BaaS
Building as a Service

**FP7-ICT-2011-6: ICT Systems for Energy Efficiency**
**Small or Medium-scale Focused Research Project**
**Grant Agreement No. 288409**

# Deliverable D1.1:

# Definition of Theoretical Case Studies including Key Performance Indicators

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## Deliverable Summary Sheet

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## Deliverable D1.1: Short Description

In this document, can be found the needed information that will be used as start point to develop other tasks within BaaS Project. They have been defined the required data for each building, the KPIs, the identified problems for each theoretical case studies within non-residential building sector and the requirements that BaaS System needs to solve these problems.

Keywords: Theoretical case studies, requirements, KPI

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## Abbreviations and Acronyms

| | |
|---|---|
| **APO** | Assess, Predict, Optimize |
| **AS** | Activity Scenario |
| **BaaS** | Building as a Service |
| **BIM** | Building Information Modelling |
| **BMS** | Building Management System |
| **BPIE** | Buildings Performance Institute Europe |
| **CDD** | Cooling Degree Days |
| **CSI** | Climatic Severity Indicator |
| **DWH** | Data Ware House |
| **EPB** | Energy Performance of Buildings |
| **EPI** | Energy Performance Indicators |
| **EPBD** | Directive on Energy Performance of Buildings |
| **ESCO** | Energy Service Company |
| **EXT** | External |
| **HDD** | Heating Degree Days |
| **HVAC** | Heating, Ventilation and Air Conditioning |
| **IPMVP** | International Performance Measurement and Verification Protocol |
| **KPI** | Key Performance Indicators |
| **PMV** | Predictive Mean Vote |
| **PPD** | Predicted Percentage of Dissatisfied |
| **PS** | Problem Scenario |
| **SCS** | Summer Conditions |
| **TCS** | Theoretical Case Studies |
| **U** | Thermal Transmittance |
| **WCS** | Winter Conditions |

# Executive Summary

This deliverable aims at the first objective of the WP1, to search a proper alignment with the application domain facilitating the replication of the BaaS System on the whole typologies of buildings covered under BaaS domain. This document collect, harmonize and align all required common information used as "key pillar" to other tasks within BaaS Project.

To best define the BaaS application domain, the typologies of buildings listed in the Directive on Energy Performance of Buildings (EPBD) have been used. Taking into account these typologies, six Theoretical Case Studies (TCS) have been chosen to study their more common inefficiencies (listed as "Problem Scenarios") and search solutions to these problems by means of BaaS system. This analysis is done from an end users point of view (ESCO).

Five Problem Scenarios have been detected and described as common inefficiencies within the TCSs, what ensures the replication potential of the BaaS system within the application domain. In order to find solutions to these problems, a set of Activity Scenarios (AS) have been defined and also their functional & non-functional requirements.

Furthermore, taking into account two key requirements, a list of building data (data requirement) as well as a set of Key Performance Indicators (supporting the evaluation requirement) has been included in this document.

As summary, this deliverable provides the basis for the correct alignment of the whole project, while summarizes the BaaS application domain by means of the theoretical case studies and their inefficiencies and defines the requirements to start to design the BaaS system. In addition, this deliverable provides a common terminology to be used along the project.

# Terminology

**Typology of building:** A typology of building is a cluster of buildings with common characteristics and similar uses. In this project, it will be taken into account only the typologies of non-residential buildings, and more specifically those typologies defined in the Directive on Energy Performance of Buildings (EPBD), 2010/31/EC.

In this Directive there are nine different typologies: single family houses of different types, apartment blocks, offices, educational buildings, hospitals, hotels and restaurants, sport facilities, wholesale and retail trade service and other types of energy consuming buildings.

**Theoretical Case Study**: For BaaS, a theoretical case study (TCS) is a specific type of building within a typology of buildings (i.e. a school could be a TCS within the educational typology) and it should be one example into the whole typology. It is the way used by BaaS to become the generalist typologies of buildings in a more specific case study (building).

**Problem Scenario:** A Problem Scenario tells a story of current practice (of a theoretical case study), where can be detected a problem which will be solved by mean of BaaS System. These stories are developed to reveal aspects of the stakeholders and their activities that have implications in the system (building) energy performance.

**Activity Scenario:** An Activity Scenario is the description of a possible set of solutions addressing some inefficiency defined in a problem scenario. The solution is made up as a set of functionalities which could be grouped in services.

**Functionalities and services:** A solution addressing a detected inefficiency is materialized in a service, in BaaS, a service is a software component able to address a set of functionalities, and these functionalities aim at fulfilling a set of specified requirements.

**Functional and non-Functional Requirement:** A Functional Requirement represents the main functionality necessary for aiming an objective in a software system and it is mandatory for the right behaviour of the system. There are two kind of functional requirements, end-user and technical. The first ones are written in an inexperienced language and the second ones are technical specification for the development staff. A Non-functional Requirement complements the functional ones and ensures the performance or offers security. They are aggregated in optional requirements which apply for improving the behaviour and efficiency of the system.

**Use Case:** Use Case is a software engineering concept (used in the analysis and design phase of SW development) which represents a functionality which should fulfil a requirement or a set of requirements. It is defined as a list of steps, typically defining interactions between a role (“actor”) and a system to achieve a goal. The actor could be human or an external/abstract system as it happens with the “time”. An actor initializes an action in the system. In BaaS, the set of all services that the system will provide is what has been named “use case”.

**Key Performance Indicator:** Key Performance Indicators (KPIs) define a set of values used periodically to assess the performance of a system (building) against different energy efficiency actuations or measures.

# 1 Introduction

Buildings account for 40% of total energy consumption in the European Union. Therefore, reduction of energy consumption in the buildings sector constitutes an important measure needed to reduce the energy dependency and greenhouse gas emissions of the European Union's member states.

In this sense, the BaaS system aims to optimize energy performance in the application domain of "non-residential buildings", in operational stage.

The main objective of the first work package of the project is to reach a proper alignment with the application domain assuring replication of the BaaS solution on the whole typologies of buildings. Concretely, this document is the result of the Task 1.1: Theoretical Case Studies Definition. In this task six theoretical case studies have been chosen to analyse each of the six typologies of buildings which characterize the BaaS application domain.

Seven sections and five appendixes make up this deliverable. The content and the order of the sections of this deliverable are based on the methodology defined in section 2 and represented in Figure 2. This methodology aims at identifying (in a very early stage of the project) what inefficiencies are commonly found in buildings and what services and functionalities should be defined by BaaS to minimize the (energy and cost) impact of such inefficiencies. Moreover, this methodology, knowing the identified inefficiencies and their solutions, helps us to identify what requirements is the basis to build the BaaS system, as well as what buildings information and key performance indicators will be used to evaluate the adopted solutions in the demonstration sites.

Section 3 explains how the theoretical case studies have been selected from the typology of buildings defined in [1], section 4 and 5 identify and describe, respectively, inefficiencies as "Problem Scenarios" and solutions as "Activity Scenarios". Having defined in section 5 the functionalities and services which address the identified problems, an preliminary set of requirements (from the end users point of view) are listed in section 6 and expanded in appendixes B and C as functional, non-functional and data requirements. These requirements are directly linked (as inputs) to technical work packages. A bidirectional feedback between both, requirements and technical developments, along the scope of the project will be necessary.

Finally, the actions and measures adopted by BaaS have to be conveniently evaluated, for this purpose, a set of key performance indicators are detailed in Section 7 and summarized in Appendix D. These KPI have been defined according to European Standards and Directives detailed in Table 3.

## 1.1 Purpose and target group

The purpose of BaaS Deliverable D1.1 is to specify the theoretical case studies selected to represent the typologies of buildings which characterize the BaaS application domain as well as to identify problem scenarios, solutions and functional and non-functional requirements which the BaaS system will address. Thus, this deliverable will be the reference used to align the technological work packages toward the BaaS application domain by means of one common set of requirements, a common terminology and a set of KPIs.

For that reason, the target group is composed of all consortium partners (CARTIF, NEC, Honeywell, Fraunhofer, TU Crete, UCC-IRU, and DALKIA). This deliverable has to compile the information collected from all technological work packages and vice versa, so as holding this link and alignment along the scope of the project.

## 1.2 Contribution of partners

This deliverable is led by CARTIF with major contributions from DALKIA, FHG, HON, NEC, and TUC partner members. The workload is distributed among the mentioned partners as explained below in table 1:

**Table 1: Summary of Contributions of Partners**

| Partner | Deliverable Focus |
|---|---|
| CARTIF | Deliverable Lead. Definition of Problem and Activity Scenarios. Building Data list. Requirements. KPI. |
| DALKIA | Definition of Problem and Activity Scenarios. Building Data. KPI |
| FHG | Definition of Problem and Activity Scenarios. Requirements from the point of view of Simulation. KPI |
| HON | Review and comments to all sections of the document. Requirements from the point of view of APO services (WP5) |
| NEC | Review of Problem Scenarios related to middleware component. Requirements from the point of view of security and interoperability. |
| TUC | Review and comments to all sections of the document. Building data list. Requirements from the point of view of APO services (WP5) |

## 1.3 State of the Art

A State of the Art (SOTA) analysis for BaaS needs to encompass what available standards are relevant, which elements from previous research are relevant, and focus on key research projects. The following table lists a sample group of relevant projects [Table 2] and the primary standards [Table 3] for reference and consideration in this deliverable.

**Table 2: Relevant Research Projects related to BaaS**

| Call | Acronym | Description |
|---|---|---|
| **EEB-ICT 2011.6.4**<br>ICT for energy-efficient buildings and spaces of public use | **CAMPUS 21** | “Control & Automation Management of Buildings & Public Spaces in the 21st Century”<br>Campus 21 focuses on the energy-efficient operation of public buildings and spaces.<br>CAMPUS 21 develops, deploys, and tests a Hardware-Software-Platform for the integration of existing ICT-subsystems supporting energy, building, and security systems management. |
| | **SEEDS** | “Self-learning energy efficient buildings and open spaces”. This project develops system that will allow buildings to maintain user comfort whilst minimising energy consumption and $CO_2$ emissions. |

| | | |
|---|---|---|
| **EEB-Energy-2011** | **NEED4B** | "New Energy Efficient Demonstration for buildings"<br><br>This project aims to develop an open and easily replicable methodology for designing, constructing, and operating new low energy buildings, aiming to a large market uptake. |
| | **DIRECTION** | Demonstration at European Level of Innovative and Replicable effective solutions for very low energy new buildings.<br><br>DIRECTION project aims at the creation of a framework of demonstration and dissemination of very innovative and cost-effective energy efficiency technologies for the achievement of very low energy new buildings. This framework is based in three pillars: Analysis of suitable energy efficiency technologies (technical and economic viability), demonstration activity deployed in three new buildings and dissemination at European Level |
| **EEB-ICT-2010.10.2**<br><br>ICT systems for Energy Efficient buildings and spaces of public use | **HESMOS** | "ICT Platform for holistic energy efficiency simulation and lifecycle management of public use facilities"<br><br>HESMOS will achieve an industry-driven holistic approach for sustainable optimization of energy performance and emissions (CO2) reduction through integrated design and simulation, while balancing investment, maintenance and reinvestment costs. The objective is to close the gaps between existing intelligent building/facilities data so that complex lifecycle simulation can easily be done in all design, refurbishment and retrofitting phases where the largest energy saving potentials exist. |
| | **SPORTE2** | "Intelligent management system to integrate and control energy generation consumption and exchange for European sport and recreation buildings"<br><br>SPORTE2 aims to manage and optimize the triple dimensions of energy flows (generation, grid exchange, and consumption) in Sport and Recreation Buildings by developing a new scalable and modular BMS based on smart metering, integrated control, optimal decision making, and multi-facility management. This tool will enable a new relationship and business model structure between facility managers and power providers. |
| **ICT 2009.6.3.**<br><br>ICT for energy | **PEBBLE** | Positive-energy buildings thru better control decisions.<br><br>In project PEBBLE an ICT-based tool has been |

| | | |
|---|---|---|
| efficiency | | developed to support the operation of EPBs and energy-smart buildings in general.<br>In the design and operation of positive-energy buildings a pragmatic target is maximization of the actual net energy produced by intelligently shaping demand to perform generation-consumption matching. A control and optimization ICT methodology that combines model-based predictive control and cognitive-based adaptive optimization has been proposed under this project |
| **FP7-Environment ENV.2009.3.1.5.2** | **SUPERBUILDINGS** | The project developed sustainability indicators for buildings, understanding about the needed performance levels considering new and existing buildings, different building types and local requirements, methods for the benchmarking of sustainable buildings and recommendations for the effective use of benchmarking systems as instruments of steering and in building processes |
| **CIP ICT-PSP PROJECTS on ICT for Energy Efficiency** | **GREEN@Hospital** | The GREEN@Hospital project aims at integrating the latest ICT solutions in order to obtain a significant energy saving in existing hospital buildings, through a better management of energy resources and losses reduction. |
| **Intelligent Energy Europe Programme (IEE) - European Commission** | **TABULA** | TABULA aims to create a harmonized structure for European building typologies. Residential buildings are the focus, but activities extend beyond them. |

**Table 3: Relevant Standards**

| Standard | Description |
|---|---|
| DIN V 18599: 2007 | Energy efficiency of buildings-Calculation of the net, final and primary energy demand for heating, cooling, ventilation domestic hot water and lighting. |
| ISO/EN 7730: 2007 | Analytical determination and interpretation of Thermal Comfort |
| EN 13779: 2007 | Ventilation for non-residential buildings-Performance requirements for ventilation and room-conditioning system |
| EN15217: 2006 | Energy Performance of buildings-Methods for expressing energy performance and for energy certification of buildings |
| EN 15251: 2007 | Indoor environmental input parameters for design and assessment of energy performance of building addressing indoor air quality, thermal environment, lighting and acoustics. |
| EN 15316 | Heating Systems in Buildings – Method for calculation of system energy requirements and systems efficiencies |

| | |
|---|---|
| EN 15603: 2008 | Energy performance of buildings-Overall energy use and definition of energy ratings. |
| ISO 50001: 2011 | Energy Management System |

NOTE: a comprehensive listing of relevant projects is available in section B.3.1.4 of the BaaS Description of Work (DoW) document.

### 1.4 Relation to other activities in the project

This deliverable has been used as starting point of other tasks of the BaaS Project, but also this deliverable brings together information from other work packages. The methodology described in the next section shows how the collaboration among work packages is a key aspect for the correct development of the phases of the BaaS project. In this deliverable it can be found a collection of information generated with the collaboration of all the participants in the project, needed for the rest of the tasks. This information can be summarized in the following points:

- Common inefficiencies found within the BaaS application domain (which is characterized as a set of TCS)
- Solutions to specific inefficiencies as a set of functionalities (service)
- BaaS System Requirements (end user and technical)
- Building information (data) requirements
- Key performance indicators to evaluate the BaaS solution

The tasks within the project closely related to T1.1 are:

- Task 2.1. Data Warehouse Requirements and extended BIM Specification
- Task 3.1. Data Modelling Harmonization
- Task 4.1. Simulation for energy performance estimation, interconnection to the BaaS system
- Task 5.1. SO2 Services Functional and Interoperability Requirements
- Task 6.1. Selection of pilot buildings

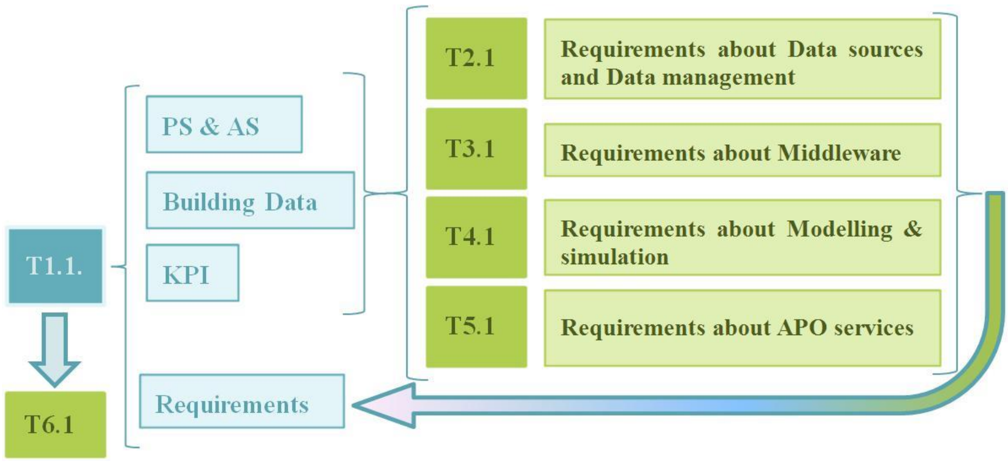



**Figure 1: Relationship of the T1.1 and other tasks of BaaS project**

Furthermore, Work Packages 2, 3, 4 and 5 have collaborated on developing the requirements needed for BaaS system [Appendix C], taking into account the information provided by this deliverable. Moreover, from these WPs there has been collaboration in the review of the building data requirements and the key performance indicators.

On the other hand, in task 6.1, demonstration buildings will be chosen based on the TCS selected in this deliverable.

### 1.5 Timeline and relations to milestones

Task T1.1 and deliverable D1.1 are linked to two milestones, milestone M1 at month 4 and milestone M2 at month 8.

- Milestone M1, entitled "Theoretical case studies and problem scenarios", highlights when this information (TCS and PS) have to be provided to the technological work packages to conveniently start (along with WP1) the analysis of such inefficiencies. Furthermore, this milestone is linked to tasks 6.1 where taking into account the specified theoretical case studies; Dalkia has to select two "real" demonstration building.
- Milestone M2, entitled "starting point of design phase in S&T WPs", highlight when the initial set of functional and non-functional set of requirements have to be ready to start the design phase (mainly) in WP3, WP2, WP4 and WP5.

Despite this work was delivered in month 12, both milestones were met, having the required information ready in both deadlines. During the period between month 8 and month 12, taks1.1 worked, in collaboration to task6.3, on the KPIs identification whereas Tasks 6.3 performed the M&V plan.

# 2 BaaS Methodology

This methodology is designed to align the technological work packages efforts and results to the application domain scope of this project.

The BaaS system aims to optimize energy performance in the application domain of "non-residential buildings", in operational stage. In the building operational life-cycle three significant tasks have to be continuously performed:

- Collect information and **A**ssess the buildings current state
- **P**redict the effect that various decisions will have to Key Performance Indicators (KPIs)
- **O**ptimize performance

Thus, the BaaS system will have to provide integrated assess, predict and optimize (**APO**) services that guarantee harmonious use of available resources in buildings. Moreover, certain horizontal services must be developed to allow the communication among different information and analytics resources. Under this consideration the BaaS solution could be considered as a set of functionalities grouped on a set of APO services which aims at solve energy inefficiencies in buildings within the BaaS application domain.

Despite the description of work of the project predefines some APO services, this deliverable explains the methodology used to find a set of specific services to be developed within BaaS project, services which address a specific set of inefficiencies found out in a coherent (and able to attempt) number of case studies. To better orchestrate the implementation of these services by the technological work packages (WP2, 3, 4 and 5), a common set of functional and non-functional requirements have to be identified and defined. So these WPs work aligned on the same rules. Two requirements have been highlighted, the building data requirement and the energy and cost evaluation requirement. To the last, a set of KPIs has been defined.

To obtain all of this information, it has been necessary to establish a methodology, which is going to be described in this section and is summarized in Figure 2.

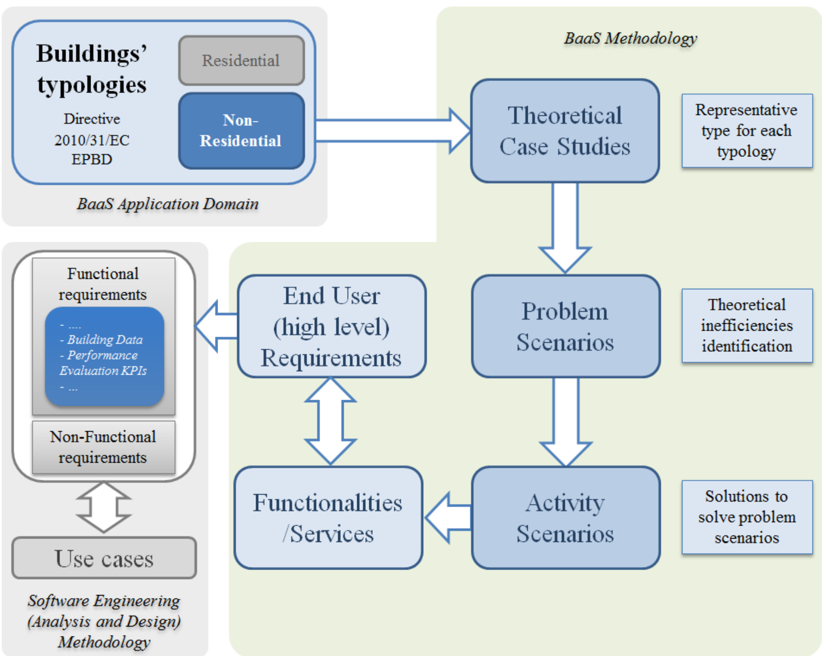



**Figure 2: Scheme of the BaaS system development methodology**

The description of these detected inefficiencies is what we are going to name as **Problem Scenario** (PS). A Problem Scenario tells a story of current practice where can be detected the problem which will be solved by mean of BaaS System. These stories are developed to reveal aspects of the stakeholders and their activities that have implications for the system (building) energy performance.

