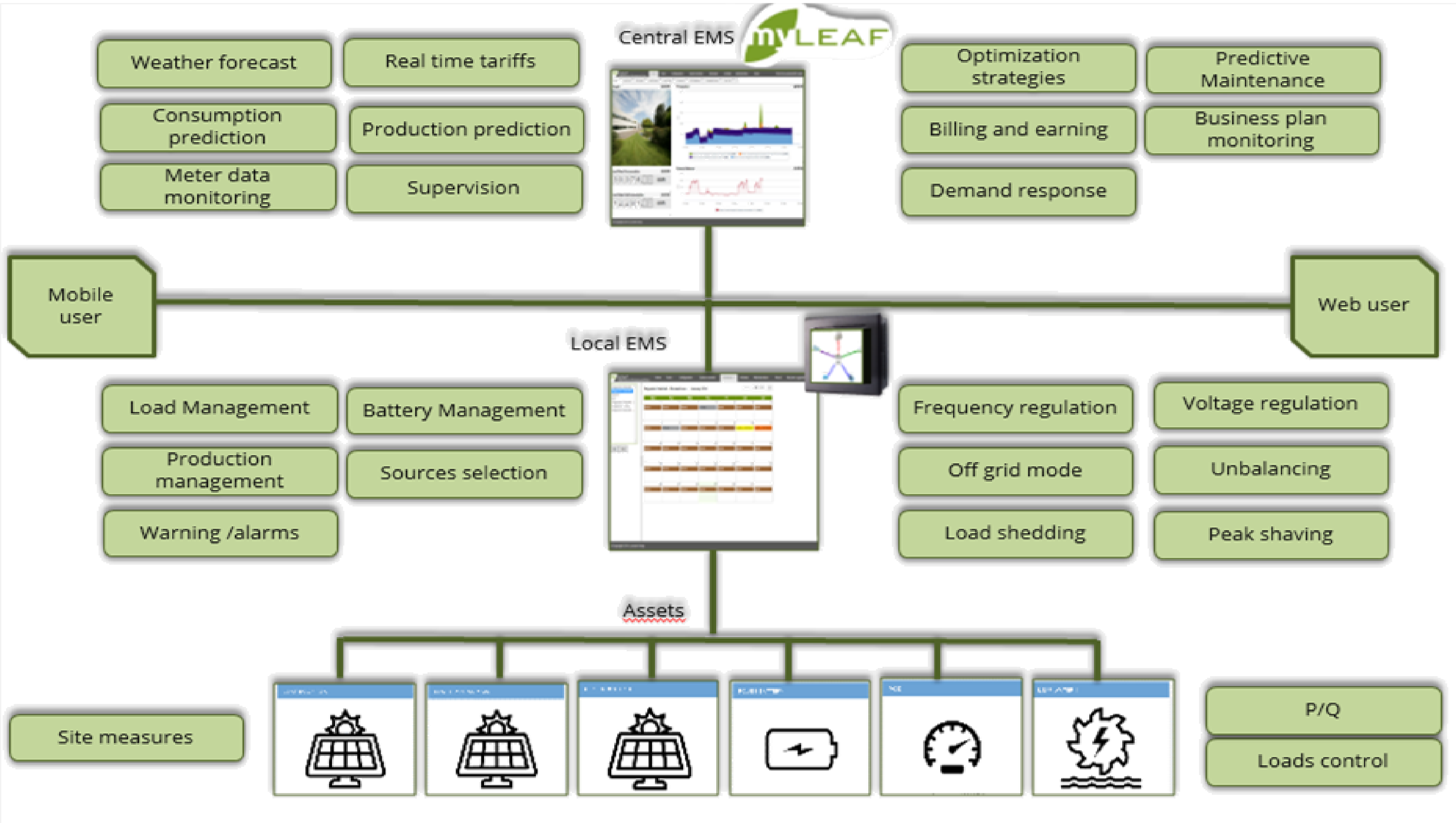
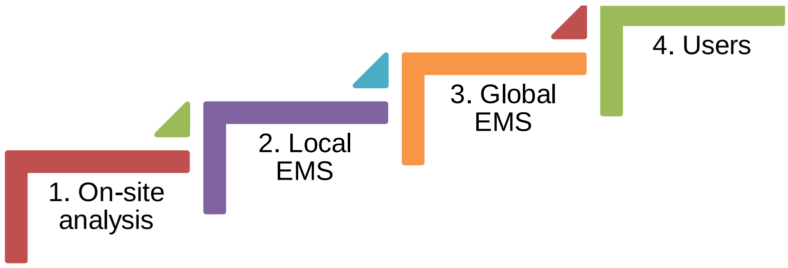


Figure 14: Loccioni myLeaf structure.

2.2.3 TUC and myLeaf

Activities have been primarily focused on how to successfully integrate measures from the meters into the myLeaf. The methodology adopted is described below:



1. On-site analysis

The person seconded from AEA cooperated with the IT and facilities staff in order to collect all the required information such as:

- Type, brand of all the smart meters installed
- What are the meters measuring?
- Sampling time
- Connection: LAN, Wi-Fi, etc.

In K1 and K2 buildings, meters are all from one firm and all measures are collected through the online platform.

2. Local EMS

The local EMS has been placed on the dedicated TUC server and connected to the platform that stores measures on a database.

3. Global EMS

At this stage, the web-based platform is linked to the local EMS that handles all the measures from the assets.

4. Users

Users have access to the measures by logging in with the provided credentials to the myLeaf web-site as shown in Figure 15. Once logged in, the user can select the desired group of measures by selecting *Tools*, *Analysis* as in Figure 16. In the top-left box, user writes *TUC_SmartGems* to access data related to the measures gathered from the TUC Campus in *myLeaf*. Measures are going to belong to the group that identifies the building from the TUC Campus, for example, K1. Figure 17 depicts how the measures can be plotted on the myLeaf. The user can select time interval, granularity, colours and type of plot to use. Moreover, it is possible to download the given plot in various format such as .jpeg, .pdf, etc.

In addition, data are also shown on the *myLeaf* webpage, as Figure 18 illustrates, and the user is enabled to download those in .cvs format.

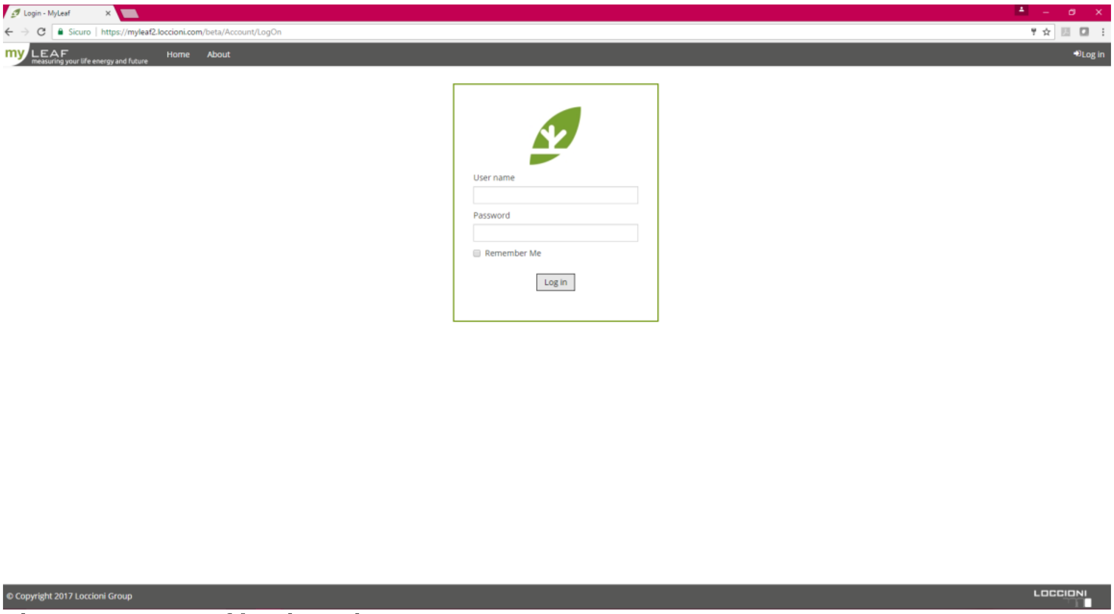


Figure 15: myLeaf log in web-page.

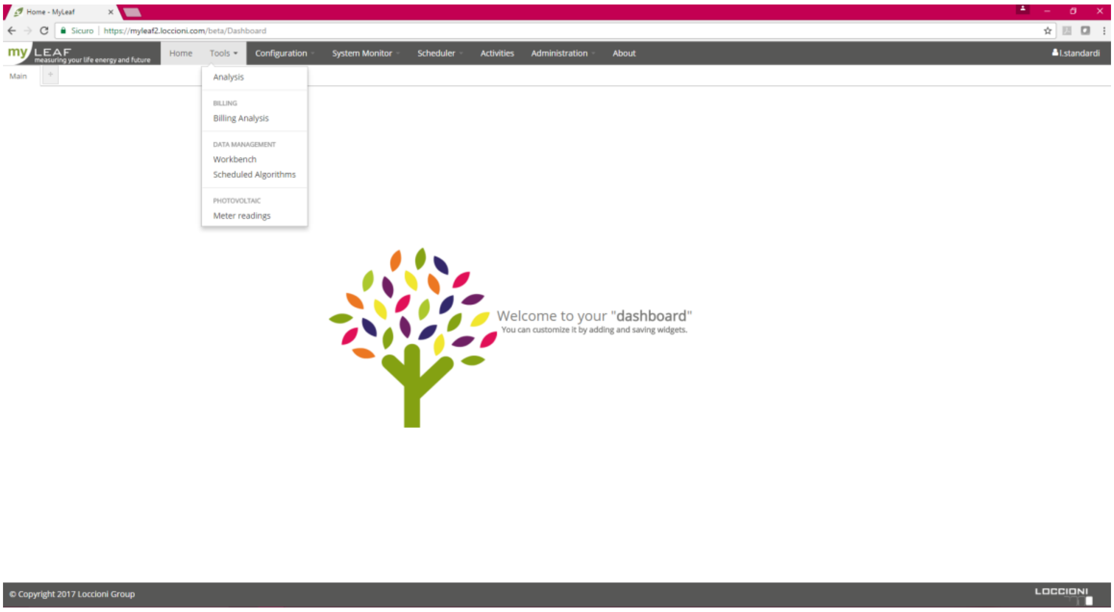


Figure 16: myLeaf logged in web-page.

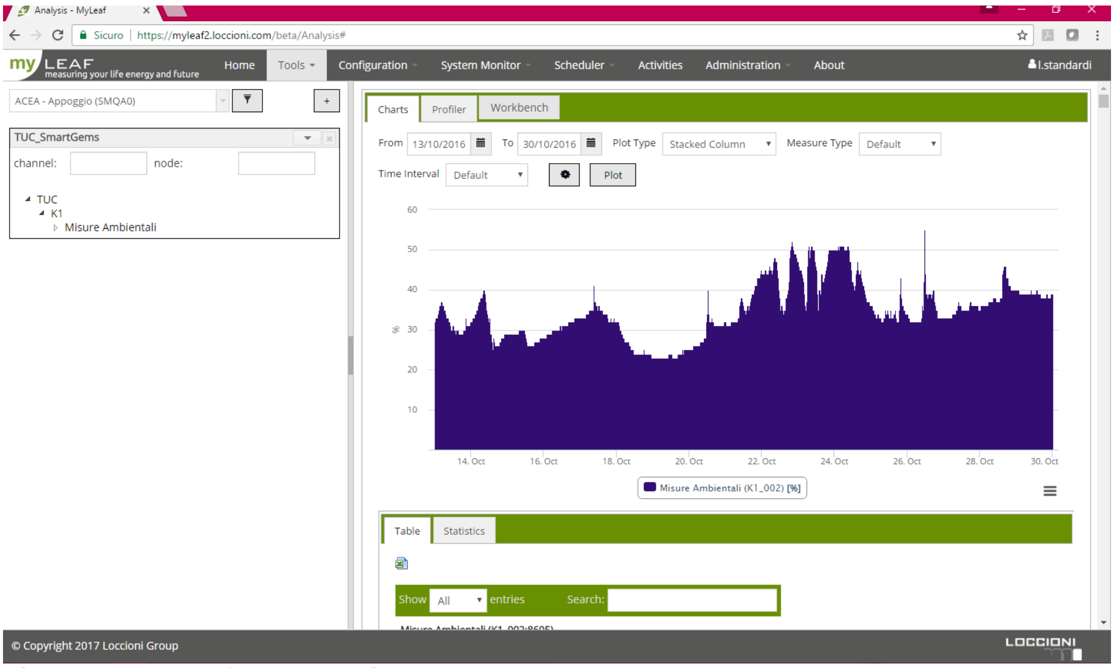


Figure 17: myLeaf results web-page 1.

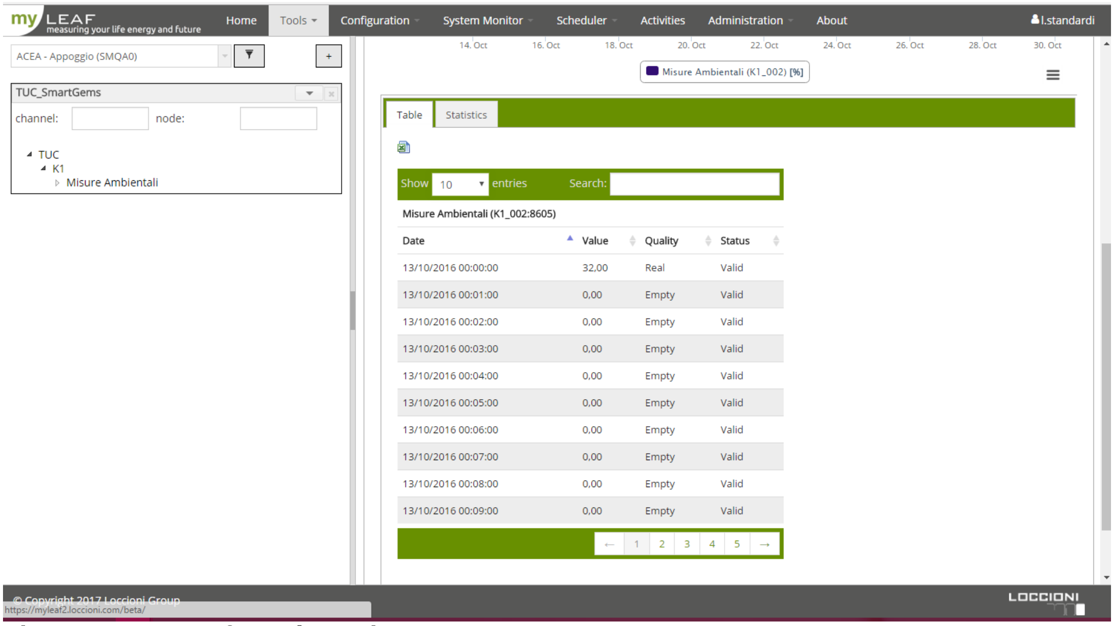


Figure 18: myLeaf results web-page 2.

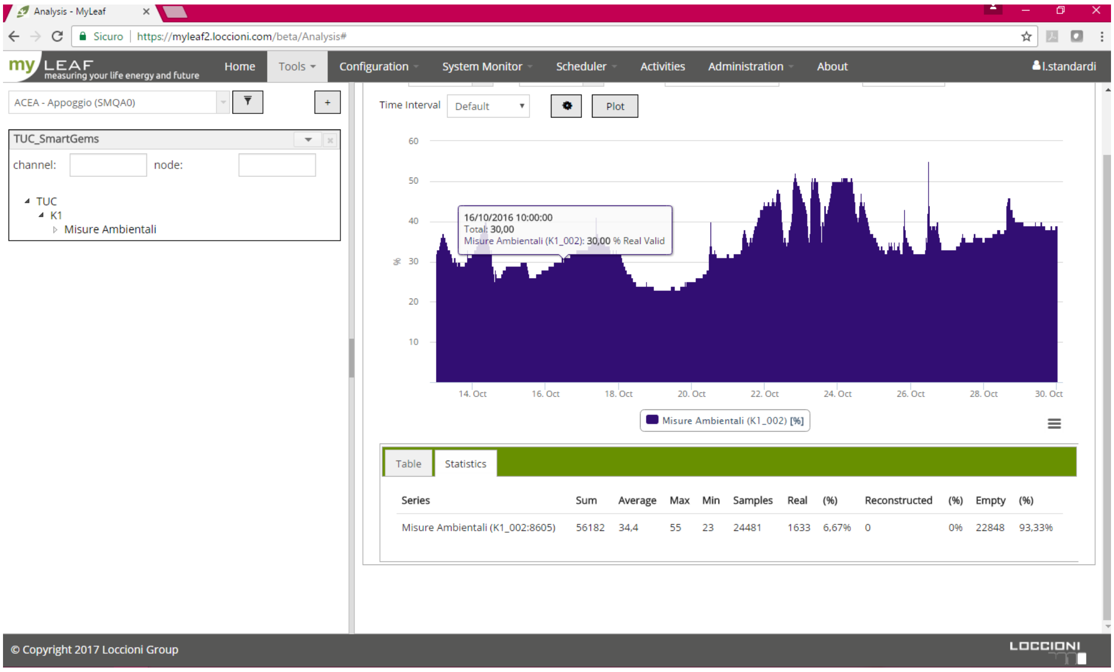


Figure 19: myLeaf results web-page 3.

3 Services and Systems

This part of the report focuses on the analysis of the energy consumptions and users satisfaction. This two aspects are very important because the former is done from an industrial/commercial point of view, which aims to maximise revenues, while the latter is studied in an industrial/office environment and it aims to guarantee comfort and satisfaction.

3.1 Analysis of the energy consumption of the Dorms at the University of Athens (UOA)

3.1.1 Introduction

This report illustrates an analysis of the energy and thermal behaviour of a building from a commercial point of view aimed to the development of solutions of economic interest for potential customers. The goal of this study is to develop a solution for integrating Photovoltaic rooftop installations in four buildings.

Nowadays, many countries are showing an increasing interest in reducing the energy consumption in as many application as possible; such a process includes, then, both public and private sectors, residential and office building, etc. The innovativeness of this work is given by the industrial and the commercial points of view on solutions aimed to increase energy savings. The goal is to develop solutions that are the most economically interesting for the customers as possible. In this view, the approach proposed enables an analysis of the energy consumption of a building that, together with information related to usage and construction, are compelling to develop a business plan of any project related to improving the energy efficiency of the building. Moreover, such an analysis is typically done at a preliminary stage, thus, is often not paid: for this reason, this study has to be efficient, reliable, accurate and done in a reasonable amount of working hours.

Analysis of energy consumptions of a building is clearly the starting point to any possible further works aimed to improve its energy efficiency.

Well-known software such as Energy+ and TRNSYS enable the modelling of the thermal behaviour of various buildings considering their features regarding constructions, materials, equipment, etc.

Thus, such modelling approaches yield to accurate, and yet time consuming, studies of the energy behaviour of the buildings in analysis. Moreover, recent studies have underlined how data-driven approaches provide proper modelling for thermal and energy behaviour of buildings (5), (6) and (7).