Working on the problems, their solutions will be identified and analysed. In this case, the definition and description of these solutions is named as **Activity Scenarios** (AS), therefore, when we speak about Activity Scenarios we refer to activities and solutions which aim at solving the identified problems.

These activities are defined as a set of functionalities which further will be grouped on services.

At this point, it is necessary to identify the requirements which characterize the services/functionalities which, in turn, define the activities (in the activity scenarios) in order to allow to the BaaS system solves the identified inefficiencies (problem scenarios).

Actually, the TCS and the Problem and Activity Scenarios definition is aimed at the identification of requirements, functional and non-functional and the provision of this information to technological work packages.

The list of requirements have been defined in collaboration with WP2 (building data acquisition and standardization), WP3 (integration, middleware platform), WP4 (building energy performance simulation) and WP5 (APO services), in order to cover all the domain of the BaaS System.

Two important requirements are:

- Building information (data) requirement, it means, the list of data required to implement the services.
- Performance evaluation requirement. To fulfil this requirement a set of KPIs has been defined to characterize and evaluate the building energy performance related to the BaaS solution.

From a software engineering point of view and under the technological work package scope, such requirements will be the starting point for the development of all SW components of the BaaS system. Using these requirements and the (SW engineering) analysis and design methodology, a set of use cases will be created in WP3 and WP5. Taking into account these use cases, **Assess**, **Predict** and **Optimize** (APO) services and other supporting components of the system will be developed to solve the Problem Scenarios defined within this document.

# 3 From BaaS application domain to theoretical case studies

Following the methodology described, the first step is the choice of the theoretical case studies taking as starting point the typologies of non-residential buildings extracted in the Directive on Energy Performance of Buildings (EPBD) [1] [2].

Non-residential buildings account for 25% of the total stock in Europe (EU27, Switzerland and Norway) and comprise a more complex and heterogeneous sector compared to the residential sector. Moreover, differences from country to country are more pronounced than in the residential buildings sector. This information has been extracted from the document "*Europe's buildings under the microscope*"; this is a country-by-country review of the energy performance of buildings [3].

In the abovementioned Directive seven typologies of non-residential buildings are described. These typologies are the following:

- Offices
- Educational buildings
- Hospitals
- Hotels and restaurants
- Sport facilities
- Wholesale and retail trade service
- Other types of energy consuming buildings

The Figure 3 shows the distribution of these typologies of buildings taking into account the occupied floor space.

Offices and wholesale and retail trade buildings make up the largest component in most countries, with a floor space corresponding to the half of the global non-residential floor space (offices 23% and wholesale and retail 28%). This analysis is significant when analyzing the replication potential of each of these typologies.

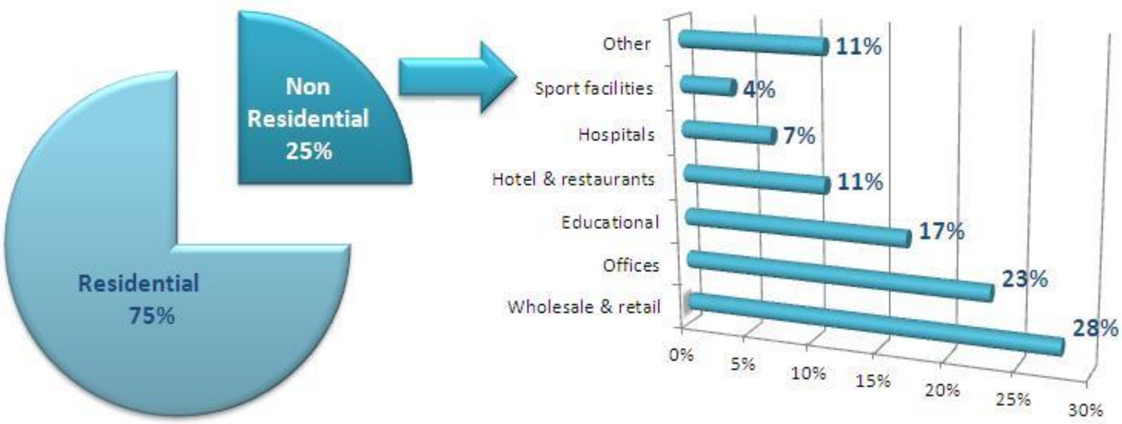



**Figure 3: Residential and non-residential building stock in Europe ($m^2$). Source BPIE survey [3]**

On the other hand, although the retail and wholesale buildings comprise the largest portion of the non-residential stock, these buildings are somewhat different from others regarding the energy behaviour, as heating and cooling conditions may differ from others categories due to large areas of wholesale buildings often being used only for storage purposes.

Office buildings are the second biggest category with a floor space corresponding to almost the 25% of the total non-residential floor space. Similar usage pattern as offices are found with educational buildings which count for almost 20% of the entire non-residential floor space. From the replicability point of view, these conclusions are remarkable.

Since every building type from each typology cannot be analysed, one Theoretical Case Study (TCS) has been selected representing the whole typology. The buildings considered for this TCS selection are the following:

- **Offices:** Offices in private companies and offices in all state, post-offices, municipal and other administrative buildings.
- **Educational buildings**: Primary and secondary schools, high schools and universities, research laboratories, professional training activities and others.
- **Hospitals**: Public and private hospitals, medical care, homes for handicapped, day nursery and others.
- **Hotels and restaurants**: Hotels, restaurants, pubs and cafes, canteens or cafeterias in businesses, catering and others.
- **Sport Facilities**: Sport halls, swimming pools, gyms, etc.
- **Wholesale and retail**: Detached shops, shopping centres, department stores, large and small retail, food and non-food shops, bakeries, car sales and maintenance, hair dresser, laundry, service stations (in gas stations), fair and congress buildings and other wholesale and retail.
- **Other types of energy consuming buildings**: Warehousing, transportation and garage buildings, agricultural (farms, greenhouses) buildings, garden buildings.

The criterion used for selecting the TCS is related to the availability of real buildings for BaaS Project (for further information see D6.1: Identification and definition of BaaS demonstration buildings). This selection is shown in the following table:

**Table 4: Theoretical case studies selected**

| Typologies from EPBD | Theoretical Cases Studies |
|---|---|
| Offices | Building of offices |
| Educational buildings | School |
| Hospitals | Hospital |
| Hotels and restaurants | Hotel |
| Sport Facilities | Swimming pool |
| Wholesale and retail | Shopping mall |

### 3.1 Characterization of Theoretical Case Studies

In the following table the theoretical case studies are characterized regarding the occupancy profiles, existing energy systems and control, all from a theoretical point of view in order to establish the basis for the demonstrator buildings selection. This characterization has been developed taking into account the portfolio of buildings available for BaaS (for further information see D6.1: Identification and definition of BaaS demonstration buildings).

**Table 5: Theoretical Case Studies characterization**

| | | School | Hotel | Office Buildings | Swimming pool | Hospital | Shopping mall |
|---|---|---|---|---|---|---|---|
| Context Building | **Occupancy profile** | Scheduled | Scheduled | Scheduled | Variable | Variable | Variable |
| | **Non-residential building stock** | 17% | 11% | 23% | 4% | 7% | 28% |
| Energy systems | **Thermal services to be given** | Heat | Heat and cool | Heat and cool | Heat and cool | Heat and cool | Heat and cool |
| | **Technologies available for the services** | Boiler, district heating | Boiler, district heating and cooling, chiller | HVAC system | HVAC system | HVAC system | HVAC system |
| | **Final elements** | Radiators, radiant floor | Combination of quick/slow systems | Combination of quick/slow systems | Quick systems | Combination of quick/slow systems | Quick systems |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Problem boundaries** | | Stand-by when there are no clients | | Need of simultaneous heating and cooling (air drying)<br>Specific problems due to the high humidity | Need of simultaneous heating and cooling | |
| Control | **Physical variables that affect the control** | Temperature | Temperature | Temperature and humidity | Temperature, humidity, air quality, stratification | Temperature, humidity and air quality | Temperature, humidity, air quality, stratification |
| | **BMS** | No | Yes | Yes | Yes | Yes | Yes |

The description of the energy systems and building controls related to each theoretical case study has been completed with the following section 3.1.1 (describing the energy elements and energy flows), and section 3.1.2 (describing the control related to the elements and the Building Automation Network standards).

### 3.1.1 *Characteristic energy systems*

Following the approach and standardized methodology defined in the guideline of the CONCERTO[1] projects, which objective is to ensure a comparable presentation, evaluation, assessment, analysis and dissemination of the individual measures realized by the CONCERTO communities, the energy flow of a demonstration building can be represented as follows.

To picture this energy supply chain of a demonstration building it is important to include the on the one hand community energy systems and on the other hand building energy systems in one diagram. It follows the following rules:

- Input community energy system

  The delivered energy carriers are displayed in horizontal lines in the upper part. Depending on the supply system possible energy carries are: domestic gas, oil, biomass, biogas, district heating, district cooling and electricity (national mix).

  Below the delivered energy carriers, the environmental energy is displayed as well as horizontal lines. Examples are: soil, groundwater, external air, waste heat from buildings/industry, solar radiation.

- Output building integrated energy systems

  The end use energy is displayed in horizontal lines at the bottom part. Examples are: domestic hot water, space heating, space cooling, and electricity.

- Generation/Transformation

  In the middle part of the diagram the generation/transformation units are displayed. For example: development of environmental energy, CHP, heating generation, and cooling generation.

  The energy supply is always displayed from top and the delivered energy downwards. In general the energy flow is displayed from top to bottom.

- Building distribution

  In this case, although in the CONCERTO guideline it is not included, for BaaS a new layer between the production layout (generation/transformation) and the energy needs in the building level. This layer includes the building distribution devices that connect the generated or transformed energy to the demands of the building.

- Energy meters

  Also, the diagram includes the devices used in order to meter the energy deliveries between the different levels of the energy flow.

On the following figures it is shown the general flow energy schemes for each theoretical case study (Office buildings, educational buildings, hospitals, hotels and restaurants, sport facilities, whole sale and other buildings.

[1] The CONCERTO Technical Monitoring Guide is based on the Agreement: Collaboration between CONCERTO communities and CONCERTO Plus regarding monitoring and impact assessment" (CONCERTO Plus, 04.12.2006), on the "Guidance note for CONCERTO proposers" (Version 1.5, April 2008) and on the "Leitfaden für das Monitoring der Demonstrationsbauten im Förderkonzept EnBau und EnSan" Fraunhofer ISE, ChN/BAS, Rev. 17.10.2006).

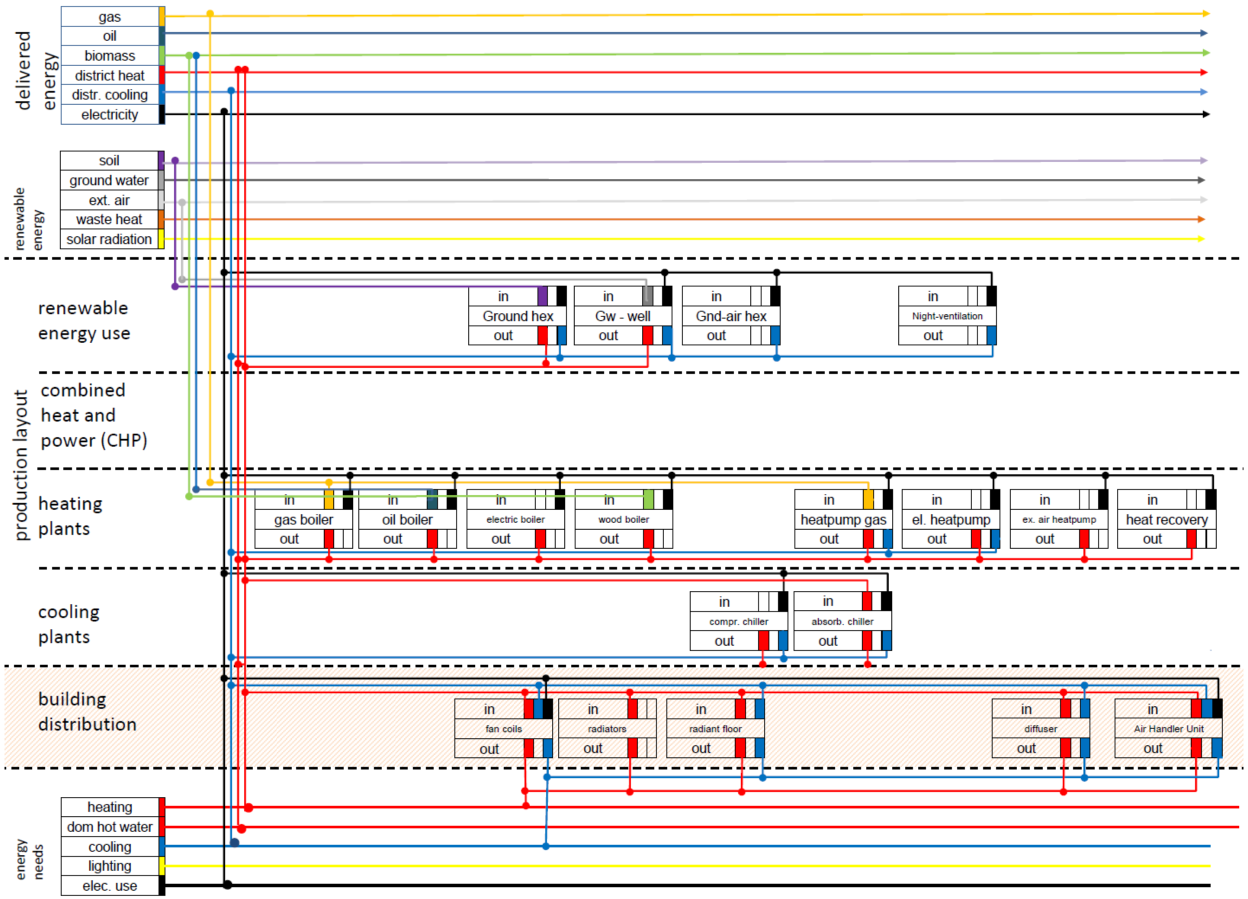



**Figure 4: Offices' energy flow**

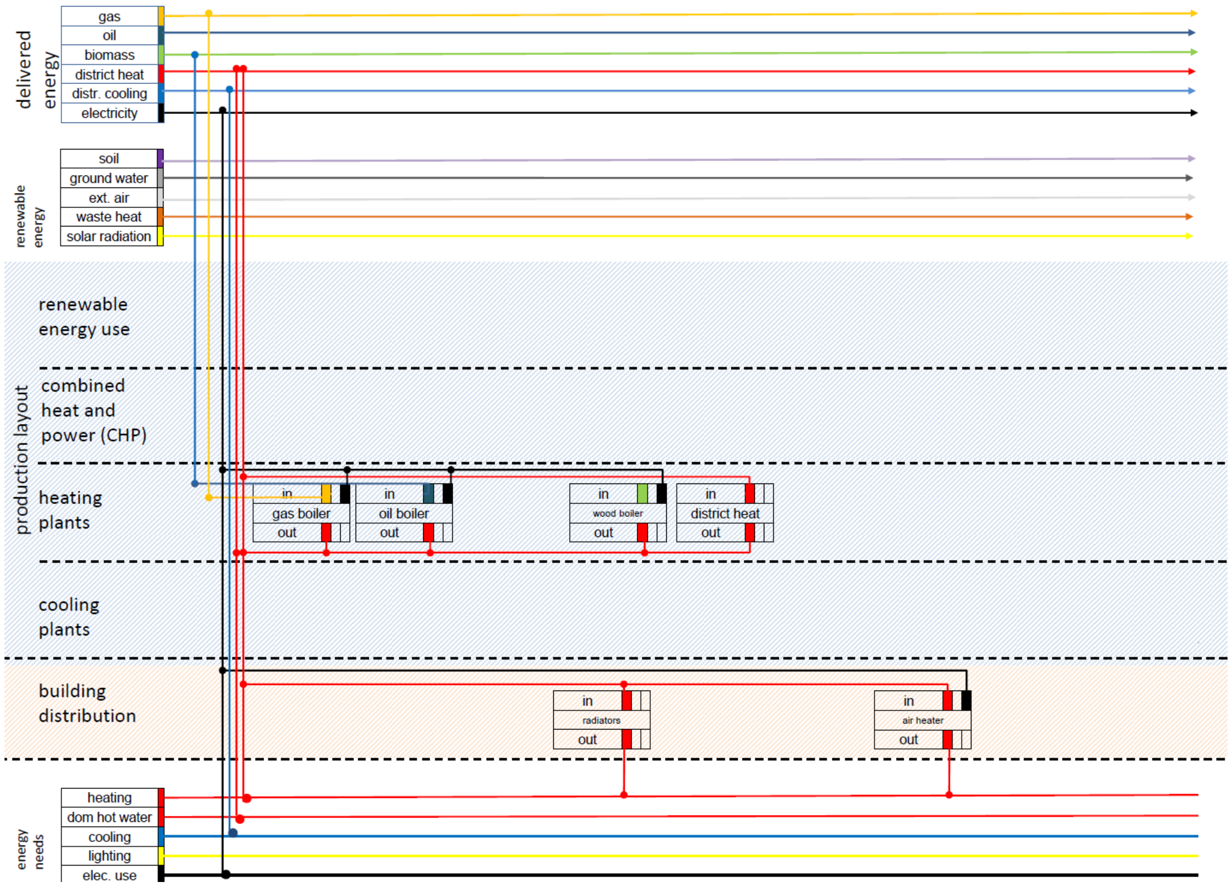



**Figure 5: Educational buildings' energy flow**

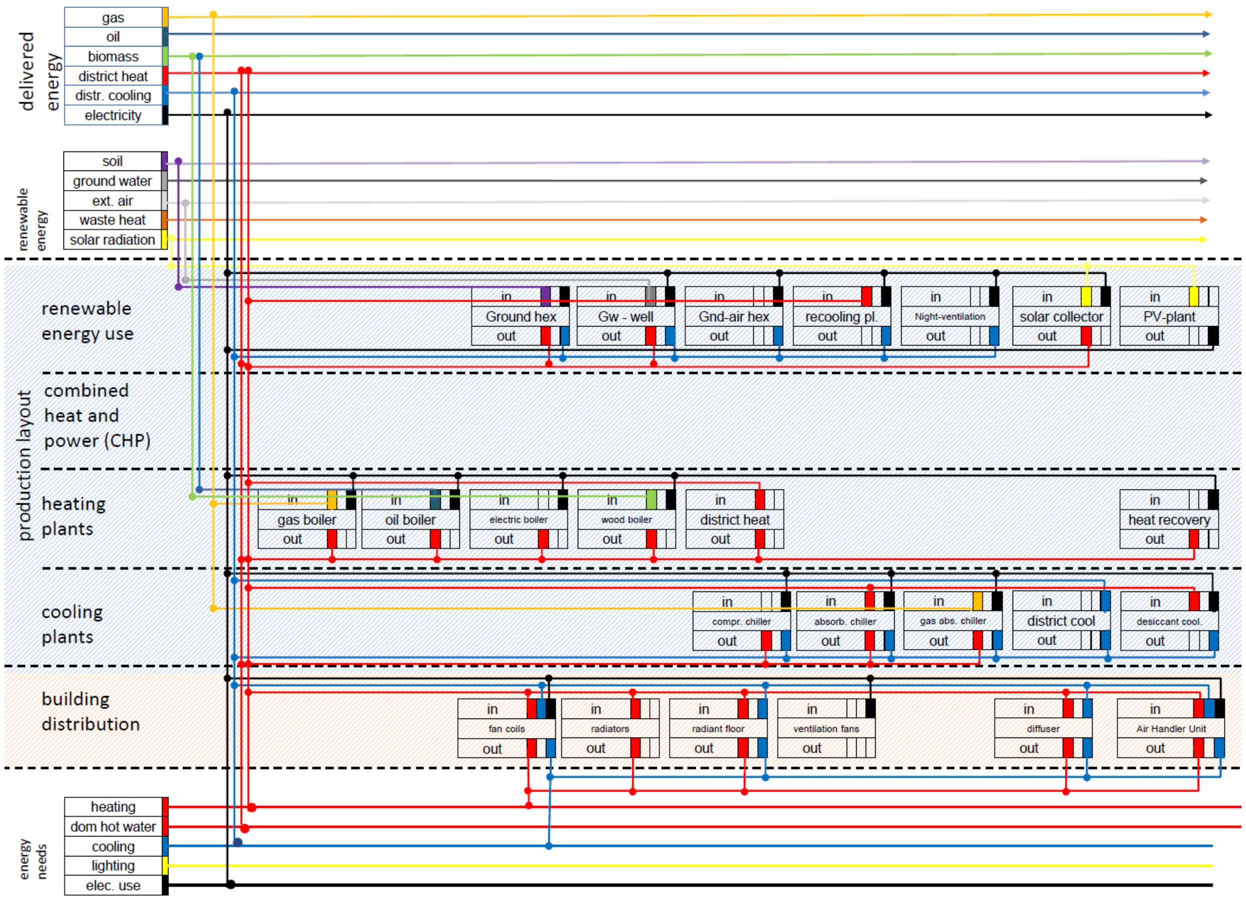



**Figure 6: Hospitals' energy flow**

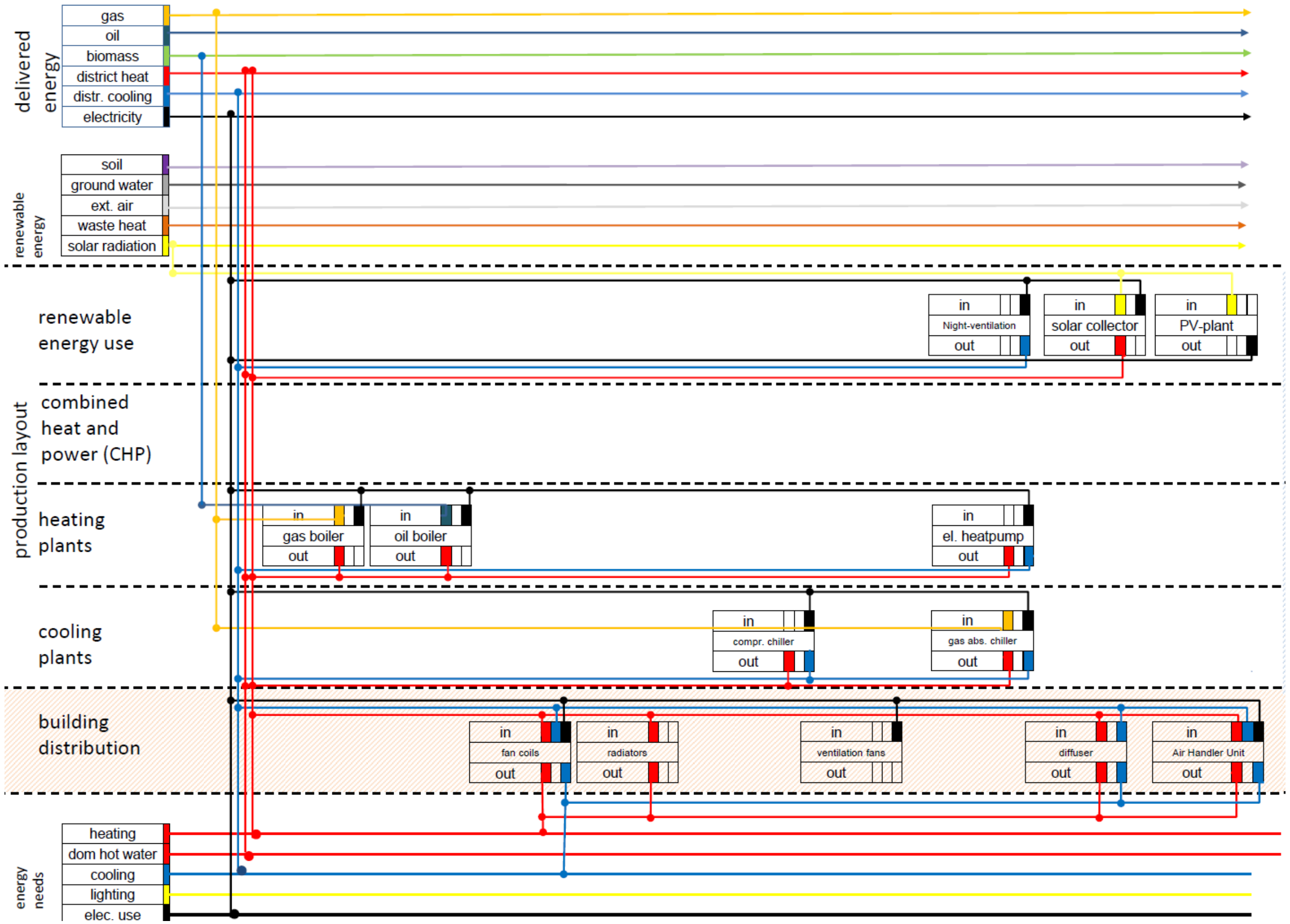



**Figure 7: Hotel and Restaurants' energy flow**

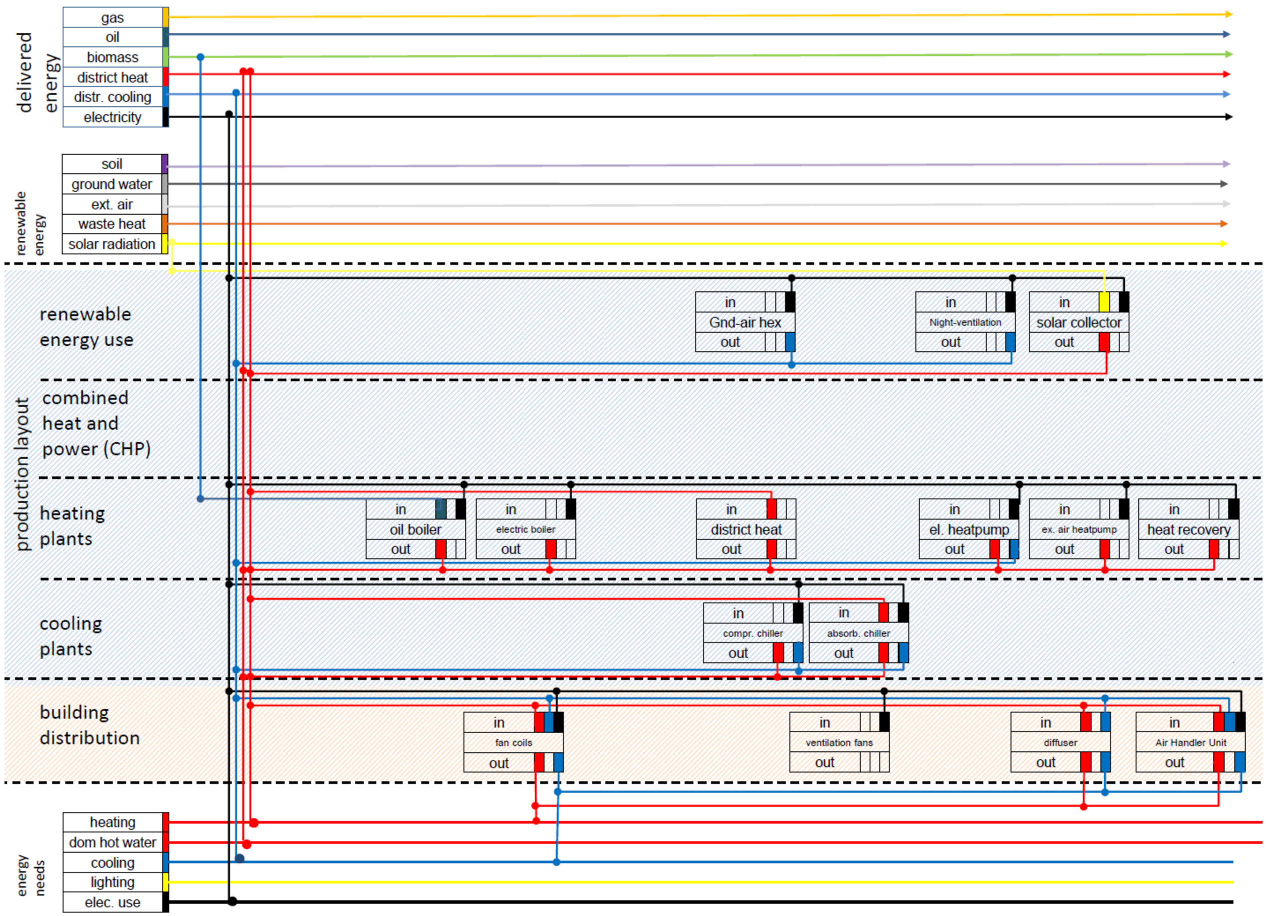



**Figure 8: Sport facilities' energy flow**

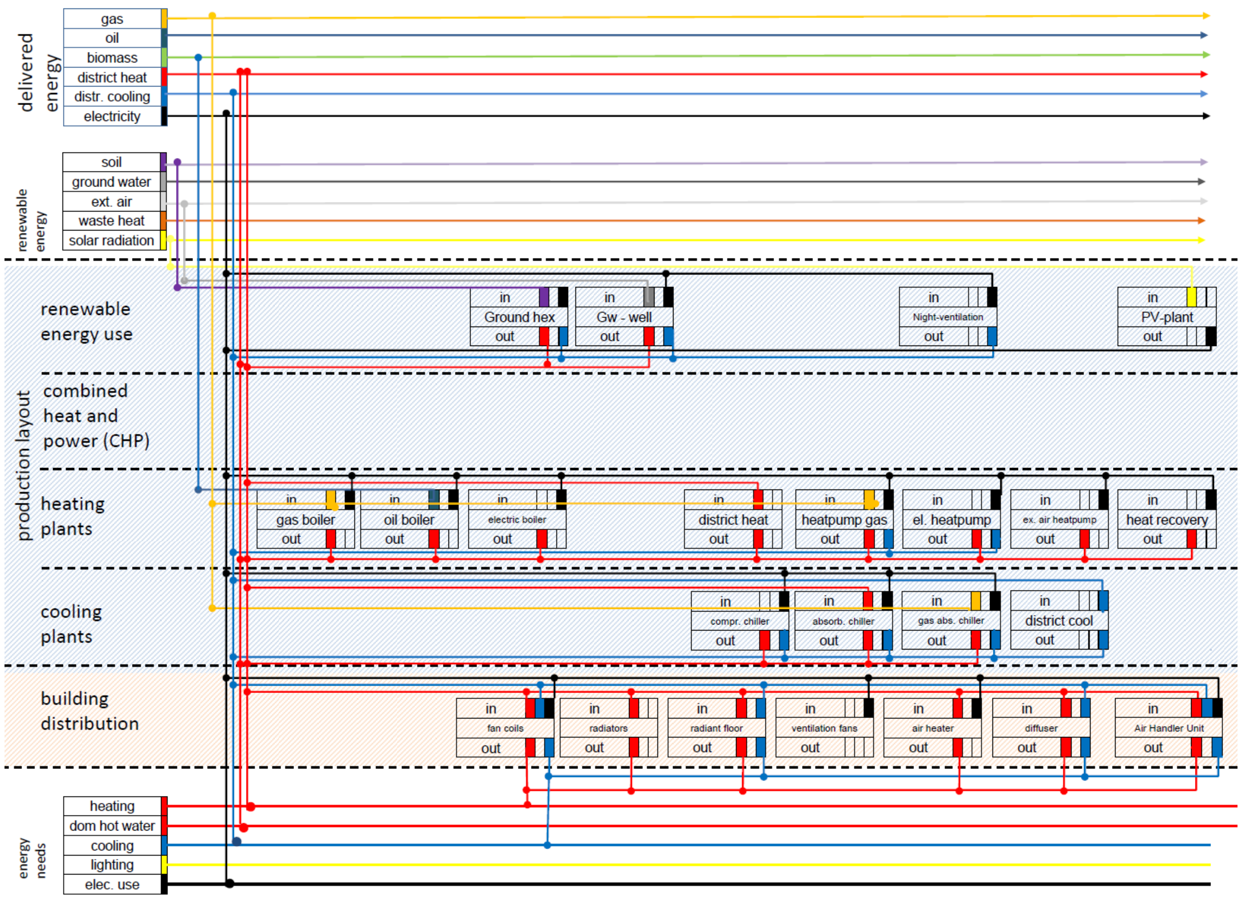



**Figure 9: Whole sale and retail trade services' energy flow**

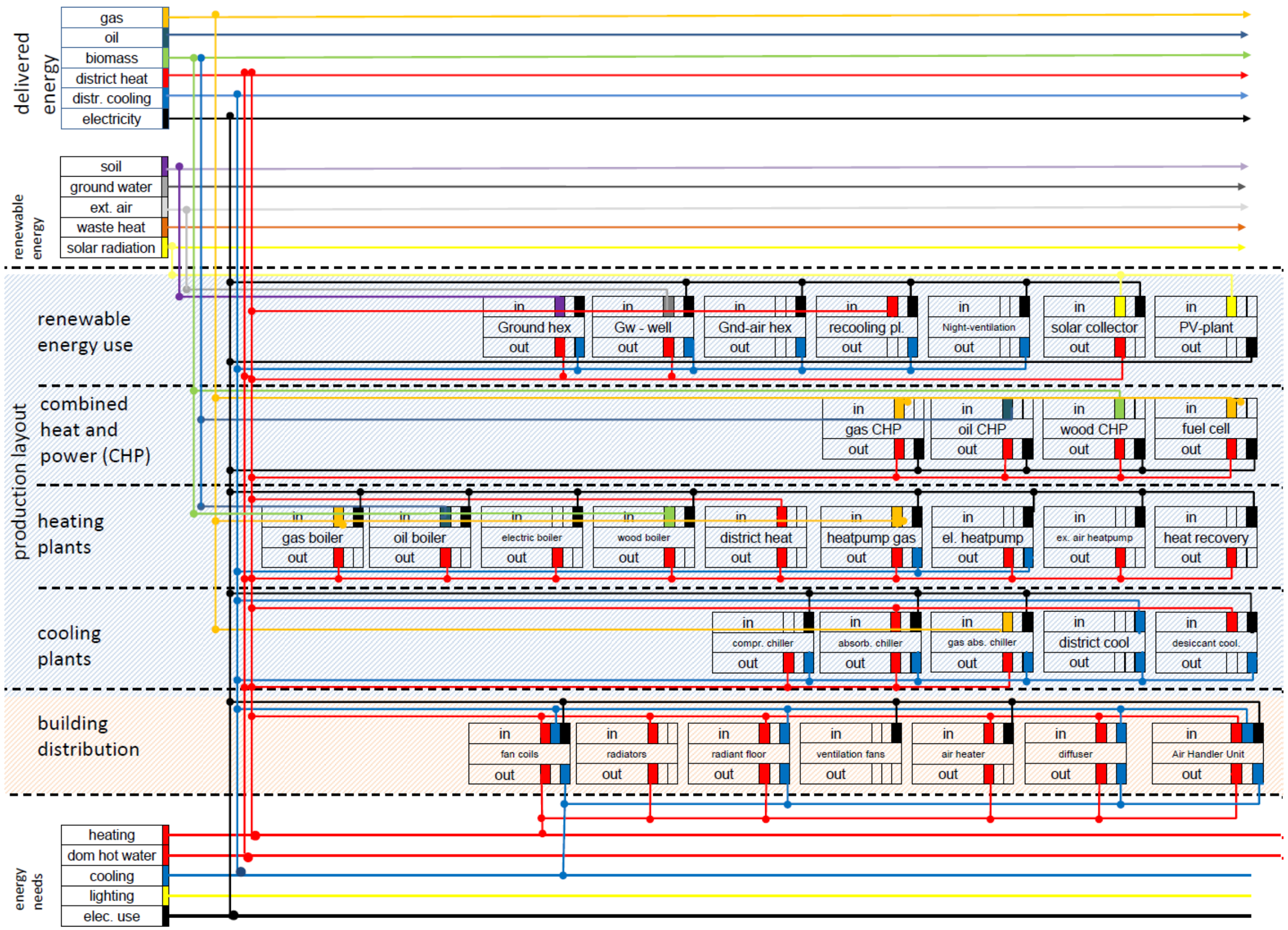



**Figure 10: Others buildings' energy flow**

The following table summarizes the considered energy systems in the analysis of the Theoretical Case Studies. All these elements classified in sources, storage and demand by system, subsystem and equipment:

**Table 6: Considered energy systems**

| System | | | Subsystem | Equipment |
|---|---|---|---|---|
| Sources | External energy sources | - | Electricity | - |
| | | | Fossil fuel | - |
| | | | Solid fuel | - |
| | | | District system | - |
| | | | Biomass | - |
| | Internal energy generation | Renewable energy sources | Solar heating | Flat plate collector |
| | | | | Evacuated tube collector |
| | | | Solar photovoltaic | Flat plate photovoltaic system |
| | | | Wind energy | Vertical axis wind turbine |
| | | | | Horizontal axis wind turbine |
| | | | Geothermal energy | - |
| | | Cogeneration | Combined heat and power | Reciprocally internal combustion engines (CHP) |
| | | | | Micro gas turbine |
| Storage | Thermal | - | Sensible thermal energy | Water tank |
| | | | | Organic liquids (thermal oil) |
| | | | | Molten salts |
| | | | Latent thermal energy | Liquid-solid phase Phase change materials (PCM) |
| | Electrical | - | - | Batteries |
| | | | | Flywheel |
| Demand | Heating systems | - | | Electric radiator |
| | | | | Electric air convector |
| | | | | Electric radiant heating |
| | | | | Air to air heat pump |
| | | | | Variable refrigerant volume |
| | | Central heating system | Production conversion subsystem | Electric boiler |
| | | | | Fuel boiler |
| | | | | Biomass boiler |
| | | | | Air cooled heat pump |
| | | | | Roof top |

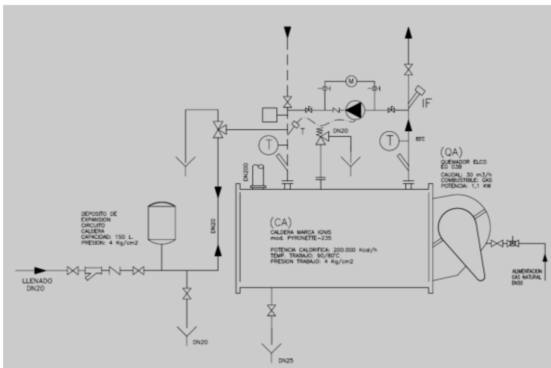
| | | | | |
|---|---|---|---|---|
| | | | | Water cooled chiller |
| | | | Distribution subsystem | Pump one speed |
| | | | | Pump variable speed |
| | | | | Fan one speed |
| | | | | Fan variable speed |
| | | | Terminal units | Hot water radiator |
| | | | | Underfloor heating |
| | | | | Fan-coil |
| | | | | Air handling unit |
| | | | | Volumetric flow controller |
| | **Hot water systems** | - | | Electric instantaneous water heater |
| | | | | Electric storage tank water heater |
| | | Central hot water system | Production conversion subsystem | Electric boiler |
| | | | | Fuel boiler |
| | | | | Biomass boiler |
| | | | | Air cooled heat pump |
| | | | | Water cooled chiller |
| | | | Distribution subsystem | Pump one speed |
| | | | | Pump variable speed |
| | **Cooling system** | - | | Air to air heat pump |
| | | | | Air cooled condensing unit |
| | | | | Variable refrigerant volume |
| | | Central cooling system | Production conversion subsystem | Air cooled chiller |
| | | | | Water cooled chiller |
| | | | | Cooling tower |
| | | | | Air cooled heat pump |
| | | | | Roof top |
| | | | Distribution subsystem | Pump one speed |
| | | | | Pump variable speed |
| | | | | Fan one speed |
| | | | | Fan variable speed |
| | | | Terminal units | Fan-coil |
| | | | | Air handling unit |
| | | | | Volumetric flow controller |

| | | | | |
|---|---|---|---|---|
| | Ventilation system | - | Distribution subsystem | Fan one speed |
| | | | | Fan variable speed |
| | | | Terminal units | Air handling unit |
| | | | | Volumetric flow controller |
| | Lighting system | - | Indoor lighting on/off control | |
| | | | Indoor lighting progressive control | |
| | | | Outdoor lighting on/off control | |
| | | | Outdoor lighting progressive control | |

### 3.1.2 *Characteristic building controls: Building Automation Networks standards*

Each of the elements considered in the previous section have its own control system. All the parameters affecting the control, in addition to the description of each element, its operating limits, the energy required and provided, the relationship between energy and comfort, etc. have been analysed by the European Project SEEDS (Self-learning Energy Efficient building and open Spaces), funded by the European Commission under the GA No. 285150. In the Appendix C (Model tables of energy demand equipment), and Appendix D (Model tables of energy sources and energy storages) of its document D1.1 – *Development of a methodology for the modelling of BEMS for a wide spectrum of construction types*, one table per element contains all this description. Here, only one of these tables has been reproduced, containing the information about a FUEL BOILER. This table has been partially modified, simplifying some fields. For the rest of the elements, this information can be found in such document.