When thermal and energy behaviour of buildings need to be analysed in order to define and develop solutions for energy savings in the actual market, the scenario slightly changes. In fact, the aforementioned detailed techniques might be tricky to utilize for commercial applications because of various reasons:

1. Time: modelling a generic building by including all the required information is time consuming, and, typically, this preliminary work is not paid by the future customers as it is on the basis of the results obtained in this phase that they decide either to invest on the proposed solutions or not.
2. Necessary information: materials used, all the upgraded/changes done over the years, building plans are often difficult to gather as buildings might be old, changes might have not been recorded, etc., so this part of the process could be very time consuming and it can even be impossible to find some of the required information.

As a result, the preliminary analysis of the energy consumptions of the building may include the studying of its energy bills and the measurements given by smart meters possibly installed. Such an approach enables a quick and efficient analysis of the energy behaviour of the building that is crucial to define future business plan parameters to the customer. In fact, the usual five steps in this process are (fig.20):

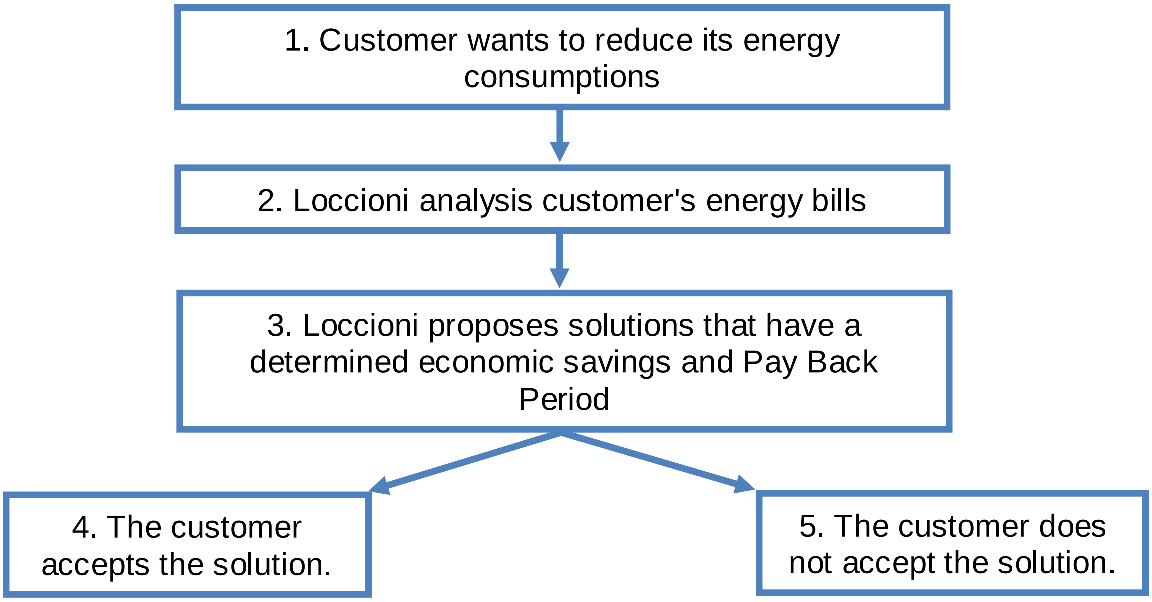


Figure20: Loccioni 5-step approach in establishing energy improvement solutions

In this scenario, steps from 1 to 3 are not usually paid by the customer, thus, the time spent in such phases has to be optimised; accordingly, a quick and efficient analysis of the energy consumption is required. To do so, this report describes the commercial, thus industrial, approach aimed to develop solutions that increase energy savings for the customers' building.

3.1.2 Methodology

The methodology used in this analysis goes through the following steps:

1. Collection of information related to energy and thermal consumption of the buildings, i.e. energy bills and measurements from smart meters where available; the energy tariff and the annual consumption provide an overview of the annual energy costs and of the possible savings. It is worth noting that it is important to gather all information related to energy consumption including both thermal and electrical loads.
2. Calculate the peak PV power that can be installed on the roof surfaces of each building as this value is then used to compute also the annual savings.
3. Calculate the related installation costs
4. Calculate the Pay Back Period (PBP).

The Pay Back Period (PBP) is the key indicator used, given by the formula:

$$PBP = \frac{Total\ Cost}{Savings\ per\ Year}$$

The PBP defines the number of years necessary to cover the overall investment costs. Clearly, a high value of PBP indicates that the investment will result in overall financial savings after many years. Typically, most investments necessary to increase energy efficiency in buildings have long PBP as the annual savings are not as high as the overall cost. For this reason, subsidies and/or pilot projects are broadly utilized to cover part or in some cases the total cost of such investments.

3.1.3 Dormitories, University of Athens Campus

In the UOA Campus in Athens, dormitories are hosted in four buildings:

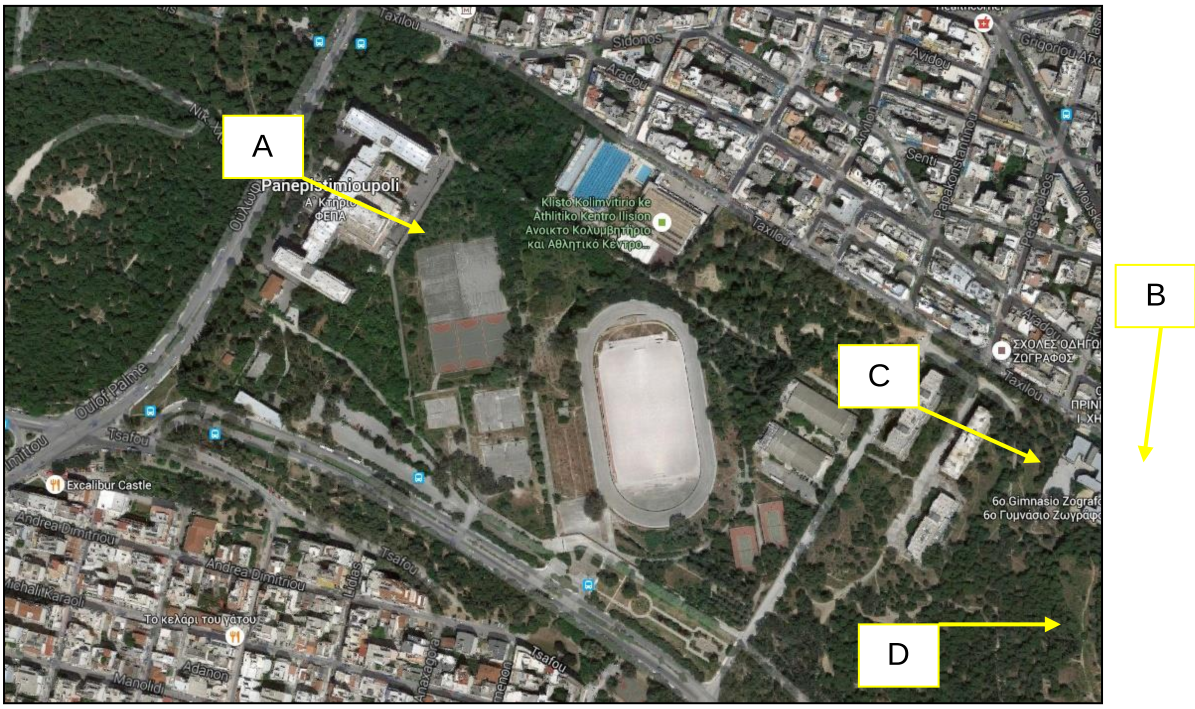


Figure 20: Dorms at University of Athens

A. Building includes offices, restaurant and rooms
B. Only rooms and common kitchen
C. Similar to building B
D. Similar to building B

First, each building is described; secondly, energy consumptions are presented and analysed collectively for all four buildings.

Table 4: UoA dormitory buildings

Building	Floors	Use
A	6+basement+ground floor	Offices + dorms + restaurant
B	4+ground floor	Dorms + common kitchens
C	4+ground floor	Dorms + common kitchens
D	4+ground floor	Dorms + common kitchens

Building A

The building is located on the northwest side of the campus, on Oulof Palme Street, where the main entrance of the Student Home is. The building consists of a basement, ground floor and six (6) floors. The total area of all building levels are 24,363m^2 with a coverage of 4,447m^2. More specifically, the distribution of the building total area and uses of space per floor are described below:

Basement

The basement has a total floor surface 4,447m^2. This surface is not counted in the SE of the building. Regarding the use of the premises of the basement are divided into: Warehouses, sports facilities areas, toilets, administration, restaurant / refreshment area. In the basement there is independent access from 5 (five) different entrances. Building A is equipped with communal areas, at the entrance, a large restaurant on the ground floor, a special room with washers and dryers in the basement. On the ground floor there are clinics that serve as interns and staff of the University Departments. Moreover, in building A are the administrative offices, some utility rooms-warehouses, restrooms, sports facilities spaces and recreational areas such as the cinema of the student dormitory. Building A has a central air conditioning system, which works with electricity and central heating system that uses natural gas.

Ground floor

The ground floor has a total surface 3,970m^2. Uses of floor space divided into: Dorms with WC, Restaurant, Assisted Accommodation - Warehouses, Accommodation, Recreation areas, Toilets and Administration.

1st floor

The first floor has a total surface 3,750 m^2. The uses of the first floor space are divided into: Dorms with WC, Restaurant, Accommodation, Leisure Area, Administration and Assisted Accommodation - Warehouses.

2nd floor

The second floor has a total surface of 2,813 m^2. The uses of the B floor space divided into: Dorms with WC, Assisted accommodation - Warehouses, Accommodation.

3rd, 4th and 5th floor

The total area of the C, D and E of floors is 2,850 m^2. The uses of the spaces C, D and E. floors are divided into: Dorms with WC, Assisted Accommodation - Warehouses, Accommodation.

6th floor

The 6th floor has a total surface 829 m^2. The uses of F-floor space divided into: Dorms with WC, Assisted Accommodation - Warehouses, Accommodation.

Building B

The building is located on the west side of the campus and it consists of ground floor and four floors of total area of 4,811 m^2 and coverage of 945 m^2. More specifically, the distribution of the total area uses of space per floor are described below:

Ground floor

The ground floor has a total surface of 945 m^2. Uses of floor space are divided into: Spaces and Recreation Storage room.

A, B, C and D floor

The total area of A, B, C and D floors is 945 m^2 each. The uses of A, B, C and D floors are divided into Dorms and WCs.

Building C

The building is located on the west side of the campus, south of the new student dormitory (N1 - building 8). The building consists of ground floor, four and (4) floors of total area of 3,888 m^2 and coverage of 830 m^2. More specifically, the distribution of the total building area and uses of spaces per floor are described below:

Ground floor

The ground floor has a total surface of 803 m^2 and uses of floor space are divided into various spaces and a recreation/storage room

A, B, C and D floor

The total area of each of A, B, C and D floors is 760m^2. The uses of A, B, C and D floors are mainly Dorms and WC.

Building D

The building is located on the west side of the campus, east of the new student dormitory (N1 - building 8) and consists of a ground and four (4) additional floors with a coverage of 745 m^2.

3.2 Objective and subjective evaluation of thermal comfort in the Loccioni Leaf Lab

3.2.1 Introduction

The aim of this study is to collect concurrent objective and subjective comfort measurements useful for the determination of any serious thermal comfort issues but also the preferred conditions in the office spaces of the Loccioni LeafLab. In effect the methodology developed for this purpose has the following objectives, shown also in Figure 21:

1. Collect subjective data from occupants on their thermal comfort
2. Collect concurrent measurements of internal and external comfort conditions
3. Analyse and compare the subjective with the objective measurements
4. Determine the Leaf Lab user preferences and satisfaction with internal conditions.

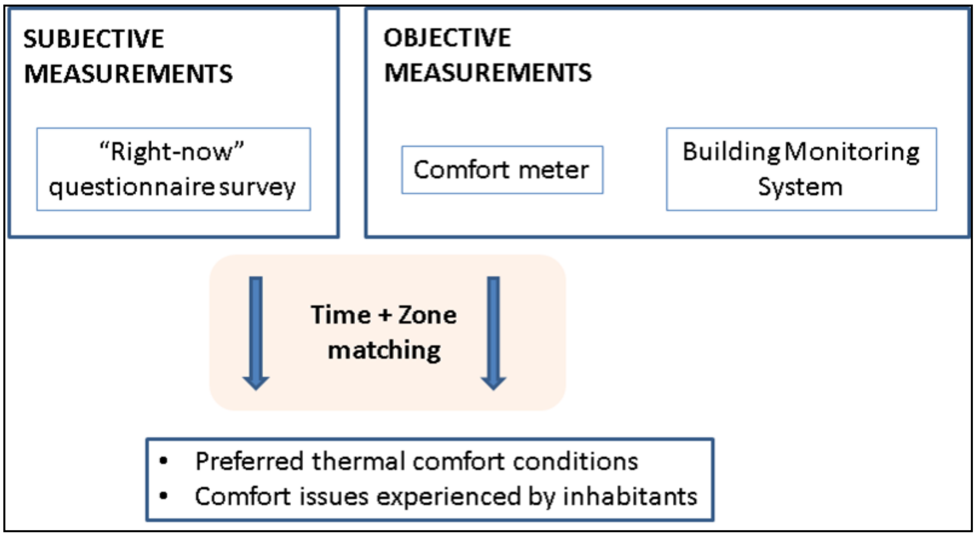


Figure 21: Outline of the study methodology

The methodology to be followed for the determination of the Leaf Lab user preferences and satisfaction with internal conditions is based on ASHRAE's *Performance Measurement Protocols for Commercial Buildings* (PMP) (5). The PMP is intended to provide "a standardized, consistent set of protocols, for a range of cost / accuracy that facilitate the appropriate comparison of the performance of six performance categories (energy, water, thermal comfort, indoor air quality [IAQ], lighting, and acoustics) in commercial buildings, while maintaining acceptable levels of building service for the occupants" (5).

For each of the six performance categories (energy, water, thermal comfort, IAQ, lighting and acoustics) protocols are developed at three levels:

1. **Basic**: basic protocols involve simple, low-cost measures that help provide a preliminary insight into annual performance of a building and usually involve measurements at building level.
2. **Intermediate**: intermediate protocols investigate the performance of the building at shorter intervals (i.e. monthly) and at major system level.
3. **Advanced**: advanced protocols are more detailed and are normally used for the deeper understanding of the building performance (more frequent and more detailed analysis).

This study involves the evaluation of thermal comfort at the **intermediate level**. In the intermediate level thermal comfort is evaluated with both **objective** (monitoring of indoor comfort parameters) and **subjective** (Right-Now survey) methods.

3.2.2 Methodology

Thermostatically controlled loads in commercial buildings, are usually ruled by set points thresholds indicated by the international standards like **ASHRAE** Std. 55 and EN 15251 (6), (7). These thresholds set the acceptable comfort range for people across the world, based on several parameters such as kind of activity, geolocation, external temperature, building orientation, time of the year and so on. However, as it is not easy to capture the actual thermal response of a building, which may change even when compared with similar buildings, it is even harder to standardize the "thermal response" of people occupying that building. There are so many aspects which can affect the perception of comfort for people, ranging from physical and mental aspects to cultural aspects, and few of them are actually measurable.

Using the approach described in this report, matching objective and subjective measurements, it is possible to draw a cleaner picture of what is the actual, real time, comfort level perceived within the building. Information regarding the real time comfort level is necessary to allow for the optimal control of the thermal conditioning system.

Knowing the actual thermal response, of both the building and the people occupying it, is even more important when addressing **demand management strategies**. To correctly evaluate the flexibility given by the thermal loads, it is important to quantify the expected consumption of the building and to be aware of the actual acceptable comfort limits. **Demand response strategies** based on **thermostatically controlled loads** use information regarding the internal temperature, the external temperature, compressor cycling ratio and meter data. However, the comfort range is assumed using the aforementioned international guidelines.

The approach presented in this report, collecting the subjective/objective measurements, enables the training of a **model** to simulate the "**thermal response**" of **people**, therefore obtaining the actual comfort level perceived within the building, based on what people felt in the past instead of what they should have felt by the guidelines. As a result, a robust model can be produced to **simulate** the thermal response of people to different demand response scenario, therefore identifying the actual imposable comfort limits.

The methodology developed for this study consists of four steps:

1. Collect subjective data from occupants on their thermal comfort
2. Collect concurrent measurements of internal comfort conditions
3. Make a combined analysis of subjective and objective measurements
4. Determine the Leaf Lab user preferences and satisfaction with internal conditions.

Subjective measurements

Subjective measurements are collected through an online questionnaire survey. The questionnaire survey is a "Right-Now" survey in which for each response the date and time is recorded and can therefore be compared against the concurrent monitored indoor environmental conditions.

The survey should be circulated for at least 1 week so as to capture the possible changes in thermal comfort conditions during the week.

The preferable frequency of response is 3 times/day:

- Morning (on arrival to the office)
- Mid-day (after lunch)
- Afternoon (before leaving the office)

At least two people should be assigned responsible for completing the survey each day in each office space, preferable one male and one female each time. Ideally, the same people should respond to the survey every day and at a higher number, however, in this work, we have different volunteers each day. On the other hand at the Research for Innovation Department's space more respondents will answer the survey at all days compared to other departments.

Objective measurements

Objective measurements of indoor environmental conditions are conducted in two different ways:

1. Standard building monitoring system measurements (MyLeaf system)
2. Measurements with a portable comfort meter (Comfort Meter)

The standard building monitoring system measurements give an indication of the conditions under which the HVAC system of the different monitored spaces operates. This is linked to how occupants feel in their thermal environment and therefore to the responses they give to the questionnaire survey. The thermal comfort parameter monitored through the building monitoring system is Air Temperature. The location of the temperature sensors is indicated in Figure 23. In addition to Indoor Air Temperature, Outdoor Air Temperatures are also monitored and the measurement frequency is 15 minutes.

The portable comfort meter provides more detailed and thermal comfort specific measurements and can therefore provide information that are closer to the objectives of this study. Namely the following are monitored with the Comfort Meter:

- Air velocity(m/s)
- Air temperature (^{o}C)
- Globe temperature (^{o}C)
- Radiant temperature (^{o}C)
- Relative Humidity (%)
- Predicted Mean Vote (PMV)

- Percentage of People Dissatisfied (PPD)

The measurement frequency is 10 seconds. This meter should be installed in the space where most responses to the questionnaire are to be collected. In this study this space is the Research for Innovation office space. The positioning of the Comfort Meter should be made according to the guidelines set in EN 15251:2007 (Table 5).

Table 5: Guidelines for the positioning of Comfort Meter

	Specifications	Explanation
Space	Research for Innovation	• Space in which the seconded people are based and can therefore safeguard the sensor. • This is the zone in which more people are likely to take the survey due to interest/relation with the study subject.
Height above floor level	~0.6m (can be placed on an office desk)	• measuring level for sedentary occupants
Location	center of the room	• most likely to be away from hot or cold surfaces or direct solar radiation • representative of room average conditions
Unwanted factors	•exposure to the sun •blockage by other objects •close to warm or hot surfaces (i.e. a computer, a window etc)	• would lead to false conclusions for indoor environmental conditions

Combined analysis of objective and subjective measurements

Through all three measurement processes (building monitoring system; Comfort Meter; Questionnaire) the measurement time is available. Therefore, it is possible to match the time that a response to the questionnaire is given with the monitored data. Information on zone characteristics (i.e. floor area, floor level, orientation) that are known to have an impact on the thermal conditions of a space were also collected with the help of a building survey. Furthermore, the zone in which each sensor is located is known, and the location of the respondent is asked through the survey thus allowing for zone matching to be performed as well.