**Table 7: Boiler description including control**

| **Device model** | | | |
|---|---|---|---|
| **Name** | BOILER | **Icon** | in<br>gas boiler<br>out |
| **Type** | | FUEL BOILER | |
| **Photograph** | | **Outline** | |
|  | |  | |

| **Description** |
|---|
| A fuel boiler is a closed vessel intended to heat water and produce hot water or steam through combustion of a fuel. It must also have a system for evacuating gases from combustion.<br>Steam and hot water boilers are available in standard sizes from very small boilers for apartments and homes to very large boilers for commercial and industrial use.<br>The fuel used can be solid (wood, coal, biomass), liquids (fuel oil, diesel) or gaseous (liquefied petroleum gas or LPG, natural gas), which determines the shape of the boilers. Currently the most commonly used fuels are oil, natural gas or biomass.<br>There are three ways to control the output of a fuel boiler:<br>- On-off (cycling) control<br>- High-fire, low-fire control<br>- Modulating control<br>On-off control is most common for small boilers up to a capacity of 300 kW. The fuel burner switches between on and off to maintain steam pressure or water temperature. On/off control causes losses in efficiency because of the cooling of the fireside surfaces by the natural draft from the chimney during the off, prepurge, and postpurge cycles necessary for safety.<br>High-fire, low-fire burners provide fewer off cycle losses since the burner shuts off only when loads are below the low fire rate of fuel input.<br>Modulating control is used on most large boilers because it adjusts the output to match the load whenever the load is greater than the low-fire limit, which is usually not less than 15 percent of the full load capacity. Steam pressure or hot water temperature is measured to control the volume of gas or oil admitted into the burner. |
| **Mathematical relation between comfort and energy** |
| A fuel boiler transfers heating energy to those terminal units which are connected to its circuit. Its Mathematical relation is between comfort and energy:<br>$$E_{th\text{-}FB} = f\,(T_{water\ return\text{-}FB}, T_{water\ supply\text{-}FB}, Q_{w\text{-}FB}, t)$$<br>Energy in fuel boiler is the outcome of multiplying power by time, so frequently the parameter to analyse are power instead of energy:<br>$$P_{th\text{-}FB} = f\,(T_{water\ return\text{-}FB}, T_{water\ supply\text{-}FB}, Q_{w\text{-}FB})$$<br>Options for power calculation:<br>1) Data from water sensor<br>If $Q_{w\text{-}FB}$, $T_{water\ supply\text{-}FB}$ and $T_{water\ return\text{-}FB}$ are known, power in a conventional water boiler is:<br>$$P_{th\text{-}FB} = Q_{w\text{-}FB} \cdot \rho_{w\text{-}FB} \cdot Cp_{w\text{-}FB} \cdot \Delta T_{w\text{-}FB}$$<br>2) Another method of measuring the thermal energy is to install a thermal energy meter between water inlet and outlet of the fuel boiler, $P_{th\text{-}FB}$. |
| **Operating limits** |
| Are given by the type of fuel boiler and manufacturer. |
| **Energy required** |
| Chemical energy. The main energy used is the chemical energy that comes from the combustion. Combustion is the set of physic-chemical processes by which there is a controlled release of internal energy of the fuel.<br>The quantity of heat (or energy) in the fuel consumed to be imparted (EFUEL) can be calculated by:<br>$$E_{fuel\text{-}FB} = Q_{FUEL} \cdot NVC_{FUEL}$$<br>Electrical energy. In fuel boilers, additional energy is necessary to operate the burner and control device. It is electrical energy and it depends on the different electrical components of the boiler (fuel pump, sensors, valves, control system, etc.) For each instant the electrical power consumed is different, therefore, the best method of measuring it is to install an energy meter in the electrical connection system. |

The energy is the sum of time and power: $E_{el\text{-}FB} = P_{el\text{-}FB} \cdot t$

This electrical energy may be negligible compared with chemical energy.

**Energy provided**

Thermal energy, $E_{th\text{-}FB}$

**CO2 emissions**

The combustion process produces gaseous emissions including $SO_2$, $NO_x$, water vapour, carbon dioxide ($CO_2$), and CO.

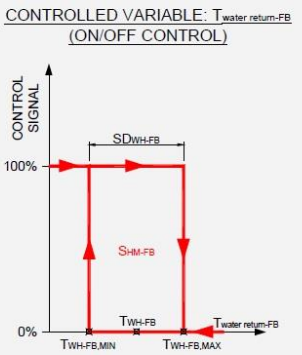
The amount of pollutants that are emitted to the atmosphere depends on each fuel, boiler characteristics and performance condition.

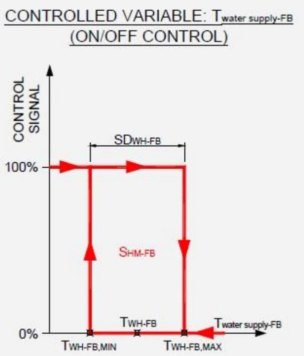
It is possible to compute the $CO_2$ emissions based on a flue gas analysis and thermal energy production or flue gas analysis and fuel consumption.

**Control system**

The control system provided by the boiler manufacturer takes care not only of thermal energy production but also of safety issues. Temperatures and pressures in the boiler can be high and should be carefully controlled. For safety reasons, boilers' manufacturers don't allow much interaction with their control system. The only parameters that can be set by the user are: the on/off status and the desired outlet water temperature (set-point). The control system provided by the manufacturer will decide on the power level according to the difference between the actual water supply temperature and the set-point.

A boiler can be managed (locally or manually) by the user, who sets the temperature set-point and on/off status or remotely via a BMS or BEMS to define on/off status and temperature set-point, it will be able to send the BMS or BEMS some information provided by the sensors monitoring the boiler status (like pressure or temperatures). Therefore, the BMS (or BEMS) can have comprehensive information on boiler performance and can decide on on/off and set-point to optimise energy performance.




1) Variables required to control the system:
   - $T_{WH\text{-}FB,MIN}$
   - $T_{WH\text{-}FBMAX}$
   - $SD_{WH\text{-}FB}$
   - $T_{WH\text{-}FB}$
   - $T_{water\ return\text{-}FB}$
   - $T_{water\ supply\ \text{-}FB}$
2) Relationships between variables:
   - $T_{WH\text{-}FB,MIN} < T_H < T_{WH\text{-}FB,MAX}$
   - $SD_{WC\text{-}FB} = T_{WH\text{-}FB,MAX} - T_{WH\text{-}FB,MIN}$
3) Conditions to control the system (function of $T_{water\ return\text{-}FB}$):

Heating mode ($OM_{PS\text{-}FB}$ =HM):
   - If $T_{water\ return\text{-}FB} \leq T_{WH\text{-}FB,MIN}$, then $S_{HM\text{-}FB}$=100%.
   - If $T_{WH\text{-}FB,MIN} < T_{water\ return\text{-}FB} < T_{WH\text{-}FB,MAX}$ in the time "$t_n$", then:
     - $S_{HM\text{-}FB}$=100%, if in the time $t_{n-1} \rightarrow S_{HM\text{-}FB}$=100%.
     - $S_{HM\text{-}FB}$=0%, if in the time $t_{n-1} \rightarrow S_{HM\text{-}FB}$=0%.
   - If $T_{water\ return\text{-}FB} \geq T_{WH\text{-}FB,MAX}$, then $S_{HM\text{-}FB}$=0%.

4) Conditions to control the system (function of $T_{water\ supply\text{-}FB}$):

Heating mode ($OM_{PS\text{-}FB}$ =HM):
   - If $T_{water\ supply\text{-}FB} \leq T_{WH\text{-}FB,MIN}$, then $S_{HM\text{-}FB}$=100%.
   - If $T_{WH\text{-}FB,MIN} < T_{water\ supply\text{-}FB} < T_{WH\text{-}FB,MAX}$ in the time "$t_n$", then:
     - $S_{HM\text{-}FB}$=100%, if in the time $t_{n-1} \rightarrow S_{HM\text{-}FB}$=100%.
     - $S_{HM\text{-}FB}$=0%, if in the time $t_{n-1} \rightarrow S_{HM\text{-}FB}$=0%.
   - If $T_{water\ supply\text{-}FB} \geq T_{WH\text{-}FB,MAX}$, then $S_{HM\text{-}FB}$=0%.

| **Input** | **Output** |
|---|---|

<table>
<tr><td colspan="3">

<u>Control system</u><br>
1) Conventional boiler<br>
- $T_{WH\text{-}FB}$ → value entered by the user<br>
- $T_{WH\text{-}FB,MIN}$ → value entered by the user<br>
- $T_{WH\text{-}FB,MAX}$ → value entered by the user<br>
- $T_{water\ supply\text{-}FB}$ → water temperature sensor<br>
- $T_{water\ return\text{-}FB}$ → water temperature sensor<br>
<u>Measuring thermal energy</u><br>
1) Data from water sensor<br>
- $T_{water\ supply\text{-}FB}$ → water temperature sensor<br>
- $T_{water\ return\text{-}FB}$ → water temperature sensor<br>
- $Q_{w\text{-}FB}$ → water flow meter<br>
2) Data from thermal energy meter<br>
- $P_{th\text{-}FB}$ → thermal energy meter<br>
<u>Measuring electrical energy</u><br>
1) Data from power or energy meter<br>
- $P_{el\text{-}FB}$ → power or energy meter<br>
<u>Measuring chemical energy</u><br>
1) Data from fuel sensor<br>
- $Q_{FUEL}$ → fuel flow meter
</td><td colspan="3">
Control system<br>
1) Conventional boiler<br>
- $S_{HM\text{-}FB}$ (On/Off type). Fuel boiler start/stop
</td></tr>
<tr><th colspan="3">Most suitable sensors</th><th colspan="3">Most suitable actuators</th></tr>
<tr><th>Type of sensor</th><th>Signal</th><th>Characteristic</th><th>Type of sensor</th><th>Signal</th><th>Characteristic</th></tr>
<tr><td colspan="6">Remote control</td></tr>
<tr><td>Two water temperature sensors</td><td>AI</td><td>Resistance (PT 100, LG-NI 1000, NTC)</td><td>Start/stop</td><td>DO</td><td>Open/close contact Potential-free</td></tr>
<tr><td></td><td></td><td></td><td>Water valve control modular</td><td>AO</td><td>0-10 Vcc singal position</td></tr>
<tr><td colspan="6">Energy efficiency oriented control system</td></tr>
<tr><td>Two water temperature sensors</td><td>AI</td><td>Resistance (PT 100, LG-NI 1000, NTC)</td><td>Start/stop</td><td>DO</td><td>Open/close contact Potential-free</td></tr>
<tr><td>Outdoor temperature sensor</td><td>AI</td><td>0-10 Vcc/4-20 mA</td><td>Water valve control modular</td><td>AO</td><td>0-10 Vcc singal position</td></tr>
<tr><td>Water flow meter</td><td></td><td>Pulse communication bus</td><td></td><td></td><td></td></tr>
<tr><td>Fuel flow meter</td><td></td><td>Pulse communication bus</td><td></td><td></td><td></td></tr>
<tr><td>Thermal energy meter*</td><td>AI</td><td>Communication bus 4-20 mA</td><td></td><td></td><td></td></tr>
<tr><td colspan="6">*These sensors are optional to measure energy in a more accurate way.</td></tr>
<tr><th colspan="6">Parameters that affect energy efficiency</th></tr>
<tr><td colspan="6">In order to evaluate the thermal energy, measuring the following parameters is required:</td></tr>
</table>

- Water flow. Sensors to measure water flows are expensive but accurate. Nevertheless it can be also evaluated using the data sheet or using flow measures in other auxiliary equipment in the system like pumps (less accurate but good enough)
- Water temperature inlet
- Water temperature outlet

A BEMS will compute electrical and thermal energy and will decide on the boiler on/off status and also on the outlet water temperature set-point in order to optimise energy consumption and take into account thermal inertia.

A boiler is the key equipment to achieve an energy efficient performance both in heating and hot water systems, where the boiler is the largest energy consumer. Therefore, an energy efficient performance of this equipment influences greatly in the efficiency of the whole system. Outlet water temperature reduction increases the equipment efficiency and reduces the primary energy consumption for a certain thermal energy generation. The outlet water temperature regulation can allow managing the total capacity of the equipment. However, if the thermal energy demanded requires the maximum power, outlet water temperature reduction is not possible. A good matching between outlet water temperature regulation and energy storage can significantly reduce energy consumption.

Considering the building systems as a whole, the model structure of a building automation network is made up of components (e.g., sensors, controllers, actuators), all necessary connections between the components have to be enabled on different layers (application and physical layer) and have to be carried out on two different levels (logical and physical level).

Two of the leading networking standards in this shift are LonMark (based on LonWorks control network technology) and BACNET standard.

#### *3.1.2.1 ISO/IEC 14908; Lonworks: Control Network Standard (LonMark)*

A LonWorks Building Automation Network consists of intelligent devices that communicate with each other using a common protocol over one or more communication channels. The LonWorks protocol, also known as the LonTalk protocol and the ISO 14908/ANSI/EIA 709.1 Control Network Standard, is the heart of the LonWorks system. The LonWorks protocol is a layered, packet based, peer-to-peer communication protocol.

The LonWorks protocol implements the concept of network variables. Network variables simplify the tasks of designing LonWorks application programs for interoperability with multivendor products and facilitate the design of information-based, rather than command-based, control systems. Via a process that takes place during network design and installation called binding, the device firmware is configured to know logical addresses of the other devices or groups of devices in the network. The binding process creates logical connections between an output network variable in one device and an input network variable in another device or group of devices. Connections may be thought of as “virtual wires”.

As the subsystems are logical divisions of a network, and devices can belong to multiple logical divisions, the user can create multiple subsystems that cross reference a network, and add individual devices to each of them. In this manner, devices can appear in multiple subsystems. For example, the user can create one subsystem to represent the physical layout of network, and another one to represent the functional layout (e.g. HVAC, lighting, etc.).

#### *3.1.2.2 ISO 16484:2005; Building automation and control systems (BACS)*

**BACnet** (**B**uilding **A**utomation and **C**ontrol **Net**work) is a standardized data communication protocol developed by the American Society of Heating, Re-frigeration and Air-Conditioning Engineers (ASHRAE) for use in building automation to enable devices and systems to exchange information. BACnet is used in numerous building automation systems worldwide and acquired the international ISO 16484-5 standard in 2003 [12].

In addition the BACnet standard defines object types that support the demands and functionality of building automation. While supporting analog and digital input/output objects, BACnet also supports complex objects relevant to system control, trending and scheduling. BACnet is also open to supporting new developed objects where required without a deployed system requiring the latest BACnet release to support such new objects.

# 4 Problem Scenarios Identification

To ensure relevance of the BaaS system and proper alignment of the RTD outcomes with the application domain, a set of theoretical case studies have been performed to characterize the application domain and identify its **problem scenarios**.

A problem scenario [8] tells a story of current practice, detecting the inefficiencies in the building energy performance, from a theoretical point of view. These stories are carefully developed to reveal aspects of the stakeholders and their activities that have implications for designing the solution. In this sense the problem scenarios should reveal the work-related issues that the field study has uncovered. These stories that describe the detected problems can be found in the Appendix A: of this document.

In this section five problems (as inefficiencies) have been identified and described. In Appendix A, the Problem Scenarios analyse these problems in each Theoretical Case Study, taking into account the opinion and contributions of end users (ESCO) and the different stakeholders participating the building energy industry.

## 4.1 Problem 1: Inefficient control strategies for thermal comfort and energy efficiency

There are a lot of buildings that have control strategies to achieve thermal comfort, but many of these control systems do not take into account energy efficiency.

It is essential achieving the comfort conditions but the ideal solution will have to ensure that the comfort is achieved with the minimum energy consumption.

Depending on each Theoretical Case Study considered, the control to achieve comfort will be done using different variables. In some cases the control will use only the temperature of the selected areas, but other buildings or facilities will need a control of temperature and humidity and there can be cases in which will be necessary controlling a greater number of variables such as air quality. Due to these differences among the different theoretical case studies, several Activity Scenarios will be generated to solve this problem taking into account the different variables needed to achieve indoor climate comfort conditions.

## 4.2 Problem 2: Control Strategies not considering known future circumstances

This problem is similar to the previous one, but in this case it has been detected a lack of predictive control strategies in general. Nowadays most buildings have control strategies where are only considered the indoor conditions (temperature, humidity) and they do not take into account the outside conditions. The outside variables (outside temperature, wind speed, relative humidity) are very important since they have influence on the building behaviour and energy consumption.

Knowing, by means of forecasting, in advance the evolution of certain variables that will affect the behaviour of the building should be useful to take better decisions to improve comfort conditions and reduce the energy consumption.

Lack of predictive control strategies has been detected in all Theoretical Case Studies, but there will be buildings where a simple control based for example in temperature will be enough and it will not be profitable a predictive control strategy as far as this type of strategies needs the implementation of more sensors and devices for the knowledge of several variables and systems for the data processing.

## 4.3 Problem 3: Optimize energy performance in buildings to increase the profit margin of the end user (ESCO)

When an ESCO starts an energy management business, different energy improvements are made for achieving a reduction in energy consumption and to increase the economic profit. If during the term of the contract, the financial ratios are met, there are no more energy improvements to increase profits.

For an ESCO it is necessary to optimize, continuously throughout the contract, the energy performance of the system, improving the economic and energy ratios and achieving an increase theoretical profit.

The energy optimization system depends on the use of the facility, the equipment status and external conditions.

## 4.4 Problem 4: Different building management system in each building and across buildings

Usually, when an Energy Service Company works with several buildings and facilities, it has to face a problem: there is a different building management system in each one of them and in some cases can even be several BMSs in the same building.

When the worker has to change a set point or some controls in several of these buildings, he will have to work with each of these BMS separately and in many cases, he will have to repeat the same operation many times. When this situation occurs there is a problem of effectiveness and therefore an economic problem for the company.

The optimum should be finding a way to connect to any BMS from one unique point. Thus, the worker would be able to do some changes in several BMS at the same time, because he would apply those changes once and the system would send the information to each BMS.

The need to collect information from multiple buildings and provide services using a uniform interface makes this problem scenario more an operational-level than a research-level problem:

1. An ESCO needs to obtain data by accessing the BMS of each particular building.
2. It needs to apply its business logic so that analytic services can be provided.

In essence having non-uniform data access methods hampers works downstream as well (in the analytic, business-logic bit). So the BaaS solution by having a uniform interface will make it easier to provide analytic services, in a heterogeneous portfolio of buildings which are being managed by the ESCO.

## 4.5 Problem 5: Lack of a fault detection and diagnosis system

When a company is responsible for the maintenance of a facility, it is very important for them to know immediately or as soon as possible that a breakdown, a performance degradation or unexpected behaviour have occurred in the operation of the installation, in order to ensure proper operation.

Depending on the contract's conditions that the owner has with the maintenance company, the time between the incident and the revision of the staff in charge may be too long which may affect the behaviour of the whole facility. During this time, the installation could work incorrectly and there will be consumptions that should not happen in the normal conditions.

This energy consumption could be avoided if an alarm signal is sent to the staff in the same moment of the incident. So, the maintenance staff could solve the problem much sooner than if there is no a fault detection and diagnosis system and therefore it would be possible to avoid unnecessary energy consumption.

In the particular case of Dalkia, currently they are working using three levels to identify the possible alarms (level 1, 2 and 3). When an alarm is detected, an SMS or email (depending of the level) is sent to the responsible for maintenance (worker, team boss, sector boss…)

There are alarms that can be seen on the control system panels, but perhaps they aren't notified to anybody. They are detected by the staff, when the correspondent person visits the installation. The problem lies on this absence of notification from the fault detection and diagnosis system.

# 5 Activity Scenarios Identification

For each Problem Scenario, one or more Activity Scenarios have been defined depending on the raised problem in order to obtain the appropriate solution. One Problem Scenario may affect to several Theoretical Case Studies, but the Activity Scenarios that solve this problem, can be different for each case study. In this sense, the Activity Scenarios have been defined from a theoretical point of view, since in the real buildings will have to be considered different factors that will make possible the solution implementation.

## 5.1 Activity Scenario 1. Control strategies for thermal comfort and energy efficiency improvement

*(PS1: Inefficient control strategies for thermal comfort and energy efficiency)*

The defined solutions for this problem scenario are divided in three levels, depending on the existing control system. Thus, only temperature, temperature and humidity and other control strategies can be found.

### 5.1.1 Activity Scenario 1.1: Temperature Control Strategies

To solve this problem, it will be necessary either to install or use several temperature sensors in the selected buildings. After the analysis of the buildings, temperature sensors will be placed in the occupancy areas.

Besides knowing the temperature in each relevant area, it will be necessary to design control strategies, to define set points and select a communication system.

The use patterns and the type of use of the building need to be analysed, as well as the schedules and all relevant information that allow designing the effective control strategies to achieve more comfortable temperature using the least amount of energy.

After analysing all theoretical case studies, it was found that this control could be implemented in **schools** and **hotels**.

Depending of each case, the level of occupancy will be different because this can be constant or known in some cases and unknown in others. For the school, there is usually a known occupancy with a fixed schedule, so the control of temperature in this type of buildings can be easier than the one in other buildings; for the case of working in a hotel, the occupation is not the same every day, so it will be necessary to calculate an **occupancy foreseen** and to establish several levels of temperature because it is possible to need immediately one room so this one has to have an appropriate comfort temperature quickly.

### 5.1.2 Activity Scenario 1.2. Temperature and Humidity Control Strategies

This Activity Scenario solves the Problem Scenario 1 too, but in this case besides taking into account temperature to achieve comfort, the control of the humidity level in the building is also considered.

This one will be implemented in **offices' buildings**, **hospitals** and **swimming pools**, because these types of buildings need controlling the humidity apart from temperature. Specially, in the case of swimming pools, the humidity control is very important and it is necessary a specific control of this parameter. In this type of building, a constant temperature in the water of the swimming pool and an adequate temperature inside the pool room are needed, but also, there is the need to maintain appropriate conditions of relative humidity in the pool room to prevent condensation and other problems.

As in the previous case, the **use patterns**, the **type of use** of the building, the **schedules** must be known and it will be necessary to install temperature and humidity sensors in the selected areas to achieve comfort through the design of control strategies that take into account these two parameters.

By adding more variables to control, the strategies in this case will be more complex than the previous one in which was considered only the temperature.

### 5.1.3 *Activity Scenario 1.3. Temperature, Humidity and others (air quality, stratification…) Control Strategies*

This is the third Activity Scenario which solves the Problem Scenario 1. As can be seen, the same problem can have different solutions depending on the type of building. This third solution will be implemented in **shopping malls**, because in these buildings it is necessary to control, apart from the temperature and humidity, other variables such as the **quality of air** or its **stratification**.

Temperature and humidity sensors must be installed as in the previous case, but additionally it will be necessary to install other type of sensors to control the quality of the air and its stratification. The definition of the control strategies in this type of buildings will be more complex than in the previous cases.

The stratification in great height spaces should be studied and encouraged during periods of cooling demand and avoided during periods of heating demand. Also has to be ensured an effective ventilation system that provides enough flow of outdoor air to avoid high concentrations of contaminants.

Regarding occupancy data of shopping malls, obtaining these data is also more complex than in the rest of typologies, because the occupancy is highly variable and it is very difficult to be predicted. There are other buildings whose occupancy is also variable, such as pools, but in that case it is more predictable as are known the schedules of swimming lessons or competitions and amount of people involved in them.

## 5.2 Activity Scenario 2. Advanced Control System

*(PS2: Control Strategies not considering known future circumstances)*

This Activity Scenario is the solution to the Problem Scenario 2. It has been detected a lack of predictive control strategies in all the TCS, but it must be taken into account that this type of control is not always profitable, because in some cases a simple control based for example on temperature control is enough due to the characteristics and the use of the building.

This kind of control system has many advantages in comparison with a simple control system. It can guarantee great savings because it will take into account more data to achieve the comfort conditions and also has the characteristic to predict certain changes.

To obtain an advanced control system, it will be necessary to develop the following three points:

- Data gathering
- Weather prediction tool
- Demand prediction tool

First of all, it will be necessary to have real performance data to work with them. Cause of that and as happened in the previous cases, must be installed sensors which will be connected to a system for the data collection.

On the other hand, weather forecast will be very important because the weather outside will have a great influence on indoor comfort conditions and energy consumption. For this, weather forecasted information will be necessary.

Finally before developing the advanced control system, it will be necessary a demand prediction tool. These two prediction tools will use the stored data by the data collection system above mentioned.

### 5.3 Activity Scenario 3. Energy and Economic Evaluation System.

*(PS3. Optimize energy performance of the facility to increase the profit margin of the end user: ESCO)*

This Activity Scenario is the solution to the Problem Scenario 3. It is necessary to know the energy costs and how to manage the energy system to reduce them.

It will be necessary to develop an updatable database with energy rates of different energy sources, to evaluate energy costs.

On the other hand it is necessary to economically evaluate each control strategy derived from Activity Scenario 2. This will be defined and calculated in the corresponding KPI. Once economically Advanced Control System options are evaluated, it will be implemented the solution that best suits energy efficiency and make more profit.

### 5.4 Activity Scenario 4. Management Integration System

*(PS4. Different building management system in each building and across buildings)*

To solve the Problem Scenario 4, it will be necessary to work on a (or a set of) communication (existing) tool that is able to communicate with any building management system and translate all the information received from those systems, so the end user will have a simpler way to connect to several buildings even when each building works with a different building management system.

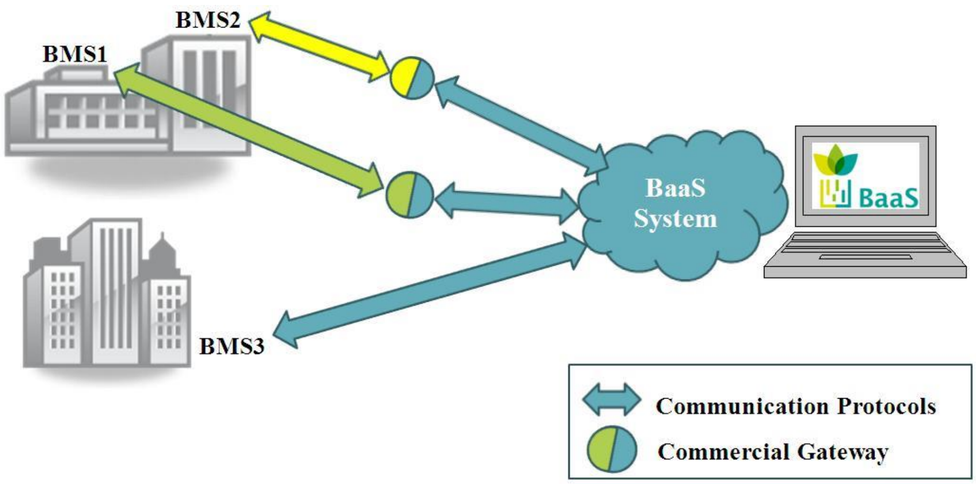



**Figure 11: Solution to Problem Scenario 4. Management integration system**

The BaaS system should implement open or standardized protocols for the communication with the BMS systems (LON or BACnet based). If this wasn't possible, it will be necessary to include one commercial Gateway mapping the proprietary protocol to BACnet or LON.

The BaaS system should be able to communicate (interworking: retrieve and write data) with the existing BMS on BaaS test-beds and demonstration buildings.

### 5.5 Activity Scenario 5. Implementation of a fault detection and diagnosis system

*(PS5. Lack of a fault detection and diagnosis system)*

The fault detection and diagnosis system will be a very important tool to avoid unnecessary consumptions. The first step is to define all possible alarms that may be useful to improve the operation of the facility and prevent that a small failure causes other type of breakdowns and higher energy losses.

When the necessary alarms for the proper operation of the facility have been selected, should be decided how to act once the alarm is activated. Depending on the type of this alarm, the system can act directly without advising anyone but sending an alert message, or sending an alert message to the person in charge of the management who will have to fix the problem that caused the alarm.

Alarms that will generate a direct action from the system and which of them will require a fast response of the maintenance staff must be defined. In this last case, the people in charge of receiving this alarm signals must also be selected. In any case, all generated alarms will be stored in the system.

### 5.6 Summary of Activity scenarios against Theoretical Case Studies

After the identification of the Problem Scenarios and their related Activity Scenarios, this section has the goal of finding a set of Theoretical Case Studies (henceforth TCS) from the point of view of the defined Problem Scenarios.

The objective is trying to assure that most of the problem scenarios (defined in each of the seven theoretical case studies) are merging on such selected buildings, so that the application scope of the final Baas solution would be as wide as possible. A TCS supporting a big number of PS will represent a bigger number of non-residential buildings.

This information is represented in the following Table 8, where the TCS affected by each of the Problem Scenarios are marked with a X.

In the table, besides of the identified Problem Scenarios and their related Activity Scenarios, it can be seen a column where can be found variables, systems or involved actors that will be taken into account in the development of the Activity Scenarios.

The Problem Scenarios 2, 3, 4 and 5 can be found in all the TCSs in the same way, nevertheless the number 1 although is represented in all the TCSs, there are three different activity scenarios to solve the same problem. Each of these activity scenarios is applied to different TCSs depending on the characteristics of the control system of each type of building.

With this information, it can be concluded that BaaS System will have a great replication regardless of the types of building finally chosen.

## 5.7 Use cases identification for covering the Activity Scenarios

Once analysed and selected the activity scenarios to solve each of the defined problem scenarios, a set of theoretical use cases has been identified. These use cases, thought here from a theoretical point of view can be related to different activity scenario, as it is shown in Table 9, and applied to different energy systems. The particularization of the use cases to the selected demo sites of BaaS project can be found in D5.1, where the description of these use cases is focused on specific energy systems and building controls.

### 5.7.1 *Zonal set point regulation*

A trade-off exists between thermal comfort and energy consumption. It is desirable to have a good way of achieving comfort, while minimizing energy. Supervisory controllers that can select automatically the set point temperatures of the heating or cooling units can yield good performance.

### 5.7.2 *Evaluation of the potential of using virtual sensors*

The virtual sensors provide calculated data points in order to use them for calculating other parameters. For example, for the calculation of thermal comfort, the Fanger PPD index is used in order to estimate the user discomfort levels. If there are no available sensors capable of measuring directly the Fanger PPD levels inside the building, the concept of virtual sensor is introduced.

### 5.7.3 *Operate the radiant floor water system loop to reduce the energy consumption*

This use case aims at covering heating demands while maintaining occupants' thermal comfort. The correct evaluation of the demands and the related energy consumption while keeping the comfort parameters in a correct level can result in energy savings.

### 5.7.4 *Optimization of the supply temperature set point*

This use case can be applied to heating/cooling systems whose control routines are considered by the outside air temperature, but without information about the temperature of the indoor conditions.

The system could be improved including in the control the effects of external environmental conditions for specific usage profiles compensating the set points in each zone and modulating supply temperature according outdoor and indoor conditions.

### 5.7.5 *Season change operation assistance according to economic and comfort parameters*

In the intermediate stations environmental conditions can change dramatically in a short period of time and affects the internal conditions of buildings with little thermal insulation. For this reason, rooms with different orientations usually have different temperature levels. These conditions cause a decrease in the level of people satisfied proportionally to the increase in temperature differences between rooms with different orientations.

This use case aims at assisting the facilities' management staff for changing the operation mode, based on parameters of economic savings while maintaining the adequate levels of comfort in the spaces.

### 5.7.6 *Optimization of the operating hours of the systems according to the internal conditions*

The control system manages the production and thermal energy. Maintenance staff according to their experience and the requirements of the occupants of the hotel is responsible for starting or stopping the distribution with thermal energy toward the building by pumps for distribution with terminal elements and air handling units for common areas.

This equipment is common to work according to a time control; maintenance staff decides which the appropriate schedule is in each time. The lack of knowledge about ambient conditions and building thermal demand causes that equipment is working so inefficient and unnecessary for most of its lifetime.

The system could set the most appropriate schedule for each time according to the occupation profile, outdoor and indoor conditions, weather forecasts and the building behavior to reduce the operating time of the generating heat and cold.

### 5.7.7 *Adjust set point of DHW accumulation according to occupation and use frequency*

This use case aims at evaluating the occupancy data and frequent schedule hot water use to optimize the accumulation set point in order to reduce the peak power increase in the boilers.

### 5.7.8 *Combined control of solar gains and radiant floor*

The goal of this task is to find an optimised relation of heating/cooling set point and solar protection elements' control in buildings with radiant floor. The long-time constant, characteristic of this king of system, causes difficulties for the optimization of internal temperatures control. A correct forecast let the control replace partially the energy delivered by the slabs with harvested solar energy that maximize comfort and minimize energy. On the other hand, an incorrect control can increase the room temperature in case of unexpected radiation or can keep the spaces under heated in case of unexpected lack solar gains.

### 5.7.9 *Optimization of the heating mode operation*

The goal of this task is to reduce the operating time of the heating system - and decrease energy consumption and costs - during periods with no occupation, i.e. where the constraint of thermal comfort has no or less influence.

The system should act in advance to ensure thermal comfort while consuming less energy. For example a "smart" weekend setback with a heating-up period early Monday morning avoids the operation of the heating system during weekend where there is no occupation of the building.

### 5.7.10 *Optimization of energy generation and/or distribution starting-stopping point*

In systems managed only by schedules, the system could be improved calculating the optimal starting and stopping time of the energy generation and/or distribution systems considering weather forecast, occupancy-profile, and indoor temperature.

### 5.7.11 *Utilization of solar energy for energy savings while ensuring comfort*

In low consume buildings with passive solutions are designed in a way that permits the capture in cold winter days of the solar radiation that point the façade, storing all energy thought inertial systems (heavy masses) that heat up occupied space. These working modes allow that from

February to November buildings nearly does not need any energy to heat up the occupied rooms.

Also the negative part of these solutions is the risk of having some sunny days during the heating period in a row without blocking the solar radiation with the blinds, what creates a quick overheating of the rooms and the correspondent thermal discomfort. The problem becomes more interesting during the cooling season because a radiation block to control the ambient temperatures causes a light decrease that create luminance discomfort and a need of electrical lighting.

The objective of this use case is to find an optimised relation among heating/cooling set point, blind control and artificial lights to keep balanced the overall consume of the building without creating visual and thermal discomfort.

### 5.7.12 *Model-based comfort monitoring*

This use case aims at developing models for passive buildings for the optimisation control trying to minimize the amount of days that the building stayed in discomfort.

### 5.7.13 *Occupancy faults detection*

There are numerous possibilities and situations for uncertain incidents within the operation of a building. In order to prevent failures of the building operation or times out of comfort conditions, the building system has to react on this abnormal situation. Depending on the type of incident, the system has to detect, react and reconfigure while occurring situations as:

- Unscheduled meeting occurs
- Scheduled meeting cancels
- Room temperature sensor fails

### 5.7.14 *Prevention of inefficient operational decision*

A necessary condition for good “optimized” control is the existence of FDD including services as the followings:

- AC-Window, where an error event is reported when the AC is operating while a window is open;
- AC-Occupancy, where an error event is reported when the AC is operating while the room is unoccupied;
- AC-Schedule, where an error event is reported when the AC is operating out of schedule;
- Simultaneous heating/cooling, where an error event is reported when the heating system is operating while a window is open.

### 5.7.15 *Fault detection, KPIs and analytics*

This use case covers different solutions for fault detection that can be applied to different energy generation or distribution systems, considering also the KPIs evaluation in order to detect failures on both the energy and control systems. Particularized solutions are necessary depending on the elements to be evaluated (i.e. boilers, pumps, etc.)

**Table 8: TCS vs. Problem and Activity Scenarios**

<table>
<tr><th colspan="2" rowspan="2">Problem Scenarios</th><th colspan="3" rowspan="2">Activity Scenarios</th><th rowspan="2">Actors Solutions</th><th colspan="6">THEORETICAL CASE STUDIES (*)</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Inefficient control strategies for thermal comfort and energy efficiency</td><td>1.1</td><td colspan="2">Temperature control</td><td>Set points, BIM, communication systems, occupancy, temperature sensor, building</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.2</td><td colspan="2">Temperature & humidity control</td><td>Set points, BIM, communication systems, occupancy, temperature and humidity sensor, building</td><td></td><td></td><td>✓</td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>1.3</td><td colspan="2">Temperature, humidity & others, control</td><td>Set points, BIM, communication systems, occupancy, temperature, humidity, air quality sensor, building</td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Control Strategies not considering known future circumstances.</td><td rowspan="3">2.1</td><td rowspan="3">Advanced control system</td><td>Data gathering</td><td>Building, Weather station, historical data, data warehouse, temperature and humidity sensors, occupation level, communication system</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Weather Prediction Tool</td><td>Weather station, weather forecast, historical data, data warehouse, temperature and humidity sensors, occupation level, communication system</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Demand Prediction Tool</td><td>Building, Historical data, data warehouse, temperature and humidity sensors, occupancy levels, loads, HVAC systems</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Control system | Building, weather station, historical data, data warehouse, temperature and humidity sensors, building management system, prediction tool, HVAC system, distribution system, real-time monitoring | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **3** | Optimize energy performance of the facility to increase the profit margin of the end user: ESCO | 3.1 | Rates to estimate consumption and others variables (Energy, Economy) | | Building, HVAC Performance, energy meters, energy bills, temperature sensor, occupancy levels, loads, historical data, operation cost | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **4** | Different Building Management System in each building and across buildings | 4.1 | Management integration system and adjusted optimization logic | | Building management system, middleware, communication system, SCADA, optimization strategy/logic | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **5** | Lack of a fault detection and diagnosis system | 5.1 | Implementation of a fault detection and diagnosis system | | Control system, HVAC system, all sensors of the building, distribution system, building management system, real-time monitoring with continuous asset commissioning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

(*) 1-School, 2-Hotel, 3-Office Building, 4-Swimming Pool, 5-Hospital, 6-Shopping Mall

As stated before, once analysed and selected the activity scenarios to solve each of the defined problem scenarios, a set of theoretical use cases has been identified. These use cases, thought here from a theoretical point of view can be related to different activity scenario, as it is shown in the following table:

**Table 9: Theoretical use cases related to Activity Scenarios**

| Problem scenario | Activity scenario | Use cases | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Zonal set points regulation | Evaluate the potential of using virtual sensors | Operate radiant floor water system loop to reduce energy consumption | Optimization of the supply temperature set point | Season change operation assistance according to economic and comfort | Optimization of the operating hours of the system according to internal conditions | Adjust set point of DHW accumulation according to occupation and use frequency | Combined control of solar gains and radiant floor | Optimization of heating mode | Optimization of energy generation and/or distribution starting-stopping point | Utilization of solar energy for energy savings while ensuring comfort | Model-based comfort monitoring | Occupancy faults | Prevent inefficient operational decisions | KPI analytics |
| Inefficient control strategies for thermal comfort and energy efficiency | Temperature Control | ✓ | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | | | | | |
| | Temperature & Humidity control | | | | | | | | | | | | | | | |
| | Temperature, humidity & others, control | | ✓ | | | | ✓ | | | | | ✓ | | ✓ | | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Strategies not considering known future circumstances | Advanced control system | Data gathering | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | Weather Prediction Tool | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | |
| | | Demand Prediction Tool | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | |
| | | Control system | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | |
| Optimize energy performance of the facility to increase the profit margin of the end user: ESCO | Rates to estimate consumption and others variables (Energy, Economy) | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | |
| Different Building Management System in each building and across buildings | Management integration system and adjusted optimization logic | | | | | | ✓ | | | | ✓ | | | | | | |
| Lack of a fault detection and diagnosis system | Implementation of a fault detection and diagnosis system | | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |

# 6 End-user and technical requirements

## 6.1 End-user requirements

After the definition of Problem Scenarios and their corresponding Activity Scenarios, it was needed defining requirements for each of these solutions. The requirements can be found in the Appendix C of this document.