The study variables to be considered for the analysis are summarized in Table 6. Statistical analysis was performed with the help of Statistical Package for Social Sciences (SPSS).

Table 6: Study variables and source of information

Variable	Variable Type*	Building survey	Building Monitoring System	Comfort Meter	Questionnaire
Time of day	scale		x	x	x
Period of day	nominal		x	x	x
Gender	nominal				x
Office floor area	nominal	x			
Floor	nominal	x			
Orientation	nominal	x			
Zone (Department)	nominal		x		x
Outdoor air temperature	scale		x		
Solar irradiance	scale		x		
Indoor air temperature	scale		x	x	
Air velocity	scale			x	
Globe temperature	scale			x	
Radiant temperature	scale			x	
Relative Humidity	scale			x	
Predicted Mean Vote (PMV)	ordinal				x
Predicted Mean Vote (PMV)	scale			x	
Percentage of People Dissatisfied (PPD)	scale			x	
Adjacency to external window	nominal				x
Duration of time sitting at desk	nominal				x
Acceptability	ordinal				x
Thermal Preference	ordinal				x

*Nominal: Categorical variable whose values have no intrinsic ranking

Ordinal: Categorical variable whose values have some intrinsic ranking

Scale: Interval or ratio variables. Values represent ordered categories with a meaningful metric.

User preferences and satisfaction with internal conditions

Multivariate analysis will apply to the combined objective and subjective measurements in order to define user preferences regarding internal environmental conditions and whether any major thermal dissatisfaction issue occurs within the office spaces.

Such findings can prove to be a valuable asset for the facilities or energy manager of the building as they can provide insights for the optimization of the HVAC system which in turn can result into identification of energy saving opportunities and improvement of the thermal comfort and therefore of the productivity of the occupants.

3.2.3 **Collection of building** background **data**

The building studied under this subject is the Loccioni Leaf Lab. The building is located in a rural area of Ancona province in Italy (fig.24).

Figure 22: Location of the Loccioni Leaf Lab

The Loccioni Leaf Lab is a two floor building consisting of many different spaces mainly: laboratories, warehouse, office spaces and meeting rooms. For this study the four main office spaces were considered:

1. Research for Innovation
2. Energy
3. Industry
4. Progettazione

These office spaces are positioned perimetrically of the building. Research for Innovation and Energy have a South-East orientation while Industry and Progettazione have a North-West orientation (see Figure 23).

The characteristics of the four studied office spaces were collected through a building survey and are summarized in Table 7. It is noted for the heating/cooling operating conditions that, although direct user override is not possible, the users can make requests to the facilities management for increase or decrease of temperature in their specific work area.

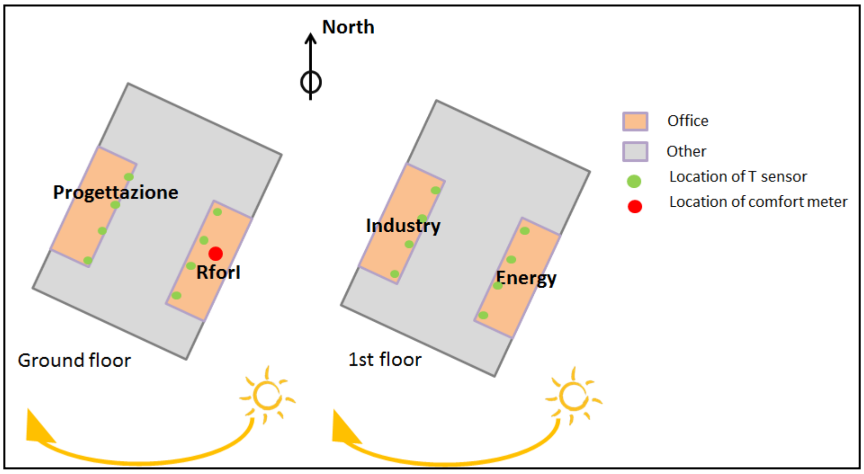


Figure 23: Office spaces considered for the study and location of monitoring equipment

Table 7: Characteristics of the Loccioni Leaf Lab office spaces

			Rforl	Energy	Industry	Progettazione
Level/Floor			0	0	1	1
Orientation			SE	NW	SE	NW
Monitoring	**Internal IEQ parameters (MyLeaf)**	T air (oC)	Y	Y	Y	Y
		internal lighting power (kW)	Y	Y	Y	Y
	External environmental parameters	T air (oC)	Y	Y	Y	Y
		solar irradiance(W/m2)	Y	Y	Y	Y
	Number of internal monitoring equipment	T air	4 sensors	4 sensors	4 sensors	4 sensors
	Measurements frequency		15 min	15 min	15 min	15 min
Occupancy	**Profiles**	Operating hours	07.00-20:00	07.00-20:00	07.00-20:00	07.00-20:00
		Working hours	08.30-18:00	08.30-18:00	08.30-18:00	08.30-18:00
	Occupancy	Occupancy (# people)	15	20	15	10
HVAC system	**Operation schedule**	Days on (from day to day)	Monday-Friday	Monday-Friday	Monday-Friday	Monday-Friday
		Days off (weekends, holidays etc)	weekends, holidays	weekends, holidays	weekends, holidays	weekends, holidays
		preconditioning (Y/N)	Y	Y	Y	Y
	Location of thermostat	T air	See Figure 23	See Figure 23	See Figure 23	See Figure 23
	Heating operating conditions	heating setpoint (oC)	22	22	22	22
	Cooling operating conditions	cooling setpoint (oC)	26	26	26	26
	Special conditioning requirements	Y/N	N	N	N	N

Controls	**Fixed setting (user cannot interfere)**	heating (Y/N)	Y	Y	Y	Y
		cooling (Y/N)	Y	Y	Y	Y
		ventilation (Y/N)	Y	Y	Y	Y
		lighting (Y/N)	Y	Y	Y	Y
	Possibility for user override of controls	heating (Y/N)	N	N	N	N
		cooling (Y/N)	N	N	N	N
		ventilation (Y/N)	N	N	N	N
		lighting (Y/N)	N	N	N	N
	Alternative options for user to adapt the environment	external operable windows	Y	Y	Y	Y
		external operable doors	N	N	N	N

3.2.4 Collection of monitored data

The thermal environment monitoring was conducted with two different methods:

1. Standard building monitoring system measurements (**MyLeaf**),
2. Measurements with a portable comfort meter (**Comfort Meter**).

The **MyLeaf** monitoring system is a monitoring system developed by the Loccioni Group and implemented in its own buildings. Monitoring data for all kinds of parameters are monitored and are accessible through the MyLeaf web-based platform (Figure 24). The monitored environmental parameters useful for this analysis are **Indoor Air Temperature** (^{o}C) and **Outdoor Air Temperature** (^{o}C). Four Indoor Air Temperature sensors are located in each office space (Figure 23); the measurement frequency is 15 minutes and all measurements can be downloaded from the MyLeaf platform in tabulated form (.cvs).

Regarding the **Comfort Meter**, this is a portable monitoring device designed and developed by the Loccioni Group and the measurements provided are:

- Air velocity(m/s)
- Air temperature (^{o}C)
- Globe temperature (^{o}C)
- Radiant temperature (^{o}C)
- Relative Humidity (%)

After inputting the clo-value (clothing insulation level) and metabolic rate (activity level) of the office space users the Comfort Meter is capable of calculating the corresponding:

- Predicted Mean Vote (PMV)
- Percentage of People Dissatisfied (PPD)

A near sedentary activity was assumed (1.2 met) and light office wear (0.5 clo) for the Loccini LeafLab office spaces.

The sampling time is 10 seconds. The Comfort Meter is connected to a PC and monitored data are saved on the PC in the form of an excel file for each monitored day.

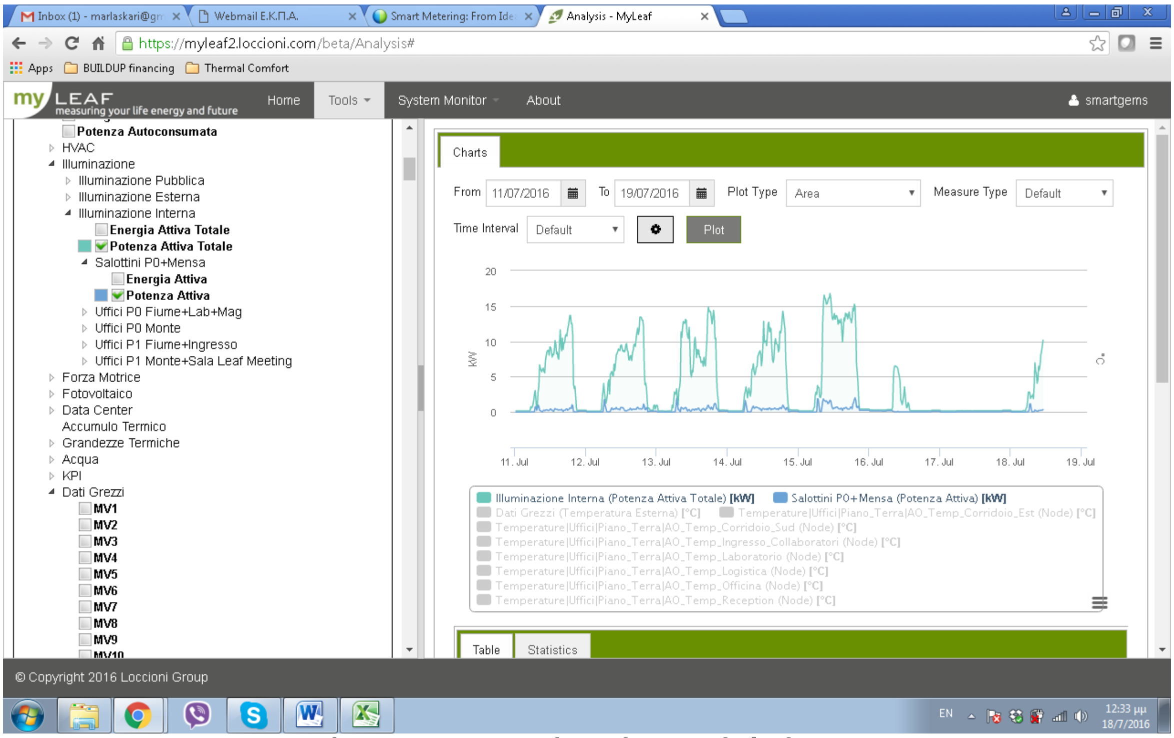


Figure 24: Screenshot of MyLeaf platform

3.2.5 Right-Now questionnaire survey

There are **two types** of **Right-Now surveys**: Self-initiated and requested. Both surveys have in common the fact that for each response the date and time is recorded and can therefore be compared against the concurrent monitored indoor environmental conditions.

- In the self-initiated survey the occupant can respond to the survey at any given moment through a continuously available link to the survey without being reminded by a managing department.
- In the requested surveys the initiative for responding to the survey is taken by a department within the building/company. This is usually in the form of a prescribed reminder email.

Because of the busy schedule of the respondents the requested survey was considered more appropriate.

The survey was created online in Google forms[1]. The survey was circulated from Friday (22/07) until Friday (29/07) to help monitor changes between Friday and Monday during which the office spaces are unoccupied and the HVAC system off. The targeted frequency of response was 3 times/day:

- Morning (arrival at office – 12:30)
- Mid-day (12:30-16:00)
- Afternoon (16:00-end of shift)

At least two people in each zone were assigned responsible for completing the survey each day. In order to design a survey that provides only the necessary information regarding the thermal comfort, the selected questions are the following:

1. Zone. The office and laboratory zones are studied: Research for Innovation, Energy, Industry and Progettazione.
2. Adjacency to external window (within 3 meters from the respondents' desk).
3. Duration of time sitting at desk (<15 minutes, 5-15 minutes, >15 minutes)
4. Thermal sensation. Numerical vote on the ASHRAE 7-point thermal sensation scale (cold, cool, slightly cool, neutral, slightly warm, warm, hot)
5. Acceptability. Can be asked in a binary or in a continuous way. It involves the thermal sensation reported in the previous question. The continuous scale (Clearly acceptable/Just acceptable/Just unacceptable/Clearly unacceptable) allows for more meaningful statistical analysis.
6. Preference. Statement of preference for the thermal environment to change or for it to remain the same. Measured on a 3-point scale (1-warmer, 2-no change, 3-cooler).
7. Gender. Male/Female.

The survey does not ask for humidity and radiant effects separately since they are perceived as temperature effects (5). Also, a question on whether thermal comfort enhances the ability of the respondents to get their work done was not included because the building is not naturally ventilated. For this study it is considered that the impact of thermal comfort on productivity is linked somehow to the level of acceptability/unacceptability.

---

[1]https://www.google.com/forms/about/

It is worth noting that although activity and clothing level are known to affect thermal sensation these were not addressed in the survey itself. The reason for not addressing them in the survey is because their values are considered to be rather constant and by removing them would help limit the number of questions to the absolutely necessary. A fixed value, relating to the performed task (near sedentary; 1.2 met) and dress code (light office wear; 0.5 clo) was considered for activity and clothing level. The age range of the Loccioni staff is not very broad (average age is 33-34 years) therefore, a specific question was not included either.

The Right-Now survey was tested before formally launched. Only the three questions dedicated to thermal comfort were included in the survey with the purpose of validating their value and suitability for this research as follows (Figure 25):

1. Thermal sensation (7-point scale)
2. Acceptability (binary)
3. Preference (3-point scale)

The survey was tested in one of the zones for 2 different yet successive days and for the three periods of time during the day that were expected to present differences in thermal sensation (morning, mid-day, afternoon) to show whether it would have meaning to have the survey answered more than once per day (Figure 26). Five respondents participated in the test. The respondents were reminded via email to take the survey at all 3 measurement periods (June 28 afternoon, June 29 morning, June 29 after lunch). The findings of the testing of the “Right-Now” survey are summarised below:

- It is interesting to monitor different times of the day as different conditions (thermal mass behaviour at different times of the day, external conditions, respondent metabolic rate etc.) → the survey should be answered 3 times/day: morning, mid-day, afternoon.
- The requested survey (reminders to all via email every day) would soon cause fatigue to the respondents → The survey will be open to everyone to take at any time but at least two people interested in this activity should be assigned to take the survey every day. Rotational allocation of the task (on

a daily basis) would help ensure that the person responding is not tired of answering the survey 3 times/day and that a variety of respondents (gender, location in room, age etc.) take the survey.

- The binary option for acceptability (acceptable/unacceptable) does not provide much insight on the level of acceptability/unacceptability. The continuous scale will be used instead.
- Gender should be included as it would be interesting to see differences in the perception of the thermal environment by different genders.

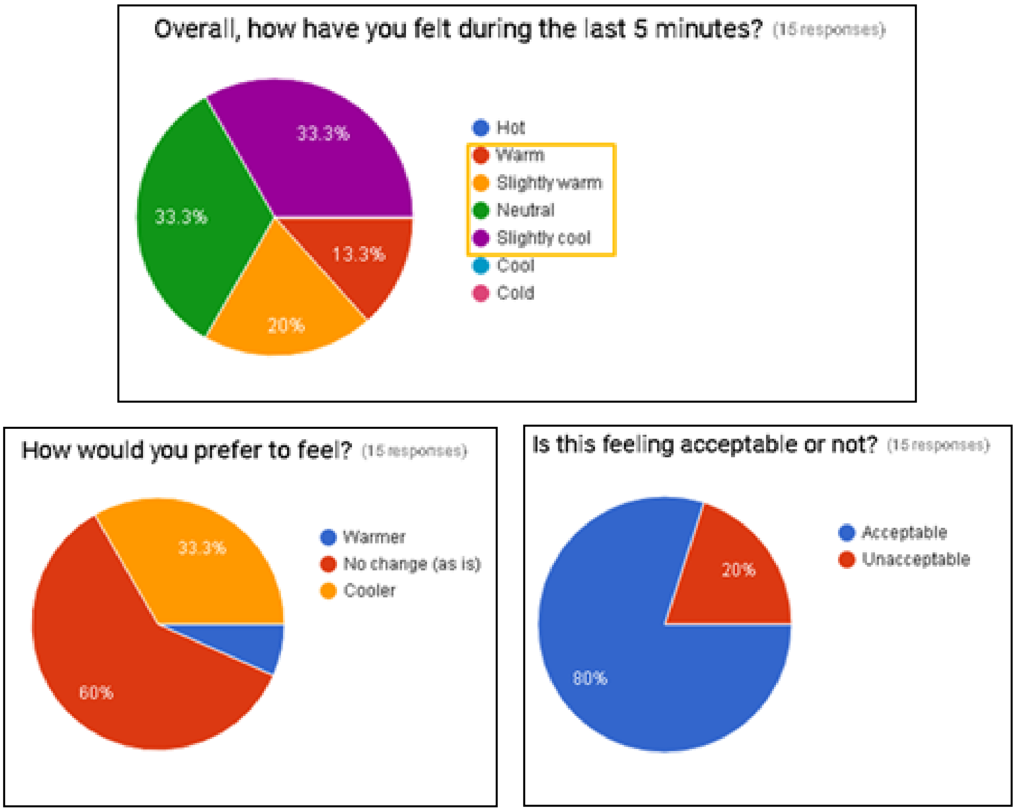


Figure 25: Testing of the Right-Now survey (general statistics)

1	Timestamp	Overall, how have you felt	Is this feeling acceptable	How would you prefer to fe
2	6/28/2016 17:12:34	Slightly cool	Acceptable	No change (as is)
3	6/28/2016 17:19:52	Slightly cool	Acceptable	No change (as is)
4	6/28/2016 17:20:34	Slightly cool	Acceptable	No change (as is)
5	6/28/2016 17:54:00	Neutral	Acceptable	Cooler
6	6/28/2016 18:24:29	Neutral	Acceptable	No change (as is)
7	6/29/2016 10:43:23	Neutral	Acceptable	No change (as is)
8	6/29/2016 10:55:22	Slightly cool	Acceptable	No change (as is)
9	6/29/2016 10:55:28	Neutral	Acceptable	No change (as is)
10	6/29/2016 11:19:49	Slightly cool	Acceptable	Warmer
11	6/29/2016 11:24:21	Neutral	Acceptable	No change (as is)
12	6/29/2016 16:00:32	Warm	Unacceptable	Cooler
13	6/29/2016 16:01:29	Slightly warm	Unacceptable	Cooler
14	6/29/2016 16:05:00	Warm	Unacceptable	Cooler
15	6/29/2016 16:28:09	Slightly warm	Acceptable	Cooler
16	6/29/2016 16:30:38	Slightly warm	Acceptable	No change (as is)

Figure 26: Testing of the Right-Now survey (individual responses)

3.3 Smart Meters and Users Engagement in the Leaf House

3.3.1 Introduction

Smart metering systems add more information than conventional meters and offer many advantages as cost effectiveness, accuracy and interactivity with the users. Once in place, interactive smart meters can allow users to control and manage their individual preferences and consumption patterns, providing incentives for energy efficient use through behavioural change.

User engagement and acceptance is a critical factor for the successful roll-out of smart meters. According to the Energy Efficiency Directive EED (Articles 9 and 12), appropriate advice and information should be given to the users at the time of installation (9). Particularly, in line with Article 9, the Member States (MS) should ensure that the objectives of energy efficiency and benefits for final customers are fully taken into account when establishing the minimum functionalities of the meters. In addition, MS should ensure the security of the smart meters and data communication and the privacy of the final users.