The starting point for the description of the requirements is the specification of the activity scenarios which collect the end-user needs for the system. Then, the process begins with the problems to be solved by the BaaS System that are translated into requirements.

These end-user requirements are listed here:

- The system should be able to allow the communication with the users through several graphical-user-interfaces in order to manage and operate the system.
- The system should allow the configuration of the main parameters for the proper behaviour of the system, interwork with heterogeneous networks and work with open systems where possible based on SOA (Service Oriented Architecture).
- The system should be able to maintain data consistency and to ensure high availability of the data.
- A transparent and generic mechanism for development, deployment and configuration of APO modules should be provided within the BaaS system. APO modules are basic software modules, providing the business intelligence of the BaaS system at the APO Service Layer.
- The BaaS system should detect abrupt changes in the monitored system (building), where the changes relate to difference from expected behaviour (correct one).
- The BaaS system should calculate KPIs describing the monitored system (i.e. building) in terms of its energy performance and user comfort (for further information see KPIs chapter in this document).
- The system should support supervisory control and control optimization functionalities. For design and optimization purposes access to simulation might be required.
- The system should be able to provide multiple simulation approaches: on the (whole) building level and, if needed, at the component level (e.g. HVAC system). These simulations should be exposed to the other system components and be made available upon request. A platform for providing “simulation as a service” to be consumed by other services is necessary.
- The system should provide a sufficiently high availability (service level agreement) and be scalable as well as fault-resilient. Scalability, replicability, reliance and robustness concepts should be taken into account.
- The system should be able to ensure confidentiality and integrity of collected data, particularly of personally identifiable data as well as ensure privacy of people affected by the operation of the system.

## 6.2 Functional and non-functional requirements for use cases development

These requirements have been defined mainly within WP3 and with the participation and contribution of WP2, 4 and 5 and they have been reviewed since they must be aligned with the Activity Scenarios and with the needs of end users.

Once the end-user requirements have been defined, these are taken as input for the technical requirements definition, which are divided into functional and non-functional requirements. Functional ones represent the main functionalities required by the BaaS platform users and the non-functional ones complement the functional requirements in order to ensure the performance and security of the system.

Once the agreement with all the users involved in the specification of the BaaS System behaviour is reached, the use cases are able to be designed (in WP3). These collect the functionalities which should be implemented for the appropriate operation of the system and carry out the requirements. Thus, WP3 has worked considering the set of all services that BaaS system will provide.

The functional requirements are split in seven sets of requirements:

- Human-Machine Interaction
- System Management (System Configuration, Interoperability and Openness)
- Data Management
- APO modules
- Fault and Detection Diagnostics
- APO services: Energy and Comfort Management
- APO services: Control Optimization Modelling and simulation

Besides, two groups of non-functional requirements have been defined:

- Performance
- Security

These requirements have been classified by their importance in three categories (high, standard and critical) and their rationales have been defined, including also the assumptions and constraints related to them. All this information is in Appendix C.

### 6.3 Data requirements: information to be collected from buildings

The building information (data) requirement should be highlighted, thus in the Appendix B, it is shown the required data regarding several topics. All this information is classified in different categories and it is shown within tables. In those tables, the last three columns indicate whether the required data belong to static building information (BIM), dynamic information (to be stored in the data warehouse) or if the data are external data.

While a BIM repository should contain all the static data, DWH will include the dynamic data, related to the static elements. These data inputs have been divided in the following topics, which are integrated inside the BaaS working domains:

- Location and climate data
- Building geometry and construction elements definition
- Thermal zones, internal gains and exterior energy equipment
- HVAC systems
- On-site energy generation from renewable sources
- Energy monitoring and control systems

This list of required data is a very complete list although when are working with real buildings, it is probably that a lot of these data will not to be, and then a default value will be set. This default values will be established by the correspondent task (WP2 from data consistency, WP4 from simulation models and WP5 from APO Services points of view).

# 7 Key Performance Indicators definition

In order to evaluate a building and its energy supply systems regarding energy efficiency and comfort, the different subsystems for heating, cooling, domestic hot water and electricity need to be evaluated separately. However, the overall investigation needs to bring these values together into an overall building performance assessment.

The parameters defined in this section will be used for the building energy performance evaluation and as a basis for the evaluation. Key Performance Indicators (KPIs) have been defined below European standard (Table 10: Relevant Standards).

**Table 10: Relevant Standards**

| Standard | Description |
|---|---|
| DIN V 18599: 2007 [16] | Energy efficiency of buildings-Calculation of the net, final and primary energy demand for heating, cooling, ventilation domestic hot water and lighting. |
| ISO/EN 7730: 2007 | Analytical determination and interpretation of Thermal Comfort |
| EN 13779: 2007 [14] | Ventilation for non-residential buildings-Performance requirements for ventilation and room-conditioning system |
| EN15217: 2006 [17] | Energy Performance of buildings-Methods for expressing energy performance and for energy certification of buildings |
| EN 15251: 2007 [13] | Indoor environmental input parameters for design and assessment of energy performance of building addressing indoor air quality, thermal environment, lighting and acoustics. |
| EN 15316 | Heating Systems in Buildings – Method for calculation of system energy requirements and systems efficiencies |
| EN 15603: 2008 [15] | Energy performance of buildings-Overall energy use and definition of energy ratings. |
| ISO 50001: 2011 | Energy Management System |

The defined KPIs are classified in six sections, covering different aspects to evaluate:

- Energy indicators
- Environment indicators
- Comfort indicators
- Economic indicators
- Data quality indicators
- Building systems' performance indicators

The following table summarizes these indicators, which are explained in the following sections:

**Table 11: Summary of BaaS KPIs**

| ENERGY INDICATORS | | | |
|---|---|---|---|
| Key Performance Indicator | | Reference | Unit |
| NECE | Net Energy Consumed Electric | Eq. 2 | $kWh_e$ |
| NECT | Net Energy Consumed Thermal | Eq. 3 | $kWh_t$ |
| SCL | Summer Cooling demand | Section 7.1.4.1 | kWh |
| WHL | Winter Heating demand | Section 7.1.4.2 | kWh |
| NFEC | Net Fossil Energy Consumed | Eq. 4 | kWh |
| NEP | Net Energy Performance | Section 7.1.4 | kWh |
| $\eta$ | Efficiency | Eq. 6 | % |
| DEP | Dependence from external sources | Eq. 7 | % |
| PEC | Primary Energy Consumed | Eq. 5 | kWh |
| PES | Primary Energy Savings | Eq. 9 | kWh |
| PESP | Primary Energy Savings Percentage | Eq. 10 | % |
| $NECE_{norm}$ | Net Energy Consumed Electric / normalisation criteria | Eq. 2 / norm. | kWh/HDD<br>kWh/CDD<br>$kWh/m^2$<br>kWh/person |
| $NECT_{norm}$ | Net Energy Consumed Thermal / normalisation criteria | Eq. 3 / norm. | |
| $SCL_{norm}$ | Summer Cooling demand / normalisation criteria | Section 7.1.4.1 | |
| $WHL_{norm}$ | Winter Heating demand / normalisation criteria | Section 7.1.4.2 | |
| $NEP_{norm}$ | Net Energy Performance / normalisation criteria | Section 7.1.4 | |
| $PEC_{norm}$ | Primary Energy Consumed / normalisation criteria | Eq. 5 / norm. | |
| $PES_{norm}$ | Primary Energy Savings / normalisation criteria | Eq. 9 / norm. | |
| HDD | Heating Degree Days | Eq. 12 | ºC DD |

| | | | |
|---|---|---|---|
| CDD | Cooling Degree Days | Eq. 13 | ºC DD |
| **ENVIRONMENT INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| $CO_2$ | $CO_2$ Emitted to the ambient | Eq. 14 | $TonCO_2$ |
| $CO_2^{extra}$ | Extra emissions | Eq. 8 | % |
| $CO_{2\ norm}$ | $CO_2$ Emitted to the ambient / normalisation criteria (HDD, CDD, area, person) | Eq. 14 / norm. | $TonCO_2$/HDD<br>$TonCO_2$/CDD<br>$TonCO_2/m^2$<br>$TonCO_2$/person |
| HDD | Heating Degree Days | Eq. 12 | ºC DD |
| CDD | Cooling Degree Days | Eq. 13 | ºC DD |
| **COMFORT INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| POR | Percentage outside range | Section 7.3.1 | % |
| DHC | Degree hours criterion | Section 7.3.1 | ºC |
| - | Temperature indoor | Section 7.3.1 | ºC |
| CPAV | Comfort parameter average value | Eq. 16 | % |
| UPT | Underperformance Time | Eq. 17 | n.a. |
| UPR | Underperformance Ratio | Eq. 18 | n.a. |
| UPP | Proportional Underperformance | Eq. 19 | n.a. |
| PMV | Predicted Mean Vote | Eq. 21 | n.a. |
| PPD | Predicted Percentage of Dissatisfied | Eq. 22 | % |
| **ECONOMIC INDICATORS** | | | |
| **Economic** | **Key Performance Indicator** | | **Unit** |
| - | Operating Costs | Section 7.4.1 | € |
| NEB | Net Expected Benefit | Section 7.4.2 | € |
| GCEI | Generation Consumption Effectiveness | Eq. 24 | n.a. |

| | | | |
|---|---|---|---|
| | Index | | |
| BPBP | BaaS Payback Period | Section 7.4.4 | n.a. |
| NPVB | Net Present Value of BaaS | Eq. 25 | € |
| IRRB | Internal Rate of Return of BaaS | Eq. 26 | n.a. |
| **DATA QUALITY INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| $DQ_C$ | Completeness of data | Eq. 27 | n.a. |
| $DQ_{TS}$ | Technical significance of data | Eq. 28 | n.a. |
| $DQ_{SS}$ | Systemic significance of data | Eq. 29 | n.a. |
| **SYSTEMS' PERFORMANCE INDICATORS** | | | |
| **Key Performance Indicator** | | | **Unit** |
| $\rho_{occup}$ | Occupant density | Eq. 30 | n.a. |
| $UI_a$ | Absolute use intensity | Section 7.6.2 | n.a. |
| $UI_{a, comp}$ | Component level absolute use intensity | Eq. 33 | n.a. |
| $UI_{a, subsys}$ | Subsystem level absolute use intensity | Eq. 32 | n.a. |
| $UI_{a, sys}$ | System level absolute use intensity | Eq. 33 | n.a. |
| $UI_{c, subsys}$ | Compared use intensity | Section 7.6.2 | n.a. |

## 7.1 Energy Indicators

The complete buildings need to be evaluated including their energy generation systems (both renewable and non-renewable), distribution and delivery systems. This all then leads to the building demand, which strongly depends on the used control strategies. For enabling the evaluation, every piece or subset need to be evaluated separately in order to be finally treated as a complete set.

The European Committee for Standardizations CEN (Comité Européen de Normalisation) proposes the adoption of a determinate structure when evaluating the building demands and primary energy needs in terms of energy and climate impact ($CO_2$ Tons).

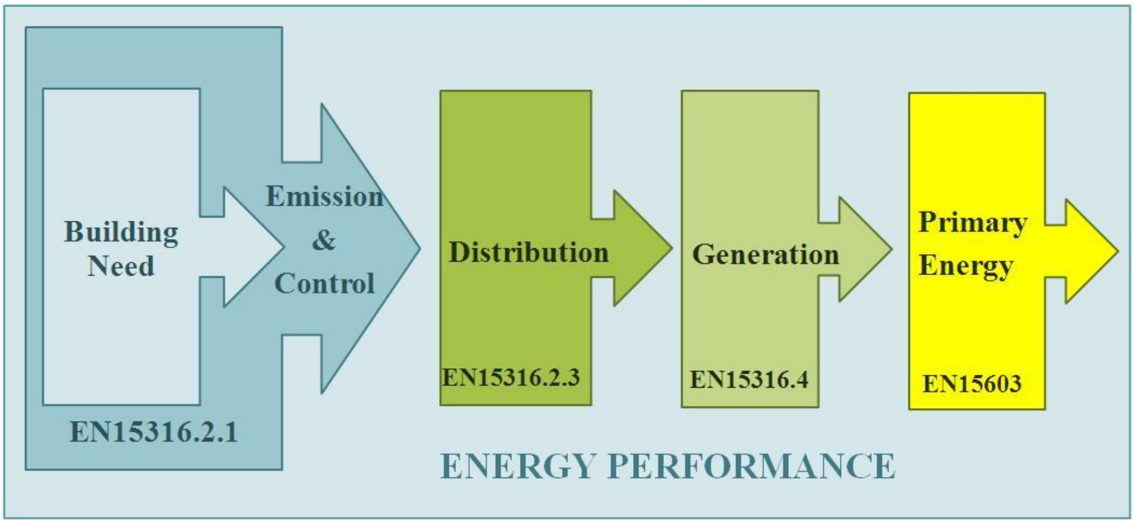



**Figure 12: Evaluation of the energy performance: energy flows from generation to need and relevant European standards**

As can be seen in the previous figure, CEN and ISO norms start the energy performance evaluation of a building from its demands, passing through the delivery systems that effectively condition the zones, over the distribution systems delivering energy to the different zones, the generation systems providing the energy until the evaluation of the primary energies needed to fulfil the building needs. An optimization of the building needs to look at all steps within this chain in order to reduce primary energy consumption and $CO_2$ emissions.

- The building demand is the net energy that will correspond to the 100% of useful energy delivered to condition the thermal zones and is only affected by the sum of different thermal losses and gains as well as the desired comfort conditions but independent on the generation and supply systems. Due to this, it is the base to "count" the energy quantities at play in the complete system, but it cannot be measured directly.
- The second step of the analysis will be the emitters and control strategies. Delivery systems like fan coils, radiators or thermally activated building element deliver heat/cold to the zones. This energy amount will cover the demand with an efficiency that will depend on the terminal system and the accuracy of the control strategies to reach the set points.
- The third stage includes the energy losses through the distribution system in the building. Here different aspects need to be considered depending on air based or liquid based energy supply systems as well as whether the energy is generated centralized or decentralized. In addition, electricity consumption for pumping and ventilation needs to be included into the energy balances.
- The fourth stage takes into account the generation losses from the production of heating, cooling and electricity in the different generation units.
- Finally, the primary energy required to produce the energy to be generated and delivered to the whole chain need to be considered. Hereby, the amount depends on the type of the generation systems as well as on the specific location/country.

The building will be considered as a black box that get energy from the external and from its "own" generators, so the measurement should be made before energy produced is distributed within the building.

The following diagram shows an example of energy flows across the system boundary as defined according to EN 15603. The displayed energy model includes adaption to the present measuring methods, i.e. the numbering of the "generation side" in order to define the references for energy types used in the description of the sample cases.

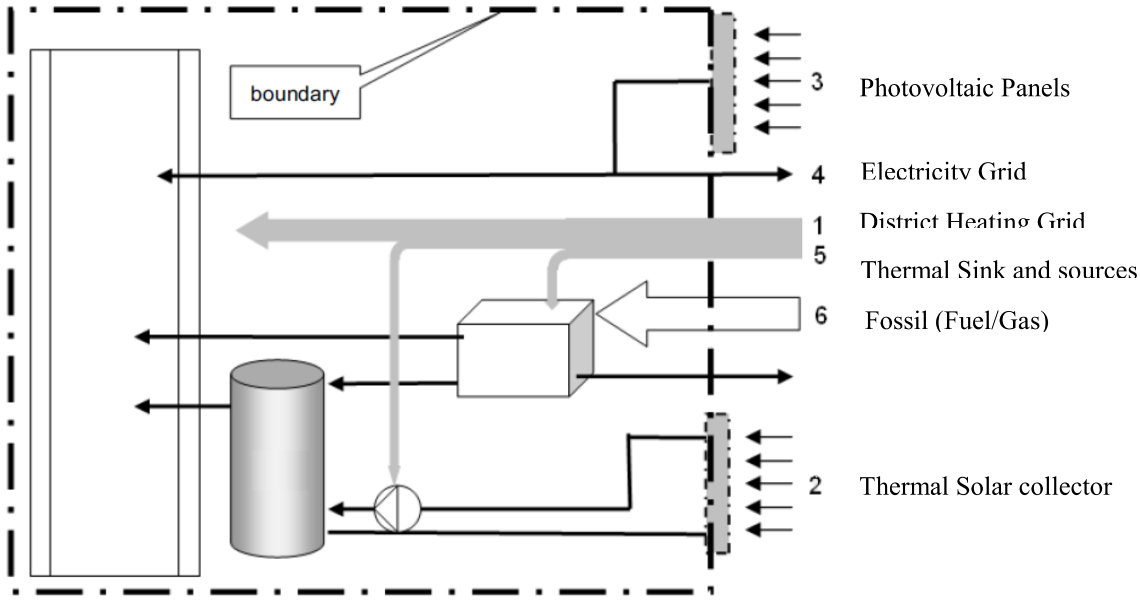



**Figure 13: Energy Model of the building on the basis of EN15603.**

Key: 1-District heating grid, 2-Thermal solar collector, 3- photovoltaic panels, 4-electricity grid, 5-thermal sink and sources, 6-fossil (fuel/gas)

### *7.1.1 Net Energy Consumed (NEC)*

The definition of the parameter Net Energy Consumed refers to the meaning of measurable energy flux ("consumed") that is consumed within the building without taking into account the primary energy process and the energy export through the system boundary to the outside ("net"). In other words the Net Energy Consumed stands for the final energy consumed within the boundary of the building.

The German standards for the assessment of the energy performance of buildings use the term "net energy" in a different way. In the context of e.g. DIN V 18599, the net energy represents the energy need to be delivered to a conditioned space to maintain the intended temperature conditions of a building/zone/room, i.e. the Net Energy Performance as defined in this report. Due to this inconsistent definitions the parameter should be distinguished by the term "Consumed" and "Performance", i.e. the consumption parameter stands for final energy (in contrast to primary energy) and the performance always corresponds to the energy need of the building without taking into account the HVAC-system.

Every one of the following parameters must be evaluated under the restrictions imposed by the different comfort norms. The number of hours that the controlled zone has been out of comfort as well as the sum of the absolute deviations of the measured comfort parameters against the acceptable ones must be closely connected to the results obtained for the energetic parameters, i.e. low energy consumptions with high discomfort values or long operating times out the comfort zones are not acceptable.

Total energy consumed by the building independently of the place where it has been produced and its possible renewable portion (EN15603).

According to the definition of a numbering key defined in the energy model displayed, the following equation shows the sum of all (six) energies delivered by the sources 1 (district heating grid), 4 (electricity grid) and 6 (fossil energies) and including internal energy production i.e. solar thermal (2) and photovoltaic (3) systems and the usage of sinks or sources within the building (5).

$$NEC = \sum_{i=1}^{6} E_{delivered,i} \qquad \text{Eq. 1}$$

The energy consumed in the building will be separated in electrical and thermal:

Net Energy Consumed Electric:

$$NECE = \sum_{i=3,4} E_{delivered,i} \qquad \text{Eq. 2}$$

Net Energy Consumed Thermal:

$$NECT = \sum_{i=1,2,5,6} E_{delivered,i} \qquad \text{Eq. 3}$$

The NEC by fossil sources will be displayed. Although the quantities are always measured in kWh, the precedence of each one of them is completely different, so the final sum will not show a clear figure of the energy consumption. Below this lines, when primary energy parameters are treated, consumes will be lately summed.

Measuring criteria for thermal systems:

- During the winter period the energy delivered as heating to the building will be considered as negative, while during the summer period is defined as positive. This classification can bring us to a mistake if we don't separate the energy by periods. If the building receives too much energy in summer time (positive values), the total energy demanded along the year can be zero. This zero should be the value of a building with null energy consume and not associated to a building that has the same losses/gains in a complete year time period.
- Energies arriving to the building must be considered in an absolute value if there is a coincidence in the working mode of the system and the cooling/heating demand. The final value is the total amount in kWh introduced in the building along the year. The authors consider this method as the most feasible one for the proposed objective. I.e. the building is demanding heating ($T_{in} < T_{set}$) and the outgoing fluid temperature of the emitter is lower than the incoming one. These two conditions convert the value measured in the calorimeters to its absolute value.