Smart meters can be a useful tool in giving customers up-to-date information on energy use and enabling accurate billing. The advanced metering infrastructure can reduce environmental impact via lowering consumption and/or load shift (10). Nevertheless, to achieve reduction in energy use the engagement of the user is crucial.

For the implementation of the smart meters and the development of **efficient communication with the users**, is necessary to carry out surveys to understand the user's need and reveal possible problems or unclear issues regarding smart meters and their potential. The role of end-users in smart metering applications and their involvement in sustainable consumption is also acknowledged by the EED Article 9.

Current research has predominantly focused on the technical and system configurations involved with smart metering with non-technological topics, such as consumer acceptance of smart metering systems, attracting considerably less attention from researchers (11) (12).

Even though the importance of the end-user has been recognized by researchers and policy makers [5, 6], there is lack of comprehensive knowledge on engagement and confidence of the consumers (13) (14).
This study aims to provide an insight to the users' perceptions on smart metering services of the Leaf House which is the first carbon neutral Italian house. In addition, the results will contribute to the design of the consumer engagement with the smart grids of the future, bringing active demand technology to everyday life.

3.3.2 Methodology

The aim of this report is to provide an insight to the users' engagement in smart metering applications. Figure 27 illustrates the specific objectives are:

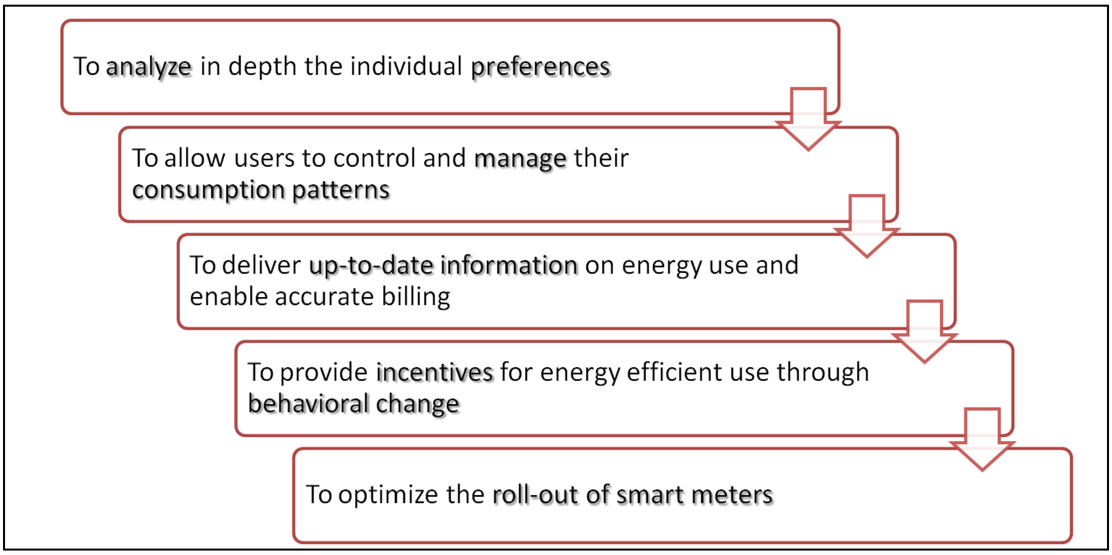


Figure 27: Objectives of this study

The **methodological procedure** consists of four main steps:

i. **Development of questionnaire**
ii. **Users 'survey and focus group**
iii. **Data analysis**
iv. **Results and discussion**

The data will be obtained by a survey to the users of **Leaf House**, a residential building which was designed and constructed in the view of minimizing energy consumption and emissions.

3.3.3 Analysis of Users Engagement

Development of Questionnaire

To fulfil quantitative data requirements, a questionnaire for the tenants/users is developed and applied to investigate the following topics:

A. **Demographics**, **socioeconomics**: To determine the basic socio-demographic and socio-economic characteristics of the sample such as: gender, average age, household size, income and education.

B. **Psychological**, **Social** and **Behavioural aspects**: Deals with the consumption behavior and attitudes of the tenants. It also identifies usual everyday energy and water behavior patterns and opportunities for promoting energy efficient behaviour change.

C. **Information about environmental issues**: Helps determine the existing (self-reported) knowledge on energy, water and environmental issues in general.

D. **Health** and **comfort**: To determine whether there are problems related to thermal comfort and Indoor Air Quality, but also structural problems (condensation, dampness and mould) and health issues that should be considered in the design of the energy management plan.

E. **Living situation**: These questions give an overview of the installed devices that consume electricity, and about the living situation of the participants.

Set of questions:

1. Living situation and building:
   - Electricity
   - Heating
   - Domestic hot water
2. Attitude towards energy saving:
   - Environmental domestic routine behaviour
   - Intention
   - Personal norms and attitudes
   - Habits
3. Attitude towards technology

4. Attitude towards nature
5. Motives for participating
6. Smart grid technologies:

- Usage of variable tariffs
- Usage of devices
- Behaviour
- Usage and evaluation of given digital information
- Comfort

7. Standard demographic questions

The tenant's questionnaire is designed to be answered by individuals. The goal is to recruit it to as many members as possible from each participating household who would independently complete their personal version of the survey. The proposed framework includes variables from the psychological areas as well as general societal socio-demographics.

Independent variables:

1. ***Socio-psychological variables***: The following sets of behaviour antecedents have been used:

- Attitude (ATT)
- Perceived Behavioural Control (PBC)
- Personal norm (PN)
- Awareness of consequences (AC)
- Habits

2. ***Knowledge***

Responses are given on six-point scales, with scores ranging from 1 'very well informed' to 5 'very badly informed' and 6 'don't know'. Lower scores show higher levels of knowledge on environmental issues.

3. ***Socio-demographic variables***

The following socio-demographic variables should be considered:

- Income
- Education
- Occupation
    - Age
    - Gender

- Family status
- Household size

Based on the feedback gathered the template will be further fine-tuned to enhance its efficiency, usefulness and user-friendliness in the Smart GEMS and beyond the end of the project.

The questionnaire was based on S3S [9] and ICE WISH (15) Projects. The questions were adapted to be in line with the Leaf House services and the aim of user engagement analysis.

A copy of the questionnaire is enclosed in Appendix 2.

Leaf House Case study

Leaf House, shown in Figure 28-Figure 31, is a carbon neutral house in Italy, aimed to be as energy independent as possible and designed so as not to have impact on the environment. A building of six apartments located at Angeli di Rosora and actually inhabited by employees Loccioni. Moreover, the building is located in Via Petrarca 4, 60030 Angeli di Rosora (AN) (43°28'23.4"N,13°04'02.1"E).

Figure 28: The Leaf House

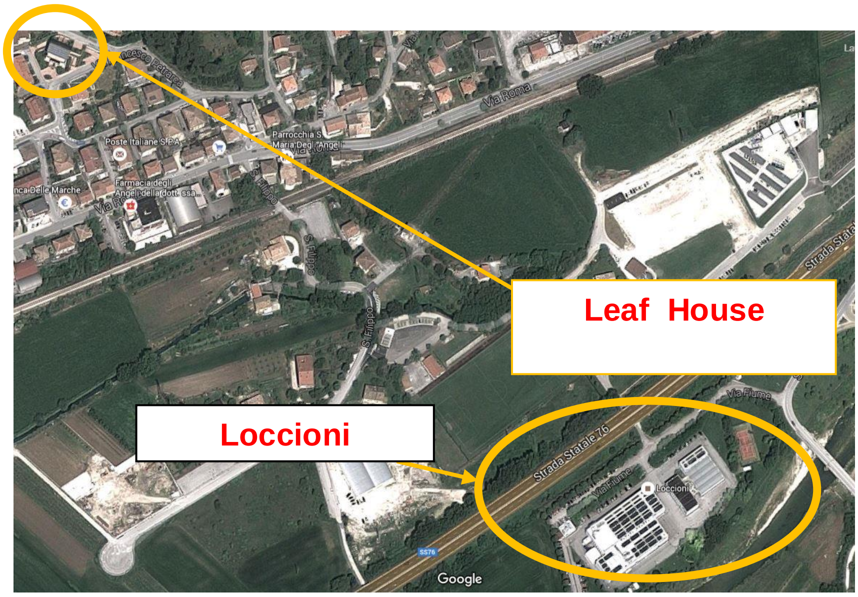


Figure 29: Location of the Leaf House (Google maps)

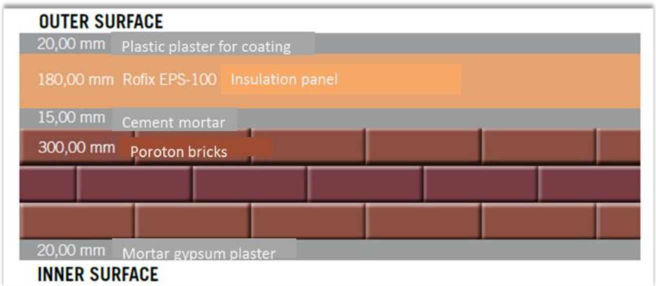
Figure 30: The Leaf House

Figure 31: The control room in the Leaf House

Building Envelope and Systems

Climate zone	Mediterranean
Year of construction	2008
Building utilization i.e. residential, office, commercial, industrial etc.	Residential apartment and garages for employees and for guests
Building occupancy schedule	It comprises 6 apartments: • 8 persons regularly living in 4 of these apartments, • 2 guest apartments. Apartments occupied by employees: 18:30-08:00 Apartments occupied by guests occasionally for few days from 18:30-08:00
Energy Utility	Enel
Energy tariffs (€/kWh)	0.06750 €/kWh - 08:00-19:00 working days during the year 0.05250€/kWh - 19:00-08:00 working days, weekends and official holidays[2]
Gross floor area (m^2)	around 220 m^2 + 40 m^2 garage
Net floor area (m^2)	-
Number of storeys	4
Architectural plans or 3D images of the building	The building has a North-West/South-East orientation. All relevant architectural plans are within the end of this document.
Building envelope description (i.e. wall – roof – floor structure, type of façade, percentage of window to wall area, roof type, etc)	The Leaf House is a residential building designed and constructed in the view of minimizing energy consumption and emissions. The structure has a rectangular plan and spread over 4 floors, of which 3 are above ground on North-side because the house is closed to a hill and the basement. The building has a reinforced concrete structure with brick-concrete secondary structure for walls. The building is south oriented and the ratio between the lengths of the south and east facades was set to 1.34 to maximize solar gains during the colder season. Since the house is located close to a hill so there are only three completely open facades while that on the hillside, has only the last flats floor with the double height. The principal façade South-East is characterized by door-windows for the day zones and common window for night zones. The lateral facades have a minor number of windows with regular size for the secondary bedrooms. In the rear part of the house facing North, the sunlight arrives carried by solar tubes. The total percentage of window is equal to 4.25%. The wooden roof has a rounded free form that reminds of the shape of a leaf from which is derived the loft of the apartments of the top floor. The roof, the solar thermal panels and the balcony have been designed to behave as solar shadings during the hottest months.

[2]https://www.enelservizioelettrico.it/it-IT/tariffe/uso-domestico/biorarie/d3

<table>
<tr><td></td><td>The floors are brick - concrete (20 + 4 cm thickness) and both in wood and terracotta, natural and comfortable materials close to the place tradition and to the natural dimension of living.
The walls structure is composed of an external layer of EPS with a factor λ of 0,036 and a thickness of 18 cm; it insulates more or less just like a thickness of about 1,5 mt. of bricks.


Remarkable is also the attention paid to heat bridges: fixtures, rolling shutters, windows, doors and the relative structures must guarantee the maximum insulation. It is not only possible to benefit of the extraordinary thermal insulation but also of the acoustic one up to 43 dB. The Leaf House flats are absolutely noiseless.
Conceived as a prototype house, to meet the needs of the domestic environment liveability, compatible with energy saving, inside there are networks of systems and sensors managed by a home automation and automation system that allows the control and integrated management. Through a display, the home automation system enables tenants to control, switch on/off the lights in the apartments.</td></tr>
<tr><td>HVAC System (kW)</td><td>• Geothermal Heat Pump
• Hot water boiler
• Air Handling Unit
Air ventilation: outer air is heated in winter and cooled in summer. In addition, it is naturally pre-conditioned through an underground path of about 10 mt. before getting to the AHU.
Radiant floors in each apartment for heating and refreshment</td></tr>
<tr><td>Lighting System (kW)</td><td>fluorescent lamps and LEDs</td></tr>
<tr><td>DHW System (kW)</td><td>-</td></tr>
</table>

Energy Management & Control System	About 1000 sensors installed: • Indoor comfort (temperature, humidity, CO_2) • Thermal and electrical measures, • Energy consumption, • Rain water level. Building Automation: each apartment has a display that enables tenants to: • set the desired temperature in the apartment, • monitor lights, • check windows/doors open, • see energy consumptions.
Current state of repair and year of last major renovation of building envelope and main technical installations respectively	Many changes and upgrades have been made over the years and this affects the annual energy consumption.In 2012 a 5.8 kWh electric storage was introduced in the Leaf House and it operated until late 2014: this caused an increase of the energy self-consumption due to the storage of PV production.

Energy Data

Energy consumption for 2015	61597kWh
Energy produced in 2015	23076kWh
Energy from the Leaf House to the grid in 2015	7057kWh
Measured average annual consumption of electrical energy and other type of fuels over the last 1 years (kWh)	5133 kWh
Peak Load (kW)	860 kW (on April, 2015)

Energy Generation and Storage Data

Energy generation by RES	PVs 20 kWp for a surface of 150m^2
Electrical storage	Planned by 2016
Thermal storage	No.
Gas Independence	Planned by 2016

Leaf House Tenants' Focus Group

The majority of the tenants of the Leaf House, current and previous, have joined the Focus Group: though emails, discussions, and meetings the remarks obtained could be sum up as:

- ✓ There is a need for more **interactive monitoring system**, so the inhabitant may control easily more parameters related to comfort and energy performance;
- ✓ New tools are needed with **indications** for the users when they consume more;
- ✓ More **customized options** on the everyday user should be provided;
- ✓ The **operative Temperature** should be used as the optimum set point;
- ✓ The **thermal inertia** of the Leaf House building results in slow response to the change of indoor temperature;
- ✓ The behaviour of the users is linked to the general profiles of the inhabitants, cultural aspects and cost and environmental benefits;
- ✓ The motivation should be connected with the values of sustainability;
- ✓ The Leaf House may provide the **educational environment** as a Living Lab.

The key points that have been addressed by the focus group are then illustrated in Figure 32.

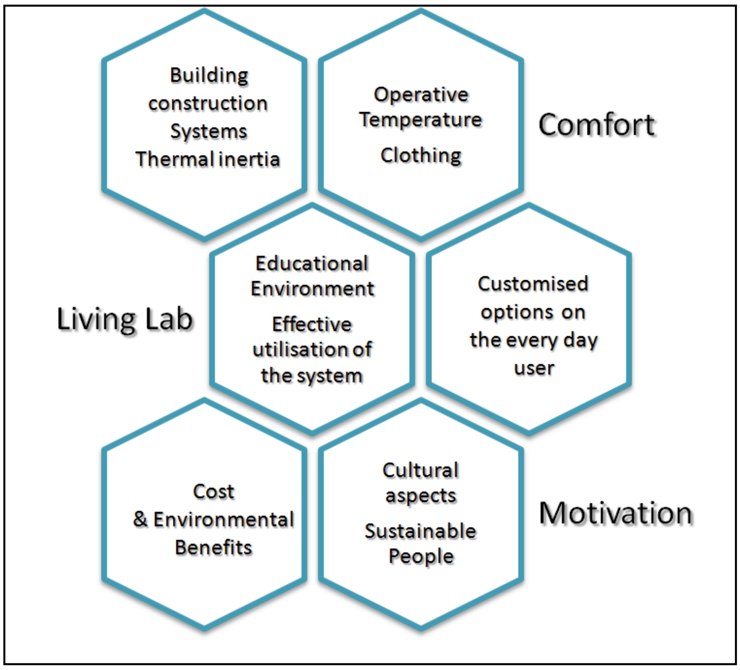


Figure 32: Summary of the main topics discussed at the FOCUS GROUP

4 Control

Control strategies must be tailored to the applied system in order to guarantee stability, be energy and cost efficient and satisfy users' needs. This is a very challenging issue as strategies must often control and coordinate distributed energy resources by taking into account variables difficult to be reliably predicted such as users load and renewable energy production. This section addresses the demand response strategy and thermal internal comfort analysis applied in Technical University of Crete and National University of Singapore respectively.

4.1 Demand Response in K1 Building of Technical University of Crete

4.1.1 Introduction

EU has developed an initial legislative framework for Demand Response (DR) with the Electricity Directive (2009/72/EC), the Energy Efficiency Directive (2012/27/EU) and the Network Codes. To increase shareholder engagement in demand response the Energy Efficiency Directive is calling on Member States to remove barriers in transmission and distribution putting demand response participation at risk. Main barriers that need to be overcome before we can expect to see the wide-scale implementation of demand response solutions are (16):

- Absence of transparent, efficient and commercially attractive regulatory framework for the role of key stakeholders in the energy markets including demand aggregator business models.
- Lack of consumer trust and resistance to participating in demand response schemes.
- Deployment of smart meters and smart applications for engaging various categories of power consumers.
- Economic barriers related to the need for leveraging investments in the technical upgrade of power and communications infrastructure of the

utilities, distribution network, microgrids, buildings, etc. in order to allow full exploitation demand response capabilities.

In order to overcome the aforementioned barriers existing efforts and successful projects should be put in a completely different perspective. Smart metering with IP connectivity have been already successfully exploited in previous projects such as Green@Hospital (www.greenhospital-project.eu) and ICE-WISH (17). Already developed Web based Energy Management & Control Systems (EMCS) should be further exploited in various building categories with a priority in large buildings. Smart systems and control algorithms for energy load prediction and shaping in small communities are ready to be integrated in the future energy grids (18), (19). Moreover, preliminary aggregator algorithms with real time energy management systems have been defined and tested within controlled lab tests (20) (21).

All the above are supported by the evolution of smart grids which through the incorporation of innovative Information and Computer technologies (ICT) will allow two-way communication between utilities and customers/users. It is evident that the electrical power grids are being transformed to become more efficient and resilient — therefore, “smarter” — than the conventional power grids. The smartness is focused not only on elimination of black-outs, but also on making the grid greener, more efficient, adaptable to customers’ needs, and therefore less costly (16) (22) .

Smart Grids open the door to new applications with far-reaching inter-disciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart buildings and distributed generators into the network; delivering power more efficiently and reliably through demand response, comprehensive control and monitoring capabilities; enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market.

Smart grids entail a more pervasive technology that influences the daily life of users. Although they have not been actively involved in previous grid innovations, the role of users in the future energy system is critical (23). Smart meters, intelligent platforms and software apps will provide the basis for the information exchange that will enable various categories of electricity consumers become also producers, so called prosumers, effectively managing their own energy production and consumption.

Various methodologies have been applied to investigate the potential application of demand response in different countries, customers and environments. Demand Response allows energy consumers and producers to interact with the power grid in real time. Some of the most crucial potential benefits of Demand Response are associated to the increased stability of the power network, efficiency of operations, RES penetration, environmental performance as well as minimisation of energy and investment costs. As the literature in this field is rapidly expanding in breadth and depth an extensive review is out of the scope of this work. However a brief description of a limited number of distinct related publications is provided as a hint of the advances related to the specific area of interest.