Measuring criteria for electrical systems:

- The demand will always be positive independently of the season and the kind of building demand making the evaluation is easier. It is only needed to read the value provided by the counters.

- The Net Energy Consumed (NEC) could be divided also in terms of evaluating the partial demands of the building depending on the season, the services provided by the energy, etc.

### 7.1.2 *Net Fossil Energy Consumed (NFEC)*

Defined in the same way as the NEC but not including the renewable energies in-home produced or the renewable fraction of the energies acquired from external grids.

Fossil fuels energy will be counted in base to their Lower Heating Values (LHV).

Every carrier must have associated a percentage of renewable (or non-fossil portion) to evaluate the fossil contribution.

The energy model displayed in the figure contains the definition of a numbering key introduced in the present evaluation methodology. Using this keys the following equation shows the sum of energies delivered by the sources 1 (district heating grid), 4 (electricity grid) and 6 (fossil energies). The parameter $\psi$i evaluates the percentage of renewable in every one of the considered energy carriers.

$$NFEC = NFEC^{fossil} = \sum_{i=1,4,6} E_{delivered,i} * (1 - \psi_i) \qquad \text{Eq. 4}$$

The common definition of NEC and NFEC will also permit the definition of:

- the renewable energy consumed in the building and
- the percentage of renewable energy consumed by the building.

### 7.1.3 *Primary Energy Consumed (PEC)*

Total energy consumed by the building independently of the place where it has been produced, expressed in primary energy values.

The source of each one of the energies must not be taking into account when evaluated in primary energy base. The transformation parameter to relate final with primary energy must be provided by the ESCO, usually done by evaluation of their first energy transformation efficiency. The factor fi corresponds to the primary energy factor of the delivered thermal and electrical energy.

The appendix of EN 15603 contains tables of national energy factors for European countries.

$$PEC = \sum_{i=1,4,6} E_{delivered,i} * (1 - \psi_i) * f_i = \sum_{i=1,4,6} NFEC_i * f_i \qquad \text{Eq. 5}$$

### 7.1.4 *Net Energy Performance (NEP)*

The Net Energy Performance is an indicator of the building's delivered energy. Every building is categorized according to the specific country's building energy certification. The European standards for the calculation of the Net Energy Performance use the term "energy need" (energy demand or energy use in former standards) with a similar definition, e.g. the energy need for heating or cooling represents the *"heat to be delivered to or extracted from a conditioned space to maintain the intended temperature conditions during a given period of time"*.

The Net Energy Performance will be obtained with the use of different simulation programs depending on the building object of study. As it is explained in EN 15603, *"the energy need is calculated and cannot easily be measured"*. For the Theoretical Case Study (TCS) TRNSYS software will be used. The use of all these simulation tools permits the user/programmer to know the dynamic evolution of the building under certain weather and occupancy conditions in at least one hour periods. An exact building demand will be obtained in cases where the model has being previously validated and it has been proved that the model has a similar performance as the real building. Validation can be done from existing stored data of the building or in the case of inexistence of these data, the ones that will be measured by the sensors installed in the building during normal working periods.

The need of a simulation model results from the impossibility of measuring directly the demand of a building in terms of energy. The combinations among all the loads, control dynamics and effects that vary the demand can only be measured in an indirect way, as the consequence of a sum of effects that provoke an over/under heating/cooling of controlled zone. These causes made impossible the measuring of the demand, letting open only the possibility to simulate the building under certain conditions obtaining the exact demand of the building in ideal working periods.

When studying the Net Energy Performance, some other complementary parameters can be obtained relating the ideal value of demand with the energies given to the system deployed in this chapter as can be:

- Differences between the energy consumed in the building and the energy demanded show the efficiency of the complete facility to deliver energy to a building when compared with the "ideal" case. This parameter should be divided by energy types since it is not possible to compare the final consumption independently to the possible origin of the energy (in house transformed fossil fuels, electricity and heat delivered by an external net).

$$\eta = \frac{NECT}{NEPT} \text{ or } \frac{NECE}{NEPE} \qquad \text{Eq. 6}$$

- Ratio between the primary energy needed by a building and the NEP, which shows the dependence of our building from external sources. In this case, the use of primary energy allows us to compare in a single parameter the building consume. Some previous parameters should be defined to "translate" NEP to primary energy (needed to compare the different types of energy). Primary energy factors of the real systems that feed the building must be applied to the fossil fuels used and the external energy sources from which the building acquire power during working time.

$$DEP = \frac{PEC}{NEP} \qquad \text{Eq. 7}$$

- Ratio between the CO2 emitted to the ambient and the NEP. As happened in the previous parameter, the NEP of the building must be transformed to CO2 emitted by this demand, to evaluate the extra emissions of the building when comparing to an ideal system that deliver the exact energy.

$$CO_2^{extra} = \frac{CO_2^{emitted}}{CO_2^{NEP}} \qquad \text{Eq. 8}$$

#### *7.1.4.1 Summer Cooling Demand (SCL)*

It is assumed that the total Summer Cooling Load or "cooling energy", including the energy for cooling and humidity treatment, is completely satisfied by the AC system. The SCL takes into account zone loads, outdoor air load, the heating of air that is passed through fans and the real system operating schedule and thermostatic control.

#### 7.1.4.2 *Winter Heating Demand (WHL)*

Winter Heating Loads represent the heat demand of the building, the equivalent of SCL in winter season. Both values are also called "energy need" or "energy use" in European standards.

### 7.1.5 *Primary Energy Savings (PES)*

Primary energy savings will be evaluated before and after the system has been implemented. Equivalent comfort values should be addressed in both cases to permit a comparison between the primary energies.

$$PES = PEC_{after} - PEC_{base} \qquad \text{Eq. 9}$$

The evaluation creates problems in the case of engines or turbines that convert the fossil fuel in electricity, heating and cooling. It must be defined a relation between electricity and thermal power produced previously to separate clearly the thermal fraction that must be compared to the boiler, or the electrical fraction which will feed the electrical consumptions (including the chiller).

The energy carriers corresponding to district heating, solar thermal, renewable sinks/sources and fossil energy (numbered 1, 2, 5 and 6 respectively, see Figure 13) will be taken as a gross demand of heating/cooling multiplied by their primary energy factors, while renewable electricity and the one provided by the grid (numbered 3 and 4) will be multiplied by the electrical energy factor of the country/region.

A possible relative parameter to the PES is the Primary Energy Savings in Percentage to evaluate the savings in a dimensionless parameter when compared to the base case.

$$PESP = \frac{PEC_{afer} - PEC_{base}}{PEC_{base}} * 100 \qquad \text{Eq. 10}$$

This parameter does not clearly show the absolute value of the savings reached but it is useful in the case of comparison needed between different buildings. When the optimal control for the buildings will be reached, a clear vision of the maximum expected savings for different building categories can be obtained.

### 7.1.6 *Normalisation*

For a more comparable performance evaluation the buildings energy demand can be normalized. In detail the following influences should be considered and used for an adequate evaluation or for the calculation of normalized indicators.

1. Local weather climate should be examined (e.g. HDD, CDD).
2. The building size and geometry should be taken into account (e.g. Net Floor Area)
3. The building occupancy is other variable that it is important to taken into account (person)

The category ‘External Conditions’ documents the weather conditions to allow the normalisation of absolute measured values.

The external conditions denote mainly the weather conditions in vicinity of a building. A dedicated weather station would represent the most straightforward way to collect data pertinent to this category. Such data is critical, if the energy and indoor environmental performance of a building are to be properly evaluated. Moreover, building systems control methods and regimes can benefit from the availability of detailed microclimatic data.

#### 7.1.6.1 *Normalisation using Degree Days:*

The usage of Heating Degree Day (HDD) and the complementing measurement of Cooling Degree Day (CDD) allow engineers to normalise the energy demand to heat or cool a building. HDD and CDD are functionally dependent on the measurements of outside air temperature and a so called base temperature.

$$HDD = f\left(\theta_{air,ext}, t_{base}, HDD\right) \text{ and } CDD = f\left(\theta_{air,ext}, t_{base}, CDD\right) \quad \text{Eq. 11}$$

The following algorithm can be used to calculate the 'normalised' energy consumption:

1. Decide about pre-dominant load (either heating or cooling).
2. Select the appropriate base temperature
3. Calculate HDD (or CDD) for relevant day/week/month
4. Determine weather-related energy consumption (e.g. by subtracting the base load from the total consumption or through sub-metering).
5. Divide the weather-related energy consumption by the actual degree days and multiply the result by the standard degree days
6. Add the non-weather related consumption to the normalised value of weather-related consumption

Determination of the Base Temperature: In general one can say in case the (average) outside temperature is above (or below) the base temperature a building needs no heating (or cooling) to maintain a given inside temperature (for heating usually 20°C). The heating and cooling requirements for a specific building (with specific insulation values at a specific location) are considered to be directly proportional to the number of HDD or CDD at that location.

Current HDD / CDD (step 3) can be calculated as described in before equation. Different formulas are given in the literature [ASHRAE3, CIBSE4, VDI 20675, VDI 38076]. However, all algorithms use similar input values. Therefore, the implementation of different, country specific modules, all using the same interface specification, becomes possible. The example below uses a rather simplistic algorithm.

#### 7.1.6.2 Heating Degree Day:

$$HDD = t_{base,HDD} - \frac{t_{min} + t_{max}}{2} \quad \text{Eq. 12}$$

$\forall HDD > 0$ *and* $HDD = 0 \ \forall HDD \leq 0$

#### 7.1.6.3 Cooling Degree Day:

$$CDD = \frac{t_{min} + t_{max}}{2} - t_{base,CDD} \quad \text{Eq. 13}$$

$\forall CDD > 0$ *and* $CDD = 0 \ \forall CDD \leq 0$

Where:
*tmin = minimum outside temperature per day*

*tmax = maximum outside temperature per day*
*tbaseline, HDD = baseline temperature HDD*
*tbaseline, CDD = baseline temperature CDD*

Standard heating and cooling degree days are usually provided by meteorological services. Standard HDD / CDD provide average values over a longer period (e.g. 20 years).

**Other instruments for normalisation:**
For mechanical ventilation, cooling and air conditioning so called degree hours are proposed, such as 'Lüftungsgradstunden' (ventilation degree hours – DIN/EN 4710) or 'Kühlgradstunden' (cooling degree hours).

## 7.2 Environment indicator

### 7.2.1 $CO_2$Tons emitted to the ambient

The contamination due to the CO2 emissions will be monitored to evaluate the environmental impact of the BaaS control decisions. The coefficient is the factor provided by the ESCO that determinates the CO2 ton numbers emitted to the ambient due to a determinate energy production process.

$$CO_2^{emitted} = \sum_{i=1,4,6} E_{delivered,i} * (1 - \psi_i) * CO_2^{fuel_i} = \sum_{i=1,4,6} NFEC_i * CO_2^{fuel_i} \qquad \text{Eq. 14}$$

Values for most of the cases can be found in Table 9 and Table 11 in EN 15603, where are described a wide amount of emission factors depending on the country and the type of fossil fuels consumed.

## 7.3 Comfort indicators

Two European standards apply: one relative to individual comfort (EN 13779) and one about overall comfort in buildings (EN 15251).

### 7.3.1 Comfort ranges based on the individual approach

The European standard EN 13779 defines the comfort parameters that should be kept for different levels of indoor quality. Here, not only the particles contaminating the air or $CO_2$ levels are indicated, but also the thermal comfort depending for example on air temperature inside living zones, temperatures of the surrounding walls, humidity, air speed, clothing factors and ambient quality for different works or domestic conditions.

Standard EN 15251 deals with overall comfort in buildings in an adaptive approach, i.e. including a behavioural component. The acceptable indoor operative temperatures, according to the adaptive approach, depend on a running mean outdoor temperature defined by the first equation below. This is an exponentially weighted running mean of the daily mean external air temperature. It is also possible to use the second equation that is a simplification of the first one.

$$\Theta_{rm} = (1 - \alpha)[\Theta_{ed-1} + \alpha \,.\, \Theta_{ed-2} + \alpha^2 \,.\, \Theta_{ed-3} + \cdots] \qquad \text{Eq. 15}$$

$$\Theta_{rm} = (1-\alpha)\Theta_{ed-1} + \alpha \,.\, \Theta_{rm-1} \quad \text{Eq. 16}$$

Where:

$\Theta_{rm}$ is the running mean temperature for today,

$\Theta_{rm-1}$ the running mean temperature for the previous day,

$\Theta_{ed-1}$ the daily mean external temperature for the previous day,

$\Theta_{ed-2}$ the daily mean external temperature for the day before and so on.

$\alpha$ is a constant between 0 and 1and it is recommended to use 0.8.

*Long term indices*:
There are two main methods to assess thermal comfort over the year. Both can be kept in this study:

- Percentage outside range: the proportion of the occupied hours during which the temperature lies outside the acceptable zone.
- Degree hours' criterion: the time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by the number of degrees by which the range has been exceeded.

*Set points:*

The energy consumption for cooling and heating purposes obviously depends on the chosen set point temperatures:

- Winter: 22°C
- Summer: 24°C (in the "middle" of the comfort range according to the analytic approach)

*Comfort indices that could be kept:*

Comfort indices are calculated in the worst places of buildings (regarding summer comfort e.g. under the roof) simulated with free evolution of temperature and humidity.

EN 15251 specifies that a building can be non-comfortable for 5% of its occupation hours per day. The logical indices to compute are:

- number of days with more than 5% of time uncomfortable
- degree hours of Summer discomfort based on summer set point

**Table 12: Comfort criteria for different building configuration**

| Air conditioned | | Naturally cooled with operable windows | | Naturally cooled with non-operable windows | |
|---|---|---|---|---|---|
| Winter | Summer | Winter | Summer | Winter | Summer |
| Set Point 22ºC | Set Point 24ºC | Set Point 22ºC | Degree hours outside zone* | Set Point 22ºC | Degree hours outside zone* |

| | | | | | |
|---|---|---|---|---|---|
| | | | Percentage of time outside zone* | | Percentage of time outside zone* |

*There are two different comfort zones presented in the following table.

**Table 13: Comfort zone for the definition of comfort criteria**

| | Analytic | Adaptive |
|---|---|---|
| Normal level of expectection (residential, offices, etc.) | 23 – 26ºC | Upper Limit $\Theta_{max}$: 0.33$\Theta_{rm}$ + 21.8<br>Lower Limit $\Theta_{max}$: 0.33$\Theta_{rm}$ + 15.8 |
| Sensitive people (healthcare etc.) | 23.5 - 25.5ºC | Upper Limit $\Theta_{max}$: 0.33$\Theta_{rm}$ + 20.8<br>Lower Limit $\Theta_{max}$: 0.33$\Theta_{rm}$ + 16.8 |

### *7.3.2 Comfort parameter average value*

A parameter must be defined that evaluates the deviation of the objective function when compared with the comfort boundaries. This parameter allows assessing the degree of compliance for a determinate control strategy under a previously defined comfort condition.

$$deviation^i = \frac{\sum_j^{time}\left(t * \left|comf_j^i - comf_{setpointi}^{max,min}\right|\right)}{time} * \frac{100}{comfort\ range} \qquad \text{Eq. 16}$$

*time:* *period while the comfort has been tested.*

*t:* *time period when there is NO comfort in the occupied zone*

$comf_j^i$: *comfort value for the instant j under the definition i.*

$comf_{setpointi}^{max,min}$: *comfort max, min value under definition i.*

*comfort range:* *amplitude of the comfort zone under the definition i.*

If the comfort parameter is over (under) the maximum (minimum) allowable value, the absolute difference of both values will be multiplied by the time period that this comfort value is out of range. The sum of all this values divided by the total length of the test will be the average of the deviation. In order to have always a clear magnitude of the deviation, the resulting values will be divided by the amplitude of the comfort range and expressed in percentage values.

The result gives a numerical value for the increment to be done to the accepted boundary conditions to be in the range, or how far we are out of the bounds.

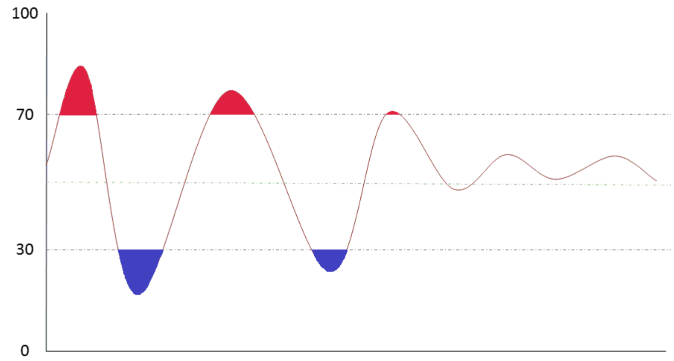



**Figure 14: Sample value for comfort parameter i for a determinate day with allowable value (30-70)**

Within EN 15251 there is a definition of acceptable time periods "out of comfort". This time period is fixed to 24 minutes every 8 hours (considered working time during the day). The definition of this kind of average value for comfort parameters will permit the evaluators or the building managers to measure in absolute terms the differences obtained. In the supposed case that the discomfort reached in this 24 minutes will be maximum (100%), it could be evaluated the difference obtained between our value and the permitted one (temperatures, CO2, ppms, etc.) shows a sample result of 2.86% in 24 hours' time and 8.6% in 8 hours base time.

If the accepted 24 minutes with a 100% of discomfort happens, the value will be 1.25% in a day and 3.75% in an 8 hours working day. These values are 228% higher than those permitted by the norm for the complete day/working period, but still relatively small deviations compared to the acceptable zone (red peaks over 70 correspond to 12.5%·h and blue peaks under 30 are 15%·h).

### *7.3.3 Indoor Environmental Performance*

To evaluate the indoor environmental performance of a building setting, conditions in individual rooms must be properly evaluated. In order to achieve this, it is required to determine if the evaluation criterion is in/out of the allowed bandwidth for each interval (usually 15 minutes). This comparison needs to be executed for the period when the building is 'under occupation'.

**Table 14: Attribute values of selected comfort parameters**

| No. | Evaluation criterion | | $L_{lower}$ | $L_{upper}$ | Standard |
|---|---|---|---|---|---|
| 1 | Indoor air temperature (offices) | $\theta_{air}$ | 18 | 26 | CIBSE Guide A |
| 2 | Relative humidity | RH | 40% | 70% | CIBSE Guide A |
| 3a | Outdoor level | OAQ | 350 ppm | n.a. | BS EN 13 779 |
| 3b | Acceptable level | IAQ | n.a. | 700-750 ppm | BS EN 13 779 |
| 3c | Acceptable level (20cfm air exch. rate) | IAQ | n.a. | 800 ppm | ASHRAE 62-1989 |
| 3d | Acceptable level (15cfm air exch. rate) | IAQ | n.a. | 1000 ppm | ASHRAE 62-1989 |
| 4a | Illuminance (floors) | $E_V$ | 200 lux | n.a. | CIBSE Guide A |
| 4b | Illuminance (rooms) | $E_V$ | 350 lux | n.a. | CIBSE Guide A |
| 4c | Illuminance (workspace) | $E_V$ | 500 lux | n.a. | CIBSE Guide A |

However, the generation of simple means out of monitored data from individual rooms or even parts of it would not be optimal. Rather, the statistical aggregation process must ensure that possible shortcomings in individual building zones are preserved in the resulting reports. It is proposed to introduce the following (relative) KPI:

#### 7.3.3.1 Underperformance Time (UPT):

$$\mathrm{UPT} = \frac{t_{open} - t_{unpe}}{t_{open}} \qquad \text{Eq. 17}$$

*With:* $t_{unpe}$ … *time with underperformance*

$t_{open}$ … *opening hours of the building*

#### 7.3.3.2 Underperformance Ratio (UPR):

$$\mathrm{UPR} = \frac{SP_{total} - SP_{unpe}}{SP_{total}} \qquad \text{Eq. 18}$$

*With:* $SP_{unpe}$ … *spaces with underperformance*

$SP_{total}$ … *total number of spaces*

The calculation of spatial-temporal values provides the basis for the calculation of further KPI for the socio-technical dimensions, as the proportional underperformance:

#### 7.3.3.3 Proportional Underperformance (UPP):

$$\mathrm{UPP} = \frac{SP_{total,Org} - SP_{unpe,Org}}{SP_{open}} \qquad \text{Eq. 19}$$

*With:* $SP_{unpe,\ Org}$… *spaces with underperformance used by an organisation*

$SP_{open,\ Org}$… *total number of spaces used by an organisation*

### 7.3.4 Predicted Mean Vote (PMV)

High indoor environmental quality may be regarded as the main expected service provided by buildings. There is not a unique schema for the specification of indoor environmental performance, but the general industry approach is well established. Thereby, a number of objective (measurable) parameters are identified to which the subjective sensation of indoor environment is believed to correlate.