Bartusch et al (24) investigated the potential of residential demand response programs in Swedish family homes based on a time-of-use electricity distribution tariff. The implemented approach involved a model of the absolute and relative change in electricity consumption, shift in adjusted electricity consumption and maximum demand between peak and off-peak hours, relative change in the shape of demand curves representing weekdays and weekends and diversified demand. The results indicated significant reductions in demand at times of stress for the local power grid and variations between the home categories assessed related to uneven communication efforts engaging residents in DR.

In addition, Motegi et al (25) published a framework for DR strategies that have been tested in commercial buildings. Strategies and techniques emphasise in HVAC for air-conditioning and ventilation but also include lighting systems, miscellaneous equipment and non-component specific control. HVAC strategies such as global temperature adjustment and systemic adjustments to air distribution / cooling systems etc. are thoroughly presented based on system applicability, DR approach, sequence of operation, energy saving potential, rebound strategies, cautions and applied sites.

Park et al (26) proposed a model of self-organizing map (unsupervised learning feedforward neural network) and K-means clustering data mining techniques for customer baseline load estimation in demand response management aimed at quantifying demand reduction and verifying performance. Lower error rates were demonstrated compared to various day matching techniques by exploiting residential consumption of three cities.

Moreover, Bartholomew et al (27) performed a comparison of the various methodologies concerning the impact evaluation and verification of demand response. Baseline methodologies such as day matching, previous days approach, average daily energy usage approach, proxy day approach, adjustment and regression methods have been explored. Authors argue that such techniques can provide baseline load curves valuable in evaluating and verifying hypothetical loads in the absence of a DR event.

Coughlin et al (28) applied various Baseline Load Profiles (BLP) to a sample of buildings to test their accuracy for evaluating load reductions in different DR schemes and such an analysis considers averaging and explicit weather models. A key finding in this study was that a morning adjustment factor could improve verification performance in weather sensitive commercial and institutional buildings. In addition it is demonstrated that for buildings with low variability most BLP models perform reasonably well. In contrast it is argued that buildings with high variable loads are difficult to characterise and therefore applying generic BLP models in such cases may not provide satisfactory results. Instead it is proposed that such customers may be given the option to enrol in a DR contract establishing a guaranteed load drop or reduction to a given firm service level.

Addy et al (29) analysed the effect of different modelling aspects on shed estimates. Weather data source, resolution of data, methods for determining building occupancy, alignment of building power data with temperature and power outage filtering were assessed. Shed estimates have been found to be particularly sensitive to outdoor air temperature data and therefore any baseline analysis is highly dependent on the availability of high quality weather data. In addition it was observed that predictions are sensitive on data filtering to flag and remove marginal data and therefore this is considered an essential step to avoid discrepancies. Another important outcome of this analysis is that shed estimates are not sensitive to building demand resolution up to one hour.

Finally, Panapakidis et al (30)proposed a methodology for pattern recognition of electricity load curve analysis of buildings using clustering techniques utilising a university campus as case study. The methodology was applied in nine buildings of the AUTH University using representative load curves and revealed significant margin for improvement in terms of energy consumption and efficiency.

The building that was used as a case study for the Smart Gems project is decided and described in detail in the following section. This building is part of the School of Environmental Engineering of Technical University of Crete.

At a previous stage significant research has been carried out to develop and optimize energy management in K1 with the aid of decentralized monitoring and control equipment as well as by integrating advanced optimization and control algorithms. Since Universities' campuses and campus buildings can be viewed as small districts and microgrids, TUC has started the implementation of a coherent strategy to integrate all buildings under a common energy and indoor environment management platform.

The overall procedure requires collection of data for the energy consumption as well as for the indoor environmental quality. The monitoring activities for TUC buildings with emphasis on K1 building are included in Section 3. The energy consumption and indoor environmental quality are evaluated using a validated 3D building energy model. A demand response optimisation approach is presented and tested based on initial simulation results. Conclusions and future research can be found as well.

4.1.2 Methodology

General description of the building

The building under study is one of the four buildings of the Environmental Engineering School of Technical University of Crete Campus (figure 62).

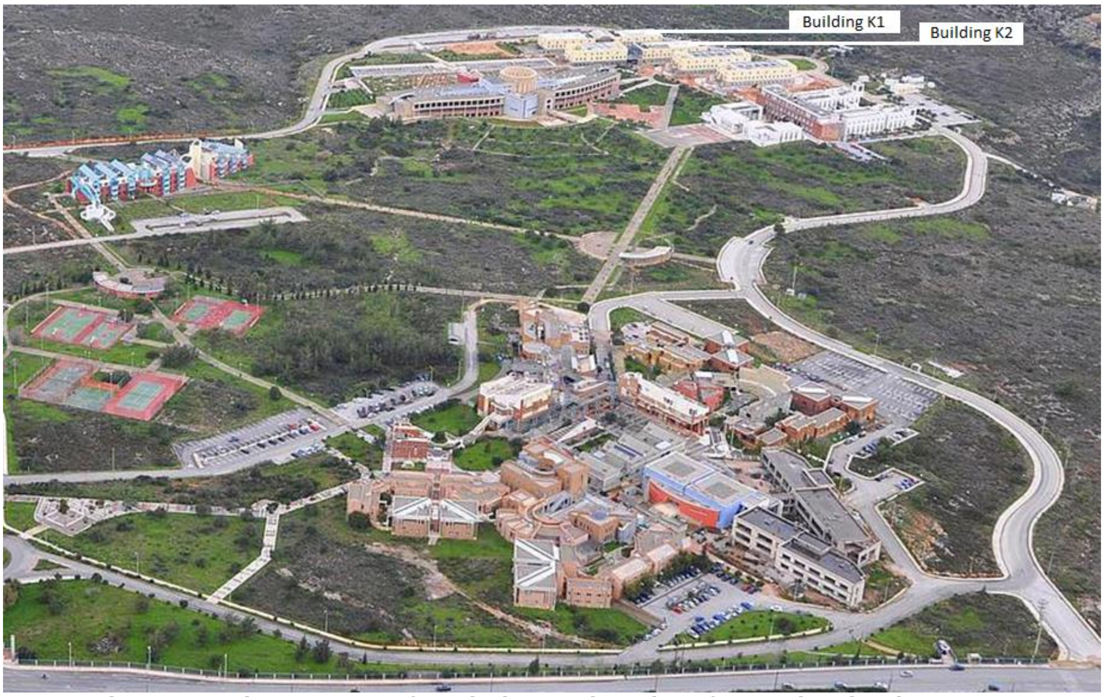


Figure 33: The campus of Technical University of Crete in Chania, Greece

The K1 building's location is pinpointed in figure 63 where buildings K2, K3, and K4 are also shown.

Figure 34: School of Environmental Engineering Buildings

Building Envelope and Systems

Climate zone	Mediterranean
Year of construction	2002
Building utilization i.e. residential, office, commercial, industrial etc.	Offices, Laboratories and Class rooms
Building occupancy schedule	09:00-16:00
Energy Utility	HEDNO S.A.
Energy tariffs (€/kWh)	0.06428 €/kWh - 07:00-23:00 working days during the year 0.05062€/kWh - 23:00-07:00 working days, weekends and official holidays
Gross floor area (m^2)	3167 m^2 (2032 conditioned & 1135 non conditioned)
Net floor area (m^2)	-
Number of storeys	3 (the 3rd floor contains the electromechanical equipment of the building)
Architectural plans or 3D images of the building	Attached at the end of this document
Building envelope description (i.e. wall – roof – floor structure, type of façade, percentage of window to wall area, roof type, etc)	The construction is a combination of concrete and metal. Specifically, the ground floor is made of concrete while the second floor has metal framework and cement plates as external walls. The building is insulated and double glazed.
HVAC System (kW)	The building is serviced by FCU systems with thermostats available in each room. 3*14.92 kW and 1*7.46kW VRV inverter heat pumps
Lighting System (kW)	1580*T18 lamps - 28.44kW total power
DHW System (kW)	11 solar collectors of 1.8m^2 each, boilers of 800lt and 600lt and electric heater 8kW each
Energy Management & Control System	2 different BEMS are used in the building. The first is used for controlling cooling and heating while the second for lights, fire systems and elevators • Multi-zone monitoring of temperature (°C), relative humidity (%), presence, CO_2 concentration (ppm), illuminance (lux), status of doors and windows (0-1), electrical energy consumption (Wh, W, A, V) • Energy management based on advanced HVAC genetic algorithms optimisation with load

	prediction based on neural network models and fuzzy logic techniques • IP remote access
Current state of repair and year of last major renovation of building envelope and main technical installations respectively	The building is fairly maintained but has not been upgraded considerably in terms of energy performance during the recent years.

Energy Data

Estimated average annual consumption of electrical energy over the last 3 years (kWh)	136 kWh/m^2
Measured average annual consumption of electrical energy and other type of fuels over the last 3 years (kWh)	276.000 kWh
Peak Load (kW)	100kW

Energy Generation and Storage Data

Energy generation by RES or other system connected to the building	PV 3kWp 14 panels Silcio SE 210W, Inverter SMA Sunny Boy 3000TL, Sunny Sensorbox, Sunny Webbox
Electrical storage	N/A
Thermal storage	N/A

4.1.3 Demand Response modelling approach

As fundamental input in this work, the validated thermal model in Open Studio / Energy Plus of K1 building of the campus in Technical University of Crete (fig.64) which was created in the framework of the Camp IT project (www.campit.gr), was exploited.

The 3D model of K1 buildings is presented in Figure 3964 below.

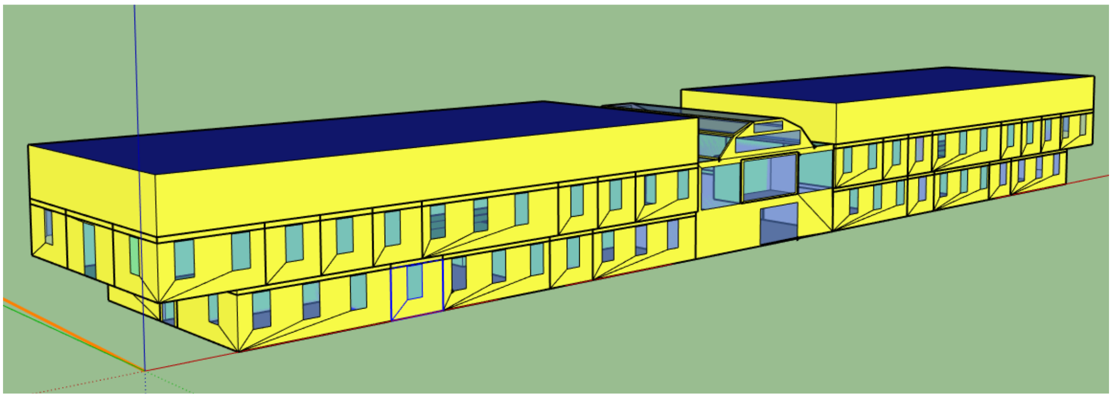


Figure 35: K1 building 3D Open Studio model

In this research work a initial demand response approach is developed and presented to highlight the potential benefits of energy and HVAC management primarily from a financial point of view. Developing and implementing energy management techniques from a demand response perspective provides the basis for realistically addressing energy cost savings. For the aims of this study, a validated model of K1 building at the Technical University of Crete based on indoor and outdoor measurements was used. Minimization of the annual total cost of energy is exploited as the major criterion of the optimization. Modelling the cost of energy involved an analysis of the various cost domains:

Energy consumption tariffs

- Maximum Power demand
- Power quality
- Transmission of energy
- Distribution of energy
- CO_2 rights
- Specific tax for emissions reduction
- Services of general interest
- Other costs

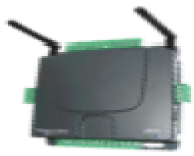
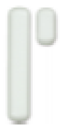
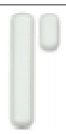
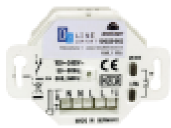
The cost of energy profile has been modelled according to the actual energy pricing profile obtained by the specific medium voltage pricing scheme for the Technical University of Crete campus.

Matlab was used to import data concerning power loads from Energy Plus and perform the necessary transformations and calculations for obtaining energy and power related costs. Validating the energy cost model was implemented using the energy bills issued by HEDNO SA for the university campus during the whole of 2015. The model of energy cost was adjusted to keep certain factors constant as they depend on externalities i.e. energy market operations the volatility of which are out of the scope in this work.

Monitoring Activities for K1 building

In K1 building a number of sensors and smart meters are installed. The monitoring equipment is tabulated in table 25. The sensors ‘position around the building spaces and floors is depicted in figure 65-66.

Table 8: The monitoring equipment of K1 Building

Description	Quantity	Image
Multi-Purpose Manager	8	
Room controllers (Temperature, Relative Humidity, Human Presence detection)	28	
CO_2 sensor	14	
Door magnetic switch	28	
Window magnetic switch	61	
CLC sensor (lux, presence detection)	14	
Wireless relay switch for lighting	28	
Autonomous sensor of presence / movement	23	

Electrical energy meter iEM3150	1	
Electrical energy meter iEM3350	11	
Electrical energy meter iEM3250 & current transformers	1	
Modbus RTU to Modbus TCP/IP EGX100	2	

Figure 36: Position of the sensors and actuators on the ground floor of K1 building

Figure 37: Position of the sensors and actuators on the 1st floor of K1 building

Energy cost model

For the purposes of this study the following variables were used as inputs to the energy cost model:

- Monthly energy consumption between 07:00-23:00 in working days during the year (E_A, kWh)
- Monthly energy consumption between 23:00-07:00 in working days, weekends and official holidays (E_B, kWh)
- Maximum Monthly Power Demand (P_{pk}, kW)

The objective function of the energy cost model is given by eq.4.11:

$$[min]g(E,P) = C_{E,t} \qquad (4.11)$$

The total cost of energy, $C_{E,t}$ is given by eq.4.12:

$$C_{E,t} = C_{E,P\_cns} + C_{adj} + C_{tax} \qquad (4.12)$$

C_{E,P_cns}, C_{adj} and C_{tax} are further calculated by eq. 4.13, 4.14 and 4.15 respectively:

$$C_{E,P\_cns} = C_{E\_cns} + C_{P\_cns} + C_{CO2} \qquad (4.13)$$

$$C_{adj} = C_{P\_tr} + C_{E\_dstr} + C_{g\_int} + C_{em} + C_{oth} \qquad (4.14)$$

$$C_{tax} = C_{SCT} + C_{5‰} + C_{VAT} \qquad (4.15)$$

The terms in eq.4.13 namely the cost of energy consumption C_{E_cns}, the cost of power demand C_{P_cns} and the cost of CO_2 rights, C_{CO2} are further specialised in equations 4.131, 4.132 and 4.133 respectively:

$$C_{E\_cns} = E_A C_{E_A} + E_B C_{E_B} \qquad (4.131)$$

$$C_{P\_cns} = C_{u\_P\_ch} P_{pk} \qquad (4.132)$$

$$C_{CO_2} = C_{u\_CO2\_ch}(E_A + E_B) \qquad (4.133)$$

Similarly terms in eq.4.14 and in specific the cost of transmitted power C_{P_tr}, the cost of energy distributed C_{E_dstr}, the cost for general interest services C_{gen_int}, the cost of the Specific Tax for the Reduction of Air Emissions (STRAE) C_{strae} and the cost for Other services C_{oth} are given by equations 4.141-4.145:

$$C_{P\_tr} = C_{u\_P\_tr\_ch} P_{pk} \qquad (4.141)$$

$$C_{E\_dstr} = C_{u\_dstr\_ch}(E_A + E_B) \qquad (4.142)$$

$$C_{g\_int} = C_{u\_g\_int\_ch}(E_A + E_B) \qquad (4.143)$$

$C_{strae}= C_{u\_strae\_ch}(E_A + E_B)$ (4.144)

$C_{oth}= C_{u\_oth\_ch}(E_A + E_B)$ (4.145)

Terms in equation 4.15 such as the Specific Consumption Tax (SCT) C_{SCT}, 5‰ Tax $C_{5‰}$and the cost of VAT C_{VAT} are provided by equations 4.151-4.153:

$C_{SCT} = C_{u\_SCT\_ch}(E_A + E_B)$ (4.151)

$C_{5‰} = 0.005\left(\left(C_{E,P_{cns}} + C_{adj}\right) - C_{STRAE} + C_{SCT}\right)$ (4.152)

C_{VAT}=0.13($C_{E,P_{cns}} + C_{adj} + C_{SCT}$) (4.153)

The model of energy cost was adjusted to keep certain factors constant as their variations mostly depend on externalities which are not taken into account in the framework of this work. Such factors are:

- Power charge rate equal to 7.1 €/kW (value of 7.1 €/kW and 6 €/kW in the period of study)
- Emissions charge rate equal to 0.00478€/kWh (value of 0.00478 €/kWh and 0.00595€/kWh in the period of study)
- Variable energy charge rate equal to 0.002873€/kWh (value between 0.0028383 and 0.0028995)
- cosφ equal to 0.99 (value between 0.99-0.999)
- Specific Tax for Reduction of Carbon Emissions per unit of energy equal to 0.01277€/kWh (value of 0.01230€/kWh and 0.01277€/kWh in the period of study)
- Transmission unit charge rate equal to 1.279 €/kW
- Distribution unit charge rate equal to 0.002873 €/kWh (yearly average)
- Other charges unit rate equal to 0.00044 €/kWh

C_{E,P_cns} : Monthly cost of energy consumption and maximum power demand C_{adj} : Monthly cost for adjustable charges C_{tax} : Monthly cost of various taxes C_{E_cns} : Monthly cost of energy consumption according to the different tarrifs C_{P_cns} : Monthly cost of maximum power demand C_{CO2} : Monthly cost of CO_2 emissions C_{P_tr} : Monthly cost of transmission of power C_{E_dstr} : Monthly cost of energy distribution C_{g_int} : Monthly cost of general interest services C_{em} : Monthly fare linked with investments in Renewable Energy technologies for the reduction of emissions C_{oth} : Other monthly costs C_{SCT} : Specific Consumption Tax $C_{5‰}$: Monthly Tax C_{VAT} : Monthly VAT cost E_A: Monthly energy consumption between 7:00-23:00 in working days during the year in kWh	E_B: Monthly energy consumption between 23:00-07:00 in working days, weekends and official holidays in kWh C_{E_A} : Unit energy charge rate for consumption between 7:00-23:00 in working days during the year (equal to 0.06428 €/kWh) C_{E_B} : Unit energy charge rate for consumption between 23:00-07:00 in working days, weekends and official holidays (equal to 0.05062 €/kWh) $C_{u\_CO2\_ch}$: Unit charge for CO_2 emissions per kWh in €/kWh $C_{u\_P\_tr\_ch}$: Unit cost for the transmission of power per kW in €/kW P_{pk} : Monthly maximum power demand in kW $C_{u\_dstr\_ch}$: Unit cost for the distribution of energy per kWh in €/kWh $C_{u\_g\_int\_ch}$: Unit cost for the general interest services per kWh in €/kWh $C_{u\_strae\_ch}$: Unit cost for STRAE per kWh in €/kWh $C_{u\_oth\_ch}$: Unit cost for the other costs per kWh in €/kWh $C_{u\_SCT\_ch}$: Unit cost for the SCT per kWh in €/kWh

4.2 Thermal Confort in the School of Design and Environment-3 at NUS

4.2.1 Introduction

The scope of the present work is to reveal the most appropriate energy management techniques for transforming an institutional building to zero energy building in the tropics. The various energy management and data driven techniques already available for transforming a building during its operational phase to a zero energy building are examined while the role of monitoring is revealed (19). Data driven techniques for building optimisation and control have been used in various buildings applications (31) (17). Neural networks are used in the present work as a tool to predict the energy loads of buildings in the tropics as well as the outdoor weather conditions, i.e. air temperature and relative humidity.

4.2.2 Methodology

The building used as a case study is part of the School of Design and Environment (SDE) in the NUS campus. Moreover, all SDE buildings are and under refurbishment while a new building (SDE4) is under construction.

Since Universities' campuses and campus buildings can be viewed as small districts and micro-grids, the SDE targets to integrate all buildings under a common energy and indoor environmental quality management platform.

The overall procedure requires collection of data for the energy consumption as well as for the indoor environmental quality, thus, the monitoring activities for all the NUS SDE buildings but with emphasis on SDE3 building are included in this report. The energy consumption and indoor environmental quality are evaluated and cross correlated. Prediction algorithms are tested using artificial neural networks.

4.2.3 Research activities is the Smart GEMS Project-Part I

4.2.3.1 Description of the SDE buildings

The building under study is one of the three buildings of the Design and Environment School (SDE) of National University of Singapore. The building's location is pinpointed in Figure 38. The other SDE buildings (SDE1 and 2 as well as the site for the SDE building under construction are also depicted in Figure 38.

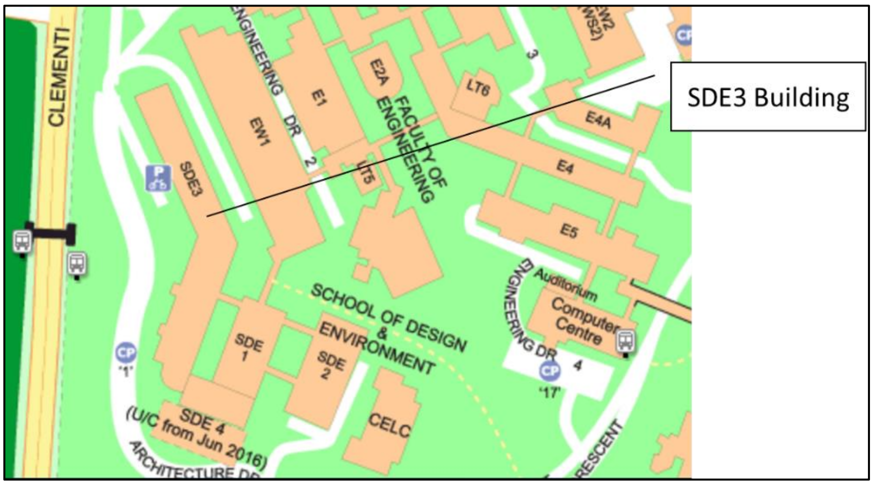


Figure 38: The SDE3 Building

Figure 39: The entrance and front elevation of SDE3

Building Envelope and Systems

Climate zone	Tropics
Year of construction	1970
Building utilization i.e. residential, office, commercial, industrial etc.	Offices, Laboratories and Class rooms
Building occupancy schedule	08:00-19:00
Energy Utility	
Energy tariffs (€/kWh)	
Gross floor area (m^2)	8680 m^2 (7946 m^2 conditioned & 734 m^2 non conditioned)
Net floor area (m^2)	-
Number of storeys	4
Architectural plans or 3D images of the building	Presented in the next section
Building envelope description (i.e. wall – roof – floor structure, type of façade, percentage of window to wall area, roof type, etc)	External Wall: 50 mm Gypsum + concrete +25 mm gypsum board Floor: 100 mm lightweight concrete + 150 mm concrete Interior wall: 25 mm Gypsum board + Wall Insulation +25mm Gypsum board
HVAC System (kW)	The building is serviced by FCU systems with thermostats available in each room. 3*14.92 kW and 1*7.46kW VRV inverter heat pumps
Lighting System (kW)	Fluorescent Lamps
DHW System (kW)	
Energy Management & Control System	

Current state of repair and year of last major renovation of building envelope and main technical installations respectively	The building is fairly maintained but has not been upgraded considerably in terms of energy performance during the recent years.

Energy Data

Estimated average annual consumption of electrical energy over the last 3 years (kWh)	N/A
Measured average annual consumption of electrical energy and other type of fuels over the last 3 years (kWh)	N/A
Peak Load (kW)	1250 kW BASED ON THE MEASUREMENTS

Energy Generation and Storage Data

Energy generation by RES or other system connected to the building	N/A
Electrical storage	N/A
Thermal storage	N/A

4.2.3.2 Monitoring Activities for SDE3

In the SDE3 building a number of sensors and smart meters are installed. The monitoring equipment is tabulated in Table 9. The sensors 'position around the building spaces and floors is depicted in figures 74-77.

Table 9. The monitoring equipment of SDE3 Building

Environmental parameter	**Sensor**	**Specifications**		
		Range	Accuracy	Resolution

Temperature & Relative Humidity	Sensirion SHT75	-40 to 123.8 ^{o}C	±0.3 ^{o}C (@25 ^{o}C)	0.01 ^{o}C
		0 to 100% RH	±1.8% RH	0.03% RH
CO_2	K-30, CO2 Meter Inc.	0 to 5000 ppm	±30 ppm + 3% of measured value	-
Illuminance	ROHM B17xx series	0 – 65,000 lx	-	1 lx

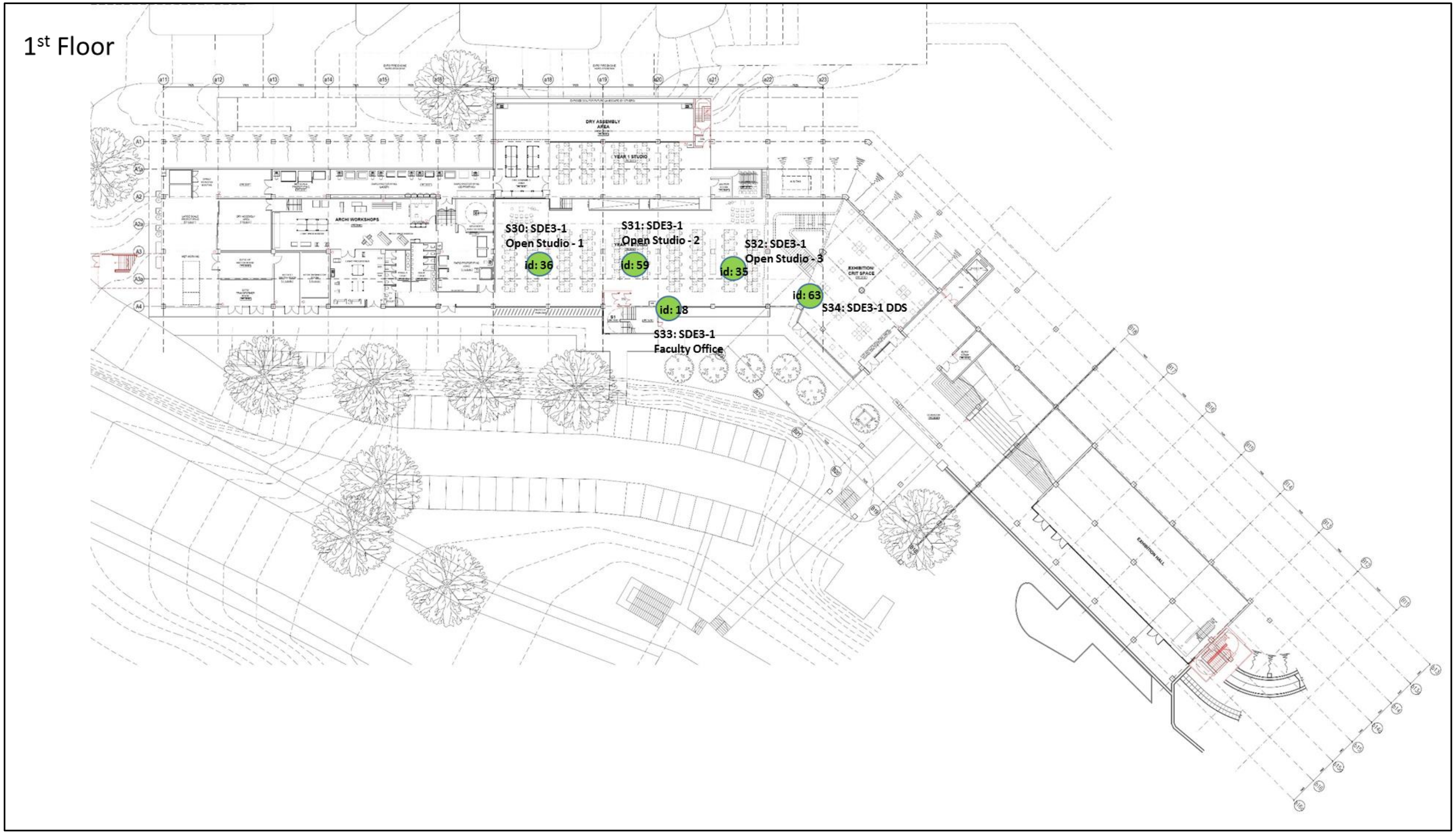


Figure 40: The position of sensors in the 1st Floor of SDE3

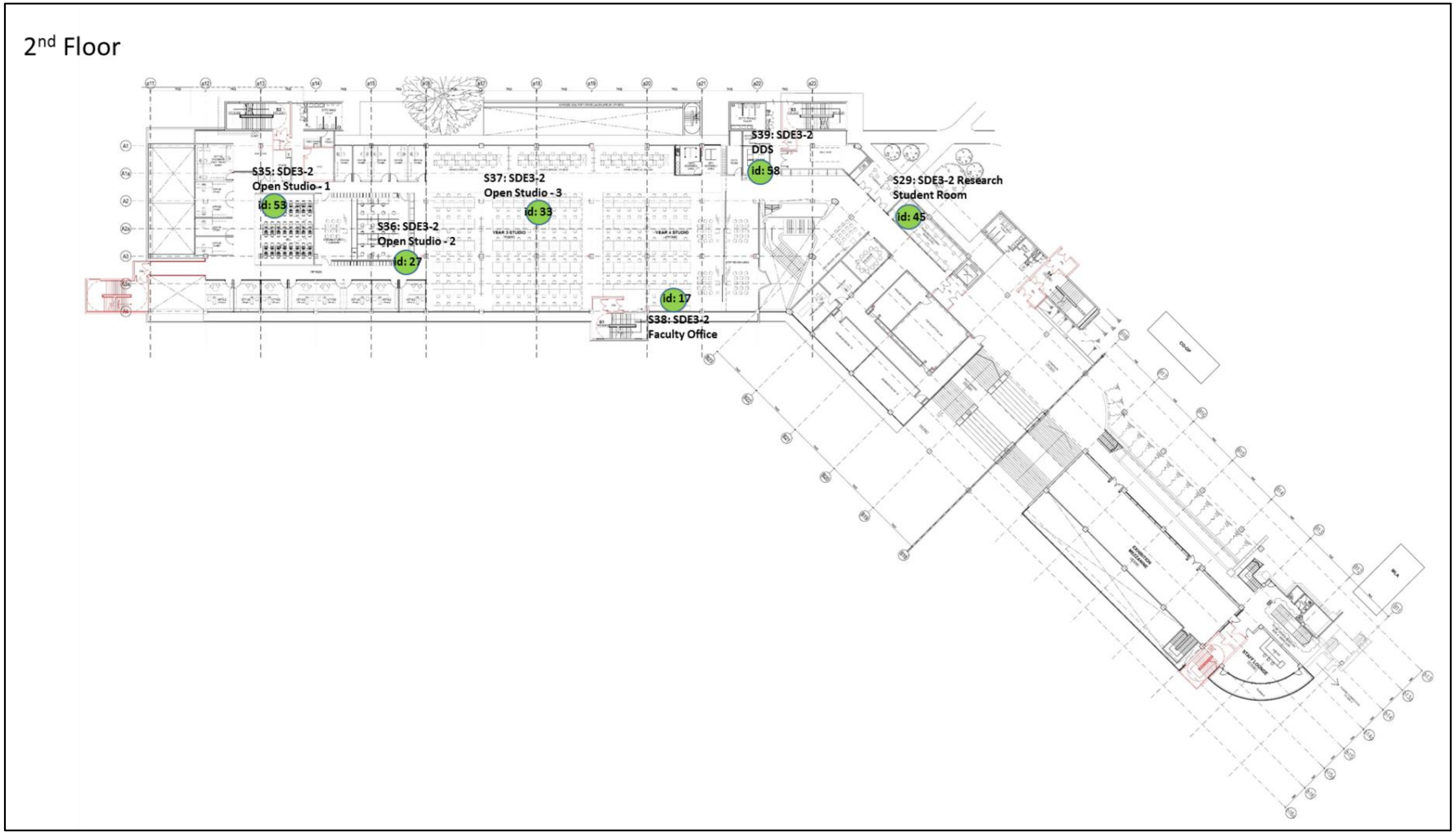


Figure 41: The position of sensors in the 2nd Floor of SDE3

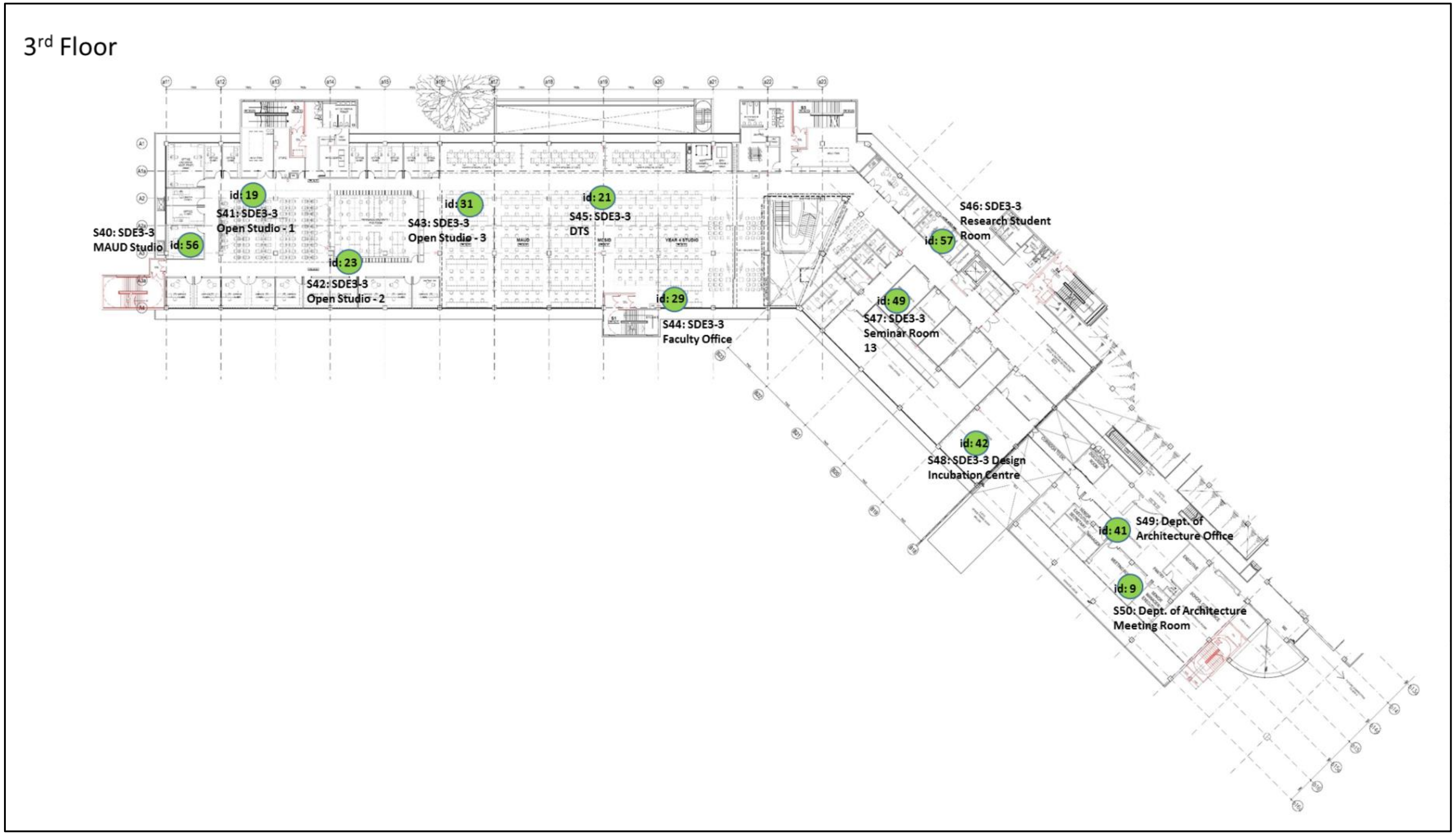


Figure 42: The position of sensors in the 3rd Floor of SDE3

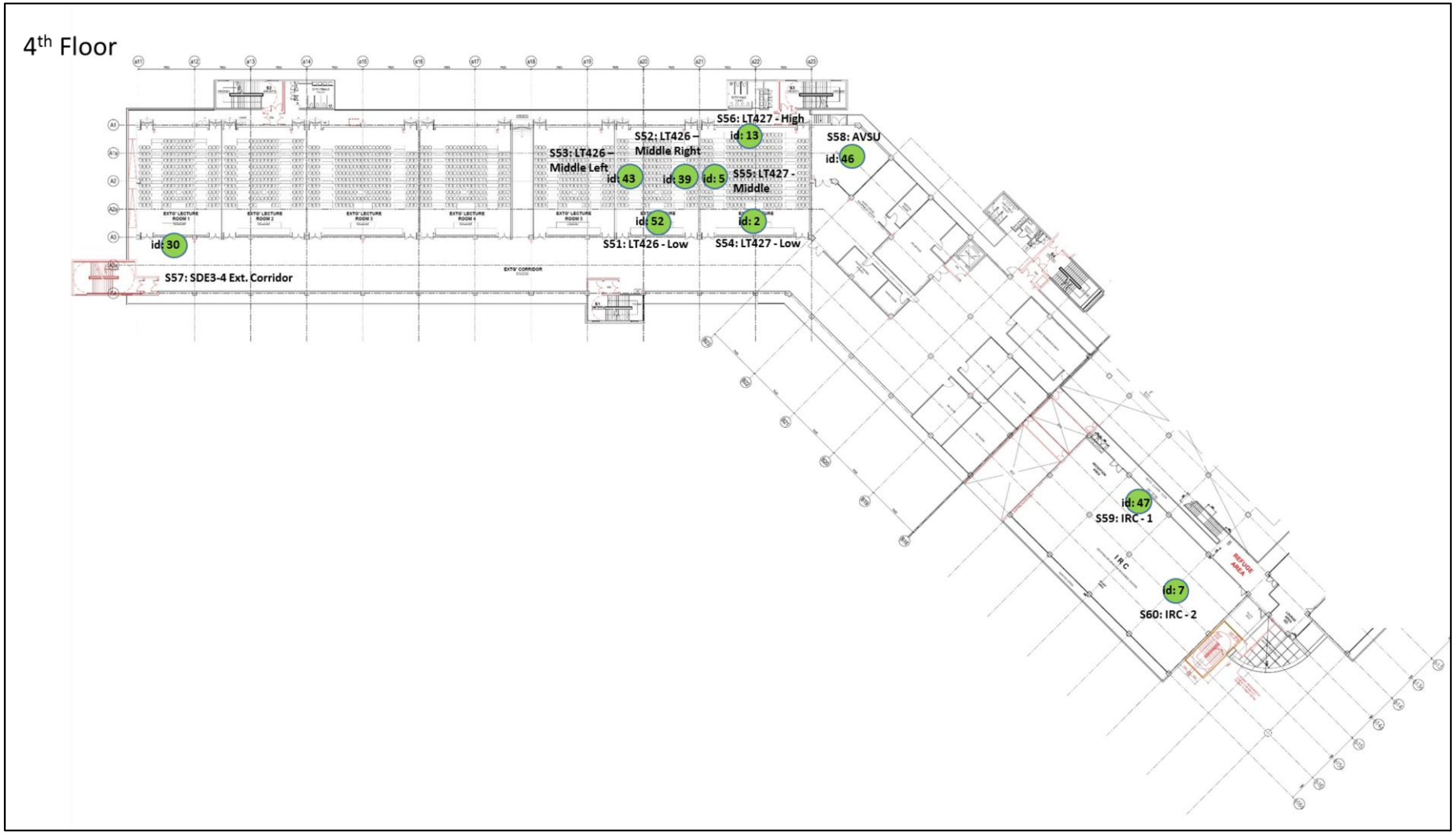


Figure 43: The position of sensors in the 4th Floor of SDE3

4.2.3.3 The scope of the integrated internet based energy management for SDE

During the last decades the role of Information and Computer Technology (ICT) for energy efficiency has gained a significant attention with numerous applications (19). Simulation and application of artificial intelligence control techniques (such as fuzzy logic and artificial neural networks), has indicated that they have the potential to make significant energy savings in buildings (32) (33).

Regarding the University Campus buildings, the main challenge in the design of control systems is to find the balance between implementation costs, operation costs, energy consumption, indoor environmental quality, users' satisfaction and contribution to sustainable living. Intelligent Campuses are those involving environmentally responsive design, taking into account the surroundings and building usage, and enabling the selection of appropriate building services and control systems to further enhance the blocks of buildings operation with a view to the reduction of energy consumption and environmental impact over its lifetime (34).

In addition, sensors, actuators and interfaces are essential components for the successful implementation and real-time operation of a web based energy management system. The evolution of the specific components was quite rapid during the last decades leading to the intelligent buildings' concept derived from artificial intelligence and information technology.

Based on the above analysis, there is a considerable room for improvement and research potential in energy management for group of buildings in a Campus context, where different buildings and outdoor spaces are considered. The School of Design and Environment has three existing buildings (SDE1-SDE3) and one building under construction. The interconnection of the SDE buildings in an integrated web based energy and indoor environmental quality management system will provide a significant boost in the research potential of SDE by developing a Cluster of Living Labs.

To this end, the aim of the present section is to provide guidelines for the implementation of integrated energy management in SDE buildings.

4.2.4 Research Activity within Smart GEMS Project -Part II

4.2.4.1 The phases for the Internet based energy management system for SDE

The implementation of the internet based energy management system is split into the phases depicted in 96:

1. Changes and preparatory work in the existing Building Energy Management Systems
2. Wiring and power supply installation
3. Installation of controllers
4. Installation of sensors/actuators
5. Installation of electricity meters
6. Integration and testing

The hardware system operation is constantly monitored due to the fact that its characteristics may change in time. The hardware parts whose operational characteristics change mainly over time are the sensors. The computers, energy meters, HVACs, relays, cabling, etc. have self-diagnostic procedures for faulty operation and are monitored using the software.

The sensors operation drifts in time (a) due to dirt or dust deposited on the sensor, or (b) due to inherent degradation of the sensor behaviour. In the case of dirt, a regular annual maintenance is foreseen to restore the sensor's operation. To cope with the sensors' functionality degradation, a yearly recalibration of the sensors characteristic, using reference measurements, is applied. After the recalibration, the appropriate parameters in the control algorithm are adjusted accordingly.

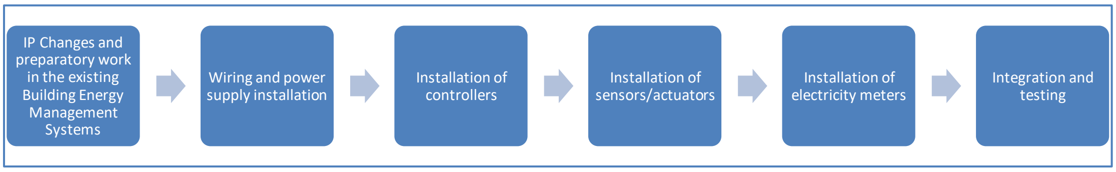


Figure 44: The phases of integrated energy management system implementation

The first phase includes the IP connectivity of HVAC system. An example of such connectivity is provided by the CampIT project (www.campit.gr) for the Technical University of Crete buildings. The HVAC is depicted in

Figure 45. A CS NET web is installed in order to achieve IP/Modbus connectivity of HVAC in Figure 46. The architecture before and after the installation of the internet based system is depicted in Figure 47. The list of possible devices needed is tabulated in Table 30. The communication

protocols among the various devices is illustrated in Figure 100. The key hardware infrastructure is the automation server and the multi-purpose controller. The automation server can act as a standalone server and also control I/O Active Directory Domains. It operates over TCP/IP protocol and supports Bacnet / Lonworks and Modbus protocol (http://www.smarterbuildingtech.com/smartstruxure-universal-input-module-sxwautsvr10001.html).

The second device is the multi-purpose Controller. This controller provides:

- Ethernet connector for BACnet Ethernet/IP
- 802.15.4 wireless mesh (25 nodes/network)

As well as it supports:

- BACnet, EWS, oBIX, FTP
- EnOcean (wireless)
- ZigBee Pro (wireless)
- Modbus
- CANbus

The MPM controller is a device that allows flexibility in the overall connectivity supporting various communication protocols. Although in TUC Campus the ZigBee Pro is selected, other protocols are supported by the multi-purpose controller.

Figure 45: The HVAC system of TUC

Figure 46: The CS NET WEB

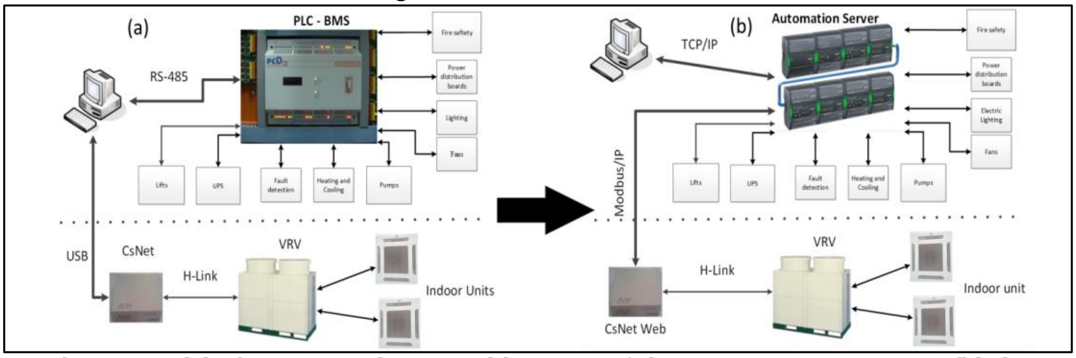


Figure 47: (a) The conventional architecture of the energy management (b) the integrated internet based architecture

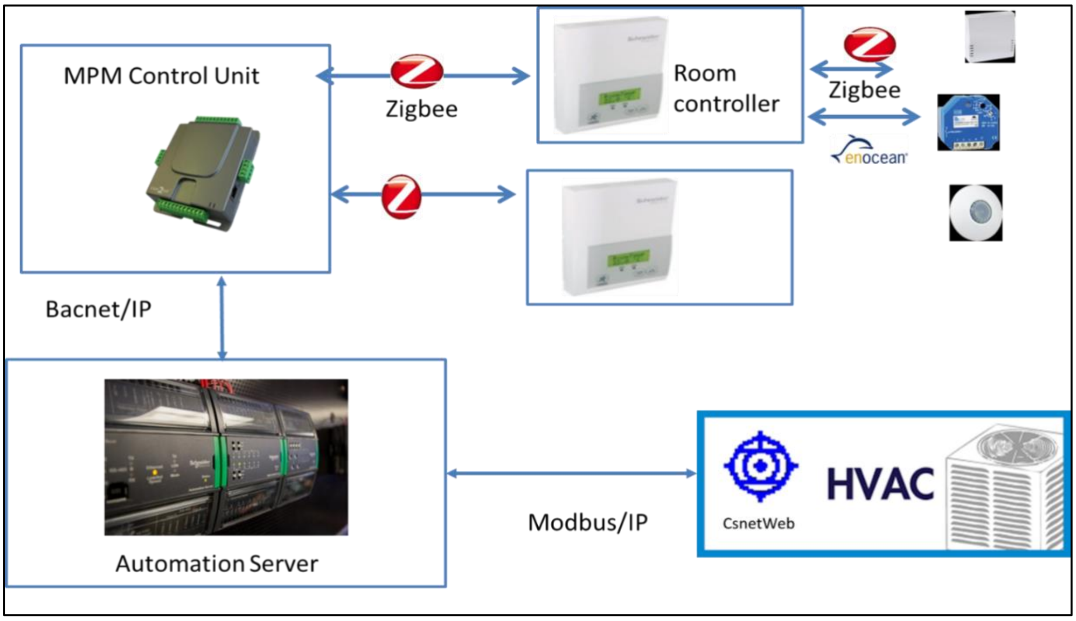


Figure 48: The communication protocols among the various components

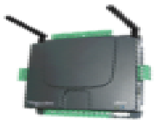
The second phase includes the necessary wiring and power supply as depicted in Figure 49.

Figure 49: The wiring and transformers' installation

The next phases require the installation of the multi-purpose controllers, the room controllers and the actuators. The installation of the multi-purpose controller in TUC is depicted in Figure 50.

Figure 50. The installation of multi - purpose controller

Table 10: An indicative list of devices for the integrated energy management

Description	Picture
Multi-Purpose Management device (MPM) enables the control, monitoring, and management of entire sites. They can also be used for wired and wireless zone control in larger buildings.	
Room controllers (temperature – relative humidity, presence detection sensors)	
CO_2 concentration measurement	
Wireless Door Switches	
Wireless Window Switches	
The sensor SLR 320 converts the illuminance measurement (lux) in 4-20mA or 0-10V.	
Remote switches	
Presence detector which detects human presence in a range of angles from 0 to 360 degrees versus the horizontal plane and with maximum radius of the 7m. ARGUS	
Electricity meter iEM3150	
Electricity meter iEM3155	

Electricity meter iEM3350	
Electricity meter iEM3250 + current transformation	
Modbus RTU to Modbus TCP/IP EGX100 Gateway	

4.2.4.1.1 Integration of software and prediction algorithms

The integration of the various algorithms can be done either using BCVTB test bench or by programming the multi-purpose controller.

The Building Controls Virtual Test Bed (BCVTB) is a software environment that allows users to couple different simulation programs for co-simulation, and to couple simulation programs with actual hardware. For example, the BCVTB allows to simulate a building in EnergyPlus and the HVAC and control system in Modelica, while exchanging data between the software as they simulate. The BCVTB is based on the Ptolemy II software environment. The BCVTB allows expert users of simulation to expand the capabilities of individual programs by linking them to other programs. Due to the different programs that may be involved in distributed simulation, familiarity with configuring programs is essential. BCVTB can provide links among:

- the EnergyPlus whole building energy simulation program,
- the Modelicamodeling and simulation environment Dymola,
- Functional Mock-up Units (FMU) for co-simulation and model-exchange for the Functional Mock-up Interface (FMI) 1.0 and 2.0,
- the MATLAB and Simulink tools for scientific computing,
- the Radiance ray-tracing software for lighting analysis,
- the ESP-r integrated building energy modeling program,
- the TRNSYS system simulation program,
- the BACnet stack, which allows exchanging data with BACnet compliant Building Automation System (BAS),

- the analog/digital interface USB-1208LS from Measurement Computing Corporati (38)on that can be connected to a USB port.

The second option is to program the multi-purpose controller using for example Lua programming environment. Lua is a programming language which can be embedded in different platforms. Lua is also based on ANSI C.

Prediction using artificial neural networks (ANN)

Various types of ANN have been developed and tested for the prediction of energy loads as well as the weather conditions (39) (40).

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. The central processing component of a neural network is a neuron, which can process a local memory and can carry out localized information. Each neuron computes a weighted sum of the inputs it receives and adding it with a bias (b) to form the net input (x). The bias is included in the neurons to allow the activation function to be offset from zero,

$x = w_{1,1} \cdot p_1 + w_{1,2} \cdot p_2 + ... + w_{1,j} \cdot p_j = b$ (Eq 4.22)

The net input (x) is then passed to the subsequent layer through a non-linear sigmoid function to form its own output:

$$y_j = \frac{1}{1+e^{-x}}$$

Afterward, the output y_j was compared with the target output t_j using an error function of the form:

$$\delta_\kappa = (t_j - y_j) y_j (1 - y_j)$$

For the neuron in the hidden layer, the error term is given by the following equation:

$$\delta_{\ j} = y_j (1 - y_j) \sum \delta_\kappa w_k$$

where δ_κ is the error term of the output layer, and w_κ is the weight between the hidden layer and output layer (41).

For the SDE3 building, it is considered that the prediction of outdoor relative humidity together with the outdoor air temperature can provide some insights on the energy loads required to maintain indoor comfort. The nonlinear autoregressive network with exogenous inputs (NARX) is used for the specific case. NARX is a recurrent dynamic network, with feedback connections enclosing several layers of the network. The NARX model is based on the linear ARX model, which is commonly used in time-series modeling. The Levengerg-Marquardt training algorithm is used.

5 Conclusions

This work have illustrated what is going to be compelling in the integration of ZEBs and NZEBs with smart grids:

I. Components, i.e., smart meters.
II. Services, such as, analysis of the energy consumption and developing solution for RESs, user engagement, and internal thermal comfort.
III. Control aimed to implement the most efficient control strategies.

Moreover, these analyses have been done and applied to different case studies:

1) Simulated residential building
2) Dorms
3) Office buildings
4) Residential Building
5) University Buildings

Components Outcomes

Results have demonstrated that meters and sensors from different brands can be connected in one common environment, i.e., a residential building. Communication is enable by dedicated protocol and a control unit collects all measurements and store them on a database. Control systems have, so, access to the measurement and, through tailored strategies, provide the optimal control signals to all the controllable energy systems connected.

The guaranteed interoperability addressed in this work is crucial as the actual market comprises different kinds of meters from various brands and they must be able to exchange information when integrated in a common smart-grid.

Services and Systems Outcomes

The increasing interests on RESs is often supported by economic analysis regarding revenues and PBP; in fact, such investments must be supported by future saving caused by the usage of the renewable energy introduced. This analysis have been done on the dorms of the University of Athens and the results illustrate that the PBPs is about 18 years; however, other solutions have been suggested such as storage systems.

Services have, then, included users' needs though thermal comfort and user engagement. The former has been addressed via survey in an office building, and results highlight that users are overall satisfied; it is worth noticed that the building considered is A+ energy efficiency, it has RES, it is connected to an industrial micro-grid and HVAC, lighting and shadings are fully automated.

With reference to the users engagement, a NZEB for residential use has been chosen as a case study. Meetings and questionnaires to the tenants, current and previous, have revealed that they are all willing to be more informed and engaged regarding how to energy savings behaviors.

Control Outcomes

Efficient control strategies have been tailored to university buildings: one in Crete and the other in Singapore.

In the former application, demand-response control have been developed and tested in simulation. While, the control strategies developed and applied at the building in Singapore have guaranteed internal comfort.

It is worth mentioned that the majority of the application proposed in this work have been done by using a web-based energy management system for monitoring, hence, collect data from the meters, and, then, implement the developed control strategies.

6 References

1. *The role of smart grids in the building sector.* **Kolokotsa, Denia.** s.l. : Energy and Buildings, 2015, Vol. Dec.
2. *Energy-Efficient Computing and Networking.* **Nikos Hatziargyriou, Aris Dimeas, Thomai Tomtsi, Anke Weidlich.** Revised Selected Papers, E-Energy, Athens : s.n., 2010, Vol. First International ICST Conference.
3. *Smart grid technologies: Communication technologies and standards.* **V. C. Güngör, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati, and G. P. Hancke.** pp. 529-539, s.l. : IEEE Transactions on Industrial Informatics, 2011, Vol. 7.
4. *Smart Grids: from innovation to deployment.* **Jimenez, M. Sanchez.** s.l. : European Commission, 2011, Vols. pp. 1-6.
5. *Performance measurement protocols for commercial buildings.* **ASHRAE/CIBSE/USGBC.** Atlanta : American Society of heating, Refrigeration, and Air Conditioning Engineers, 2010.
6. *Thermal environmental conditions for human occupancy.* **ASHRAE, ANSI/ASHRAE.** Atlanta : American Society of Heating, Refrigeration and Air-Conditioning Engineers, 2004.
7. *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.* **15251:2007, CEN EN.** Bruxelles : European Standardisation Organisation, 2007.
8. *Ergonomics of the Thermal Environment - Analytical Determination and Interpretation of Thermal Comfort UsingCalculation of the PMV and PPD Indices and Local Thermal Comfort Criteria.* **ISO, BS EN ISO 730:2005.** s.l. : Iinternational organization for standardization, 2005.
9. *Smart Meters and Consumer engagement.* **Action, Concerted.** 5/3.6, s.l. : Executive Summary, 2015, Vol. 3.
10. *The British public's perception of the UK smart metering initiative: Threats and opportunities.* **K.Buchanan, N.Banks, I. Preston, R.Russo.** 87-91, Corrigendum to : Energy policy, 2016, Vol. 91.
11. *What we do–and don't–know about the Smart Home:An analysis of the Smart Home literature.* **S.Solaimani, W.Keijzer-Broers,H.Bouwman.** 370-383, s.l. : Indoor Built Enviroment, 2015, Vol. 24 (3).
12. *Smart homes and their users: a systematic analysis and key challenges.* **C.Wilson, T.Hargreaves, R.Haxwell-Bauldwin.** s.l. : Pers. Ubiquitous Comput., 2014, Vols. 1-14.
13. *How to engage end-users in smart energy behaviour?* **P.Valkering.** s.l. : 3rd European Energy Conference, 2013, Vol. E2C.
14. *End-user engagement within innovative public procurement practices: A case study on public-private partnership procurement.* **H.Torvinen, O.Ulkuniemi.** 58-68, s.l. : Industrial Management, 2016, Vol. 58.
15. *The Common ICT-PSP Methodology for Impact Assessment.* **270898, Grant Agreement number.** s.l. : ICE-WISH Project.
16. *Smart Grid projects in Europe : Lessons learned and current developments 2012 update.* **C.F.Covrig, A.Mengolini.** 2013.
17. *Building Optimization and Control algorithms implemented in existing BEMS using a Web based Energy Management and Control System.*

S.Papantoniou, D.Kolokotsa, K.Kalaitzakis. s.l. : Energy and Building, 2014.
18. *Development of optimization algorithms for the Leaf Community microgrid.* **E.Provata, D.Kolokotsa, S.Papantoniou,M.Pietrini,A.Giovannelli,G.Romiti.** 782-795, s.l. : Renewable Energy, 2015, Vol. 74.
19. *A roadmap towards intelligent net zero- and positive-energy buildings.* **D.Kolokotsa, D.Rovas,E.Kosmatopoulos,K.Kalaitzaki.** 3067-3084, s.l. : Solar Energy, 3011, Vols. 85,12.
20. *Optimal Energy Management for a Residential Microgrid Including a Vehicle-to-Grid System.* **L.Igualada, C.Corchero, M.Cruz-Zambrano,F.J.Heredia.** 2163-2172, s.l. : IEEE Transactions on Smart Grids, 2014, Vols. 5, 4.
21. *Demand Aggregator Flexibility Forecast: Price Incentives Sensitivity Assessment.* **K.Kostis, I.Moschos,C.Corchero,M.Cruz-Zambrano.** s.l. : 12th INternational Conference on the European Market (EEM), 2015.
22. *The Smart Grid—State-of-the-art and Future Trends.* **M.E.El-hawary.** 239-250, 2014, Vols. 42,no 3-4.
23. *Smart grids or smart users? Involving users in developing a low carbon electricity economy.* **G.P.J.Verbong, S.Beemsterboer,F.Sengers.** 117.125, s.l. : Energy Policy, 2013, Vol. 52.
24. *Furhter exploting the potential of residential demand response programs in electricity distribution.* **C.Bartusch, K.Alvehag.** s.l. : Applied Energy, 2014.
25. *Introduction to comemrcial building control strategies and techniques for demand response.* **N Motegi, M.A.Piete, D.S.Watchon, S.Kiliccote, P.Xu.** s.l. : Demand Response Research Center, Lawrence Berkley National Laboratory, 2007.
26. *Data-driven baseline estimation of residential buildings for demand responde.* **S Park, S Ryu, Y.Choi, J.Kim, H Kim.** s.l. : Energies, 2015.
27. *Demand response measurement and verification:applications for load research.* **P. Bartholomew, W. Callender, C.Hindes, C.Grimm, K.Johnson, M.Straub, D.Williams, M.Williamson.** s.l. : AEIC, 2009.
28. *Estimating demand response load impacts:evaluation of baseline load models for non-residential buildings in California.* **K.Coughlin, M.A.Piette, C.Goldman, S.Kiliccote.** s.l. : Demand response research center, Ernest Orlando Lawrence Berkeley National Laboratory, 2008.
29. *Understanding the effect of baseline modelling implementation choices on analysis of demand response performance.* **N.Addy, J.L.Mathieu, S.Kiliccote, D.S.Callaway.** s.l. : Ernest Orlando Lawrence Berkely National Laboratory, 2013.
30. *Pattern recognition algorithms for electricity load curve analusis of buildings, .* **I.P.Panapakidis, T.A.Papadopoulos, G.C.Christofidis, G.K.Papagiannis.** 137-145, Power systems laboratory, Dep. of electrical and computer engineering,Aristotle University of Thessaloniki, Department of Electrical engineering, Technological education institute of western macedonia : Energy and Buildings, 2014, Vol. 73.
31. *orecasting energy consumption of multi-family residential buildings using support vector regression: Investigating the impact of temporal and spatial monitoring granularity on performance accuracy.* **R.K.Jain, K.M. Smith, P.J.Culligan,J.E.Taylor.** 168-178, s.l. : Applied Energy, 2014, Vol. 123.

32. *Modeling and predicting building's energy use with artificial neural networks: Methods and results.* **S.Karatasou, M.Santamouris, V.Geros.** 949-958, s.l. : Energy and Buildings, 2003, Vol. 38 (8).
33. *Genetic algorithms optimized fuzzy controller for the indoor environmental management in buildings implemented using PLC and local operating networks.* **D.Kolokotsa, S.G.Stavrakakis,K.Kalaitzakis,D.Agoris.** s.l. : Engineering, 2002.
34. *Development of a web based energy management system for unviersity Campuses:the Camp-IT platform.* **D.Kolokotsa, K.Gobakis,S.Papantoniou,C.Georgatou,N.Kampelis,K.Kalaitzakis,M.Santamouris.** 119-135, s.l. : Energy and Buildings, 2016, Vol. 123.
35. *Analysis of the summer discomfort index in Athens, Greece, for cooling purposes.* **I.Tselepidaki, M.Santamouris,C.Moustris,G.Poulopoulos.** 51-56, s.l. : Energy and Buildings, 1992, Vol. 18 (1).
36. *Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.* **7730, ISO.** 605-615, s.l. : Management, 2005, Vols. 3 (7-10).
37. *Thermal comfort of a typical secondary school building in Cyprus.* **M.C.Katafygiotou, D.K.Serghides.** s.l. : Sustainable Cities and Society, 2014.
38. *Performance analysis of a planted roof as a passive cooling technique in hot-humid tropics.* **S.Hodo-Abalo, M.Banna, B.Zeghmati.** 140-148, s.l. : Renewable Energy, 2012, Vol. 39 (1).
39. *Development of a model for urban heat island prediction using neural network techniques.* **K.Gobakis, D.Kolokotsa, A.Synnefa,M.Saliari, K.Giannopoulou, M.Santamouris.** 104-115, s.l. : Sustainable Cities and Society, 2011, Vol. J(2).
40. *Artificial neural networks for temporal processing applied to prediction of electric energy generation in small hydroelectric power stations.* **E.C.E.Joaquim, J.L.G.Rosa.** 2625-2630, s.l. : Proceedings of the International Joint Conference on Neural Networks, 2005, Vol. 4.
41. *Prediction of hourly and daily diffuse fraction using neural network, as compared to linear regression models. .* **H.Elminir, Y.Azzam, F.I.Younes.** 1513-1523, s.l. : Energy, 2007, Vol. 32(8).
42. **Ivan Korolijaa, Yi Zhanga, Ljiljana Marjanovic-Halburdb, Victor I. Hanbya.** *Regression models for predicting UK office building energy consumption from heating and cooling demands.* Elsevier : Energy and Buildings, 2012.
43. **Rongxin Yin, Emre C. Kara, Yaping Li, Nicholas DeForest, Ke Wang, Taiyou Yong, Michael Stadler.** *Quantifying flexibility of commercial and residential loads for demand response using setpoint changes.* Elsevier : Applied Energy, 2016.
44. **Emre Can Kara, Michaelangelo D. Tabone, Jason S. MacDonald, Duncan S. Callaway and Sila Kiliccote.** *Quantifying Flexibility of Residential Thermostatically Controlled Loads for Demand Response: A Data-driven Approach.* 2014.
45. *Development of a web based energy management system for University Campuses: The CAMP-IT platform.*

7 Appendices

7.1 Annex I

Descriptor	Values
Overall, how have you felt during the last 5 minutes?	3 = hot, 2 = warm, 1 = slightly warm, 0 = neutral, -1 = slightly cool, -2 = cool,-3 = cold
Is this feeling acceptable or not?	1 = Clearly acceptable, 2 = Just acceptable, 3 = Just unacceptable, 4 = Clearly unacceptable
How would you prefer to feel?	1 = warmer, 0 = no change, -1 = cooler
Which zone are you located in?	1 = Research for Innovation, 2 = Energy, 3 = Industry, 4 = Progettazione
What is your gender?	1 = Male, 2 = Female
At this moment are you located within 3 meters from an external window?	1= yes, 2 = no
For how long have you been sitting at your desk?	1 = less than 5 minutes, 2 = between 5-15 minutes, 3 = 15 minutes or more
Period of day	1 = Morning, 2 = Mid-day, 3 = Afternoon
Day of week	2 = Saturday, 3 = Sunday, 4 = Monday, 5 = Tuesday, 6 = Wednesday, 7 = Thursday, 8 = Friday
Orientation	1=NW, 2=SE
Floor level	0=ground floor, 1=first floor

7.2 Annex 2

a/a	Suggested wording of questions/options	Characteristics/Values
A – DEMOGRAPHICS, SOCIOECONOMICS [baseline and final stages; all tenant groups]		
A1	Including yourself how many people live in your home?	__________ people
A2	Gender (M/F) of each person in your household. [Select one description for each individual in your home] a. male b. female	Person 1:_____ Person 2:_____ Person 3:_____ Person 4:_____
A3	Age of each person in your household. [Select one description for each individual in your home] A. 0-14 B. 15-24 C. 25-49 D. 50-64 E. 65-79 F. 80+	Person 1:_____ Person 2:_____ Person 3:_____ Person 4:_____
A4	Approximately how long have you and your family lived in your current home?	___ Years ___ Months
A5	Please think of a representative weekday of your normal course of life. Which of the following statements best describes a representative weekday for each member of your household? [Please select one of the following for each member of your household.] a. at home most of the day and only out of home awhile short-term b. at home longer than half a day and few hours out of home c. at home half a day and out of home half a day d. less than half a day at home and mostly out of home e. at home only for sleeping at night	Person 1:_____ Person 2:_____ Person 3:_____ Person 4:_____
A6	How many weeks during the last 12 months was no one of your household at home (because of holiday, journeys or other reason)?	_____ weeks [Please fill in.]
A7	Approximately how many hours a day is your home empty?	___: hours on weekends ___: hours on week days [Please fill in]
A8	Select the description which most closely meets the education level of each individual in your home from the list below: a. no –school b. primary education c. lower secondary education d. upper secondary education e. Post-secondary non tertiary f. First stage of tertiary (university degree, bachelor, Masters or equivalent) g. Second stage of tertiary (Doctorate)	Person 1:_____ Person 2:_____ Person 3:_____ Person 4:_____

A9	Please indicate your household's net monthly household income. Please select the option that better suits your household from the list.	□ below 1000 € □ 1001-2000 € □ 2001-3000 € □ 3001-4000 € □ 4001-5000 € □ more than 5,000 € □ n/a
A10	What is the employment status of your household? [Select one description for each individual in your home] a. Full-time employed b. Part time employed c. Self-employed/working from home d. Retired e. Full-time student f. Unemployed g. Temporarily sick or injured h. Long term sick, injured or disabled i. Other	Person 1:_____ Person 2:_____ Person 3:_____ Person 4:_____
B- PSYCHOLOGICAL, SOCIAL AND BEHAVIORAL ASPECTS [baseline and final stages; all tenant groups]		
B1	During which months is the heating on in your home?	□ Jan □ Feb □ Mar □ Apr □ May □ Jun □ Jul □ Aug □ Sep □ Oct □ Nov □ Dec □ Don't know
B2	How is your home heated? [Mark all that apply.]	□ Central heating **--> Go to question B4** □ Separate heating devices **--> Continue with question B3**
B3	Which of the following separate heating devices do you use? [Mark all that apply.]	□ Oil filled radiator □ Electric fan heater □ Gas/electric fire □ Wood burning fire □ Wood burning stove □ Other □ Don't know
B4	During the coldest months of the year, approximately how many hours a day is the heating on in your home?	___: hours on week day [Please fill in] ___: hours on weekend day [Please fill in] □ Don't know

B5	When you are too cold in your home, what do you do to keep warm? [Mark all that apply.]	□ Do nothing □ If not already on, turn on the heating system □ Increase the temperature on your main heating system □ Put on more clothes □ Use other heating devices (e.g. a portable fan heater) □ Other _____________________ [Please fill in]
B6	Does your home have air conditioning or any other cooling system?	□ Yes --> **Continue with question B7** □ No **--> Go to question B9**
B7	During which months is your home being cooled?	□ Jan □ Feb □ Mar □ Apr □ May □ Jun □ Jul □ Aug □ Sep □ Oct □ Nov □ Dec □ Don't know
B8	During the warmest months of the year, approximately how many hours a day is your home being cooled?	___: hours on week day [Please fill in] ___: hours on weekend day [Please fill in] □ Don't know
B9	When you are too hot in your home, what do you do to keep cool? [Mark all that apply.]	□ Do nothing □ Decrease the temperature on your main cooling system □ Wear less/thinner clothes □ If not already on, use the air conditioning system □ Use other cooling devices (e.g. an electric fan) □ Open window(s) □ Other _____________________ [Please fill in]
B10	Do you monitor the climate in your home in any way?	□ Yes □ No □ Don't know
B11	Please briefly explain what tariffs you are on?	_____________________ _____________________ [Please fill in] □ Don't know
B12	Approximately how many times per week are the following items used by anyone in your home?	Washing machine ___ Dish washer ___ Bath ___ Shower ___ [Please fill in]

B13	This section of the questionnaire is designed to find out about your attitude to different issues. Please consider each of the statements below, and indicate to what extent you agree with it. If you feel you a statement does not apply to you then please leave it blank. We are interested in your own personal opinion, there are not “right” or “wrong” answers. a. I sometimes find a tap dripping because it has not been turned off fully __ b. I often forget to unplug mobile phone chargers once the phone has fully charged__ c. When buying a new electrical appliance I consider its energy rating__ d. During the winter I have the heating on most of the day__ e. I recycle as much of my waste as I can__ f. I sometimes use wastewater generated from activities such as dishwashing, clothes washing and bathing for other household tasks__ g. Climate change is caused by energy use__ h. I leave my equipment on standby when I am not using it __ i. I rarely use my washing machine at 40°C or lower__ j. I use a lot of bottled water at home__ k. When the heating is on and it is too hot, I open my windows to cool my home__ l. I usually leave the taps running while I brush my teeth__ m. I always fully load the washing machine when I use it __ n. I think there is little I can realistically do to reduce how much energy I use__ o. I always turn the lights off in unoccupied rooms__ p. It’s not worth me doing things to help the environment if others don’t do the same __	1. Fully agree 2. Somewhat agree 3. Somewhat disagree 4. Fully disagree
B14	To what extent do you agree or disagree with the following statements? For each statement tick one box only. a. I think I should save more energy at home__ b. I think I should save more water at home__ c. In my opinion protecting the environment is a very important issue__ d. To ensure the decrease of carbon dioxide emissions is important for the protection of the environment__ e. I’m interested in my energy/water consumption at home__ f. I’m interested in possibilities of saving energy/water at home__ g. Energy and water conservation means I have to live less comfortably__ h. Energy and water conservation will restrict my freedom. i. I can reduce my energy/water use quite easily__ j. I know how I can save energy/ water__	1. I strongly agree 2. I rather agree 3. I neither agree nor disagree 4. I rather disagree 5. I strongly disagree 6. I don‘t know
C –INFORMATION LEVEL [different stages and tenant groups as indicated]		
C1	How informed do you feel about: a. the possibilities to protect the environment? __ b. the consumption of energy/water in your home? __ c. the possibilities of saving energy/water in your home? __	1. I feel very well informed 2. I feel fairly well informed 3. I feel neither well nor badly informed 4. I feel fairly badly informed 5. I feel very badly informed 6. I don‘t know
D– HEALTH AND COMFORT [baseline and final stages; all tenant groups]		

D1	Have you noticed any of the listed problems in any of the following rooms in the last 6 months? [For each item on the list mark all that apply] a) kitchen __ b) bathrooms(s) __ c) living room __ d) bedroom(s) __ e) other room(s) __	1. Condensation on windows/walls/ceiling 2. Damp* patches on walls/ceiling 3. Mould** on walls/ceiling 4. Mould on furniture, carpets or clothes 5. None of these problems in this room (*Damp is the presence of unwanted moisture in the structure of a building **Mould often appears as dark spots or patches on surfaces and is caused by a fungus)
D2	How would you describe the temperature in your home? [For each item on the list tick select one] a) in the winter__ b) in the summer__	1. Uncomfortably hot 2. Comfortably warm 3. Comfortable 4. Comfortably cool 5. Uncomfortably cold
D3	How would you describe the temperature in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Stable □ □ □ □ □ Varies b. Stable □ □ □ □ □ Varies
D4	How would you describe the temperature in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Satisfactory overall □ □ □ □ □ Unsatisfactory overall b. Satisfactory overall □ □ □ □ □ Unsatisfactory overall
D5	How would you describe the air movement in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Still □ □ □ □ □ Draughty b. Still □ □ □ □ □ Draughty
D6	How would you describe the air quality in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Stuffy □ □ □ □ □ Fresh b. Stuffy □ □ □ □ □ Fresh
D7	How would you describe the air quality in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Dry □ □ □ □ □ Humid b. Dry □ □ □ □ □ Humid
D8	How would you describe the air quality in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Odourless □ □ □ □ □ Smelly b. Odourless □ □ □ □ □ Smelly
D9	How would you describe the air quality in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Satisfactory overall □ □ □ □ □ Unsatisfactory overall b. Satisfactory overall □ □ □ □ □ Unsatisfactory overall
D10	How would you describe the natural light in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. No glare at all □ □ □ □ □ A lot of glare* b. No glare at all □ □ □ □ □ A lot of glare *Glare: when light, usually reflecting from a surface, is uncomfortably bright
D11	How would you describe the natural light in your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Satisfactory overall □ □ □ □ □ Unsatisfactory overall

		b. Satisfactory overall □ □ □ □ □ Unsatisfactory overall
D12	Taking each of the above factors into consideration, how would you describe overall comfort of your home? [For each item on the list tick one box only.] a) in the winter. b) in the summer.	a. Satisfactory overall □ □ □ □ □ Unsatisfactory overall b. Satisfactory overall □ □ □ □ □ Unsatisfactory overall
D13	Does anyone in your household smoke inside of your home?	□ Yes □ No
D14	Does anyone in your household suffer from any of the listed health issues? [Mark all that apply.]	□ Asthma or other chest/respiratory problems □ Stroke or other circulatory problems □ Rheumatism or other joint problems □ Requires the use of a wheelchair □ Eczema or other skin conditions □ Color blindness □ Allergies □ None of the above
D15	Who chooses the organization that provides you with <u>electricity</u>?	□ I choose, □ My housing provider chooses, □ I don't know who chooses
D16	Who chooses the organization that provides you with <u>water</u>?	□ I choose, □ My housing provider chooses, □ I don't know who chooses
D17	Who chooses the organization that provides you with <u>gas</u>?	□ I choose, □ My housing provider chooses, □ I don't know who chooses
D18	Who chooses the organization that provides you with <u>heating</u>?	□ I choose, □ My housing provider chooses, □ I don't know who chooses
E– LIVING SITUATION		
E1	Which electrical appliances do you use in your household	□ Fridge □ Freezer □ Microwave □ Oven □ Electrical heating □ Air conditioning □ Dishwater □ Washing machine □ Computer (e.g. desktop, laptop, iPad) □ Digital TV □ Games console □ Other ________________[Please fill in]
E2	Do you heat the bedrooms more, the same or less than your living space (living room, workroom and kitchen)?	□ More □ The same □ Less
E3	Which is the set point temperature during the day?	… in degrees Celsius
E4	How often do you reduce the room temperature during night manually?	□ Never □ Rarely □ Sometimes □ Often □ Always

E5	If you reduce the room temperature at night: At what temperature do you set the heating system at night?	… in degrees Celsius
E6	How and how often do you generally change the air in your household during the heating period? □ Allow ventilation (tilted window) ……minutes per day □ Open windows…………………. ……………minutes per day □ Electric ventilation system □ Yes □ No	
E7	How long do you or other members of your household generally shower?	□ less than five minutes □ between 5-10 minutes □ between 10-15 minutes □ more than 15 minutes □ don't know
E8	How often do all members of the household generally shower in a week?	…. times

The questionnaire was based on ICE-WISH EU Project, http://www.ice-wish.eu/uk/icewish.asp.The questions were adapted to be in line with the Leaf House service and Smart GEMS objectives.