The quality of services provided to the occupant (or building user) is documented by monitoring the indoor environment conditions. The indoor environment monitoring category typically addresses parameters that are relevant for the health and comfort of the occupants (thermal and visual conditions, indoor air quality, etc.). These comfort service levels often represent the target of the building operation process (e.g., indoor air temperature, relative humidity). Control systems for thermal environment at times use one or more of the above criteria in terms of sensory feed back to the control logic.

Thermal comfort is achieved when the heat generated by a human body can dissipate, i.e. the thermal equilibrium with the surrounding is maintained. Factors influencing thermal comfort are heat conduction, convection, radiation, and evaporative heat loss. Thus, the sensation of feeling hot or cold depends on multiple factors, such as:

- mean radiant temperature,
- indoor air temperature, air flow speed,
- metabolism, clothing level, and
- humidity (evaporative heat loss)

Fanger developed a system of equations which combines the effect of the six parameters in a single functional relationship – determining an indicator called *Predicted Mean Vote* (PMV).

$$PMV = f \cdot \left(M, I_{cl}, v_{air,}\theta_{air}, \theta_r, RH\right) \qquad \text{Eq. 20}$$

with *Metabolism [M], Clothing level [$I_{cl}$], Air Temperature [$\theta_{air}$], Mean Radiant Temperature [$\theta_r$], Air velocity [$v_{air}$], and Humidity [RH]*

Fanger determined the PMV with the following empirical equation:

$$PMV = \left(0.303 \cdot e^{-0.036 \cdot H} + 0.0275\right) \cdot L \qquad \text{Eq. 21}$$

with: $L = q_{met,heat} - f_{cl}h_c \cdot (\theta_{cl} - \theta_{air}) - f_{cl}h_r \cdot (\theta_{cl} - \theta_r) - 156 \cdot \left(W_{sk,req} - W_a\right) - 0.42 \cdot \left(q_{met,heat} - 18.43\right) - 0.00077M \cdot (93.2 - \theta_{air}) - 2.78M \cdot (0.0365 - W_a)$

where: $q_{met,heat} = M - w$

M = rate of metabolic generation per unit DuBois surface area, Btu/h · $ft^2$

w = human work per unit DuBois surface area, Btu/h · $ft^2$

and where: $f_{cl}$ = ratio of clothed surface area to DuBois surface area ($A_{cl}/A_D$)

$h_c$ = convection heat transfer coefficient, Btu/h · $ft^2$ · ºF

$\theta_{cl}$ = average surface temperature of clothed body, ºF

$\theta_{air}$ = air temperature

$h_r$ = radiative heat transfer coefficient, Btu/h · $ft^2$ · ºF

$\theta_r$ = mean radiant temperature, ºF or ºR

$W_a$ = air humidity ratio

$W_{sk}$ = saturated humidity ratio at the skin temperature

Additionally, Fanger introduced the index of *Predicted Percentage of Dissatisfied* (PPD) as a quantitative measure for the thermal comfort of a group of people at a particular thermal environment. Fanger related the PPD to the PMV as follows:

$$PPD = 100 - 95\, e^{-\left(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2\right)} \qquad \text{Eq. 22}$$

#### *7.3.4.1 Achieving comparability*

In order to achieve a better comparability with the non-integrated KPIs an additional-simplistic normalisation is introduced.

Service quality (SQ) is a measure to represent PMV-values on a scale of "0" to "1". It delivers comparability and allows a homogeneous analysis with earlier introduced KPI.

$$SQ = \frac{3 - |PMV|}{3} \quad \text{Eq. 23}$$

With $-3 \leq PMV \leq 3$

The service quality does no longer indicate if a cohort of persons feels either “too hot”, “comfortable” of “too cold”, but only indicates if thermal comfort is achieved or not.

## 7.4 Economic indicators

### *7.4.1 Operating Costs*

The Operating Costs represent the monetary evaluation of the energy consumed in a determinate time period, evaluated under the previously defined comfort boundaries.

The monetary evaluation must take into account:

- Different tariffs depending on the European country and in certain cases, depending also on the region.
- Different tariffs depending on the daytime, i.e. electric companies in some of the EU-countries price differently the consumption during peak demand hours and the purchased energy when the total regional/national demand is low, optimizing power generation.
- Different tariffs depending on the season, i.e. district heating companies apply different prices to the kWh consumed if it is used in summer or winter. A base produced energy during the summer must be kept, never mind there is nearly no heat demand, the producers give lower vending costs to the acquired energy in that season, incentivizing new consumers to change their habits or technological processes for cooling as can be the use of sorption technologies for the air-conditioning of buildings.
- Feeding incentives to the renewable productions.
- Distribution of the costs depending on the part assigned to the distribution and the part assigned to the generation.
- The different terms of the applied electricity bill (i.e. the operating cost) will be measured and kept for evaluating the monetary performance of the BaaS building, i.e. the energy charge, the maximum demand charge and the gain over renewable energy electricity generated, depending on the locally available electricity tariffs. Among the energy charge can be distinguished the charge at full load hours and low load hours illustrating the capability of the building to shift its load according to the level of price of the daily or season Time-Of-Use.

As a resume to all these differences must be clearly noticed the country, region and tariffs that the users are paying because the "picture" of the saving change considerably. Comparisons among savings obtained in the different buildings cannot be done.

### *7.4.2 Net Expected Benefit (NEB)*

The Net Expected Benefit represents the monetary comparison between the energy consumed in a previous state and the final energy consumed after BaaS measurements were applied, evaluated under the previously defined boundaries of comfort and building equivalences.

The monetary evaluation must take into account (similar to the definition of operating costs):

- Different tariffs depending on the European country and region.
- Different tariffs depending on the daytime.
- Different tariffs depending on the season.
- Feeding incentives to the renewable productions.

#### *7.4.3 Generation Consumption Effectiveness Index (GCEI)*

Production compared parameters need of a primary state to compare the results obtained after the introduction of new control strategies in the system. In the present case, it must be a building with the same internal and external loads, occupancies and comfort demands but with a basic control strategy and normal cooling and heating production. Distribution and emission systems must be similar.

It is defined as an objective and quantitative indicator to compare the effect of different decision strategies on the system performance. To measure system performances, a relevant metric is selected like, for example, the Net Expected Benefit (NEB). The GCEI for a selected decision strategy (DS) is defined as follows, comparing the selected to the optimal strategy.

$$GCEI_{DS} = \frac{NEB_{DS} - NEB_{no\ control}}{NEB_{optimal} - NEB_{no\ control}} \quad \text{Eq. 24}$$

For the computation of the GCEI index, the "no-control" case is used as the base, while the optimal control case will be computed a posteriori.

The BaaS system takes decisions with the goal of maximizing the selected metric, trying to obtain results as close as possible to the 1, that means, the last control strategy tested is the optimal one, for a determined instant. Values over 1 means that the optimized control considered as the optimum wasn't the best possibility and the new one improves the results, being needed a recalculation of the previous GCEI to evaluate better the effects of determined control actions developed in past strategies against a new optimum.

Other metrics could be used, as can be PEC, NEC and $CO_2$ emissions, to evaluate the GCEI, eliminating every possible distortion of the optimization caused by over-elevated electrical tariffs (i.e. PV incentives tariffs). But also in the cases, some differences are introduced by particular primary energy conversion factors, electrical mixes or time variable proportion of renewable energy in the generation that will make obligatory the use of daily, weekly or monthly averaged values of this generation parameters or the access to online generation data provided by the serving companies.

The use of the GCEI in the case of each one of the explained values permit a vision of the efficiency obtained from different control approaches.

The Generation Consumption Effectiveness Index is a parameter that depends highly on the type of renewable source and the type of controls that can be done with the buildings.

- If it is feasible to connect the renewable production to an infinite storage or load, the renewable energies will work in their optimum working point and the Net Expected Benefit will vary only based on the shift of the loads (not exactly on the shift but on the decrease of the loads). The benefit will be the difference between the integrals of loads and generation. In this case, the parameter doesn't measure anything about Generation-Consumption Effectiveness and should be called "saving loads parameter".

- In the case of not being able of selling the energy or sending the energy to the grid, the GCEI will measure the capability of using the maximum self-produced energy for the building demands. The parameter will also evaluate the efficiency of electrical or thermal storages and their control algorithms that will help in the maximum use of the free generation.

Summarizing, this parameter or the name and the formula of the parameter only go together in the case of auto consuming energy from renewable sources without connection with external entities.

### 7.4.4 *BaaS Pay-Back Period (BPBP)*

The Pay-Back Period represents the number of years it takes to recover the initial investment in control technology through the obtained BaaS savings. The project becomes positive in the year in which accumulated cash flows exceed the initial investment. Admitting the identical evolution of the building performance during the future years, the BaaS Pay-Back Period will be defined as the total cost of the new instruments that permit the savings (controlling systems, software development, etc.) divided by the calculated savings of the year.

BaaS Pay-Back Period will count the price of new components installed to decrease the energy demand. As it has happened previously with the compared starting point, it should be discussed the necessity of comparing with the actual point of a well monitored building or with a typical building that only have the minimum sensors needed for its basic work.

Possible imputable costs:

- Men/month costs of manager or programmer (in the case an external collaboration for this tasks is needed and there is no one in the company covering that role).
- Computer or PLC with enough high computation power (again, it will be a cost if the building does not need the hardware in a normal operation mode or the existing hardware is not able to run the simulation software needed).
- Actuators, relays, motors, sensors etc., i.e. general hardware not needed in normal buildings with the same characteristics.
- Software not usually installed.

### 7.4.5 *Net Present Value of BaaS (NPVB)*

The difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of BaaS project. The NPVB in BaaS project is defined by next equation:

$$NPVB = \sum_{t=1}^{T} \frac{NEB_t}{(1+r)^t} - I_c \qquad \text{Eq. 25}$$

Where:

NEBt = Net Expected Benefit was defined before.

r= kind of interest.

t= the time of the cash flow

Ic= Initial investment of BaaS.

If NPVB >0, BaaS gain monetary value,

If NPVB = 0, BaaS the investment would neither gain nor lose value,

If NPVB<0, BaaS adds no monetary value.

### *7.4.6 Internal Rate of Return of BaaS (IRRB)*

The IRRB of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.

IRRB calculations are commonly used to evaluate the desirability of investments or projects. The higher a project's IRRB, the more desirable it is to undertake the project. Assuming all projects require the same amount of up-front investment, the project with the highest IRR would be considered the best and undertaken first.

A firm (or individual) should, in theory, undertake all projects or investments available with IRRs that exceed the cost of capital. Investment may be limited by availability of funds to the firm and/or by the firm's capacity or ability to manage numerous projects.

$$IRRB = NPVB = \sum_{t=1}^{T} \frac{NEB_t}{(1+r)^t} - I_c = 0 \qquad \text{Eq. 26}$$

## 7.5 Data Quality indicators

### *7.5.1 Completeness of data*

This KPI provides the opportunity to get an overview about the "completeness" of data. In case of "event driven data collection" it is possible to identify "missing data" by exploiting the "BIM-knowledge"; i.e. the "behaviour" of components with similar features is expected to be comparable. Example: All offices "south facing" and connected to AC1 should provide temperature curves with similar features.

$$DQ_c = \frac{\sum_{EP} S_t}{\frac{RI}{EP}} \qquad \text{Eq. 27}$$

*With:* *DQc* ... *dataQuality:Completeness*

*EP* ... *Evaluation Period*

*$S_t$* ... *total number of samples in database*

*RI* ... *Reading Interval*

### *7.5.2 Technical and systemic significance of data*

These KPIs allow comparing "specifications of expected values" against current readings. On a first instance (**$DQ_{ts}$**) the "technical limitations" of the device are checked.

In a second case (**$DQ_{ss}$** ) the "case specific limitations" are used for evaluation.

Example: A sensor could be used in a temperature range between 80°C and -20°C ((**$DQ_{ts}$**-limits). When deployed in an office the expected temperature should be between 40°C and 10°C – providing the “limits” for (**$DQ_{ss}$** ).

$$DQ_{ts} = \frac{\sum_{EP} S_{tr}}{\frac{RI}{EP}} \qquad \text{Eq. 28}$$

*With:* *DQts* ... *dataQuality:Data within technically possible codomain*

*$CN_{tr}$* ... *CoDomain of technically possible readings (according to device manufacturer's specification)*

*$S_{ts}$* ... *number of samples within codomain specified by device manufacturer*

$CN_{min} \leq s_{ts} \leq CN_{max}$

*Pre-requisite:*

*A table containing all device types and the related minimum and maximum values for each type that can be monitored*

$$DQ_{ss} = \frac{\sum_{EP} S_{tr}}{\frac{RI}{EP}} \qquad \text{Eq. 29}$$

*With:* *DQss* ... *dataQuality:Data within case-specific codomain*

*$CN_{cr}$* ... *CoDomain of “systemically” possible values (according to architect's or engineer's specification for a specific component)*

*$S_{ss}$* ... *number of samples within codomain specified by architect / engineer*

$CN_{min} \leq s_{ss} \leq CN_{max}$

*Pre-requisite:*

*A table containing all (1) room types with related possible ranges for comfort parameters, or (2) device types with all system specific device parameters*

## 7.6 Building systems' performance indicators

One deficit in operating non-residential buildings is the deviation of planned or timetabled occupation of rooms compared to the real occupation density of rooms. This results in the unnecessary operation of building services systems and leads to unnecessary consumption of resources (energy used, operational hours). By using data from access control systems one can provide a qualitative overview about the occupation density.

### 7.6.1 Occupant density

Thus, the following KPI for “used services” is introduced:

$$\rho_{occup} = \frac{O_{real} - O_{max}}{SP_{open}} \qquad \text{Eq. 30}$$

*With:* $O_{real}$ = *Occupant density measured*

$O_{max}$ = *max. number of occupants in "Spatial Zone"*

In order to allow an easier comparison of occupant density levels, three categories are introduced:

**Table 15: KPI for used/unused services for occupancy density categories**

| OD category | $\rho_{occup}$ | Space usage | Interpretation |
|---|---|---|---|
| OD = 100 | $75\% \leq \rho_{occup}$ | Space fully used | Provided services fully required |
| OD = 75 | $40\% \leq \rho_{occup} \leq 75\%$ | Space normally used | Provided services required on standard level |
| OD = 40 | $\rho_{occup} < 40\%$ | Space underutilized | Provided services not fully required |

### 7.6.2 *Quality of Services' Delivery*

The intensity in which the provided services are used by the occupant (or building user) is documented by monitoring the internal processes.

The internal processes category refers to the presence and activities of the occupants as well as to the position (state) of devices that can be controlled by occupants or the building's control system. Thereby, a differentiation between events and states can be useful. In this taxonomy, events are either system-related (e.g., switching lights on/off) or occupancy-related (occupants entering or leaving a room). Likewise, states can refer to systems (position of shades/windows) and occupancy (room occupied/vacant).

In complex installation scenarios it might be possible that building services systems with different functionality are operational at the same time, i.e. these systems are working "against each other". This might result in extreme load profiles and finally lead to unnecessary energy consumption. Therefore, we propose to introduce the Use Intensity as a new measure.

The Use Intensity should be defined as a measure documenting when and how intensively a component, sub-system, or system was "active". The Absolute Use Intensity ($UI_a$) can be determined as following:

**Table 16: Determination of absolute use intensity**

| Granularity | $UI_a$ | Eq. | With |
|---|---|---|---|
| System level | $UI_{a,\,sys} = \frac{W_{metered}}{W_{max\,capacity}}$ | Eq. 31 | Provided services fully required |
| Subsystem level | $UI_{a,\,subsys} = \frac{\sum_{all\,components} EC_{component}}{100}$ | Eq. 32 | $EC_{subsystem}$ = Evaluation Criterion for subsystem |
| Component level | $UI_{a,\,comp}$ = ActPos | Eq. 33 | ActPos = position actuator |

In order to allow a better comparability a Compared Use Intensity ($UI_{comp}$) is introduced. The Compared Use Intensity ($UI_{comp}$) defines three categories as given in the following table, and allows to group values for $UI_a$ into three groups:

**Table 17: Determination of compared use intensity**

| OD category | $\rho_{occup}$ | Space usage | Interpretation |
|---|---|---|---|

| | | | |
|---|---|---|---|
| OD = 100 | $75\% \leq \rho_{occup}$ | Space fully used | Provided services fully required |
| OD = 75 | $40\% \leq \rho_{occup} \leq 75\%$ | Space normally used | Provided services required on standard level |
| OD = 40 | $\rho_{occup} < 40\%$ | Space underutilized | Provided services not fully required |

A Building Performance Monitoring System can evaluate if systems' functionality is overlapping. Summary reports, using $UI_{comp}$, will help to quickly identify those malfunctioning devices or systems. In a next step the determined $UIc_{omp}$ for each (sub)-system can be compared to each other.

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# Appendix A: Problem and Activity Scenarios

## Problem Scenario: 1

### Problem Scenario Name:

**Inefficient control strategies for thermal comfort and energy efficiency**

### Theoretical Case Studies:

This is a problem that can affect to the following TCS:

Scenario 1.1.:

- School
- Hotel

Scenario 1.2.:

- Office Buildings
- Swimming pool
- Hospital

Scenario 1.3.:

- Shopping Mall

### Actors/Context:

Scenario 1.1.:

- **School**: heat, constant occupancy level, boiler, temperature sensors, distribution system, control system
- **Hotel**: heat and cool, variable occupancy level, HVAC system, temperature sensors, control system, distribution system

Scenario 1.2.:

- **Offices Building**: heat and cool, variable occupancy level, HVAC system, distribution system, temperature and humidity sensors, control system
- **Hospitals**: (traffic zones and other common areas and rooms) heat and cool, variable occupancy level, HVAC system, distribution system, temperature and humidity sensors, control system
- **Swimming Pool**: heat and cool, variable occupancy level, HVAC system, distribution system, temperature and humidity sensors, control system

Scenario 1.3.:

- **Shopping mall:** heat and cool, variable occupancy level, HVAC system, temperature and humidity sensors, control system, air quality, stratification, distribution system, airtightness

### Scenario 1.1

Mary is a teacher in a school located in a village. In this school, there is only a heating system, as far as the school is closed during two months in summer, so there is not any system for cooling.

This school has always the same schedule during the academic year and the heating system is turned on a couple of hours before the children arrive and it is turned off when school ends.

In the cold days of winter, this system works well but there are some days in autumn and spring, which are very cold in the morning when children arrive to the school, but the outside temperature rises along the day and comes a time when it is too hot in the classrooms.

The inside temperature rises too much because the heating system is turned on and the outside temperature is so high that the boiler could be stopped.

When this happens, Mary opens the windows in order to decrease the indoor temperature. This action is translated to a loss of energy because the boiler is working and all the generated energy is lost. These days there are two problems, the lack of efficiency of the system and on the other hand the thermal discomfort that must be solved by opening windows.

### Scenario 1.2

Marc is the person in charge of the maintenance in a sports complex. This building has several areas and one of these is a swimming pool.

He is very worried about thermal comfort in the pool area and controls the temperature of the room, but it has several problems. On one hand the temperature gets too high in the room when the sun comes through the windows and often he has to solve it by opening the windows and on the other hand due to the high humidity of this area, a problem of condensation occurs because they have never controlled humidity.

This lack of control causes a lack of energy efficiency and also a discomfort by pool users due to the high temperatures and the condensation on certain surfaces.

### Scenario 1.3

It has been detected a problem in the main shopping mall of the city. In this mall there is a control system to ensure the thermal comfort, but they do not take into account the energy efficiency either the quality of the air. In this type of building it is very important to consider this last factor because a large number of people runs through these areas and can cause high concentration of harmful substances.

In this case, there is not an optimized control for the ventilation system that provides the enough flow of outdoor air to avoid high concentrations of contaminants.

## Activity Scenario: 1.1

**Activity Scenario Name:**

**Temperature control strategies**

**Actors:**

- **School:** heat, constant occupancy level, boiler, temperature sensors, distribution system, control system
- **Hotel**: heat and cool, variable occupancy level, HVAC system, distribution system, temperature sensors, control system

In this school, it would not be profitable installing a complex control system because of the characteristics of this building, its heat system and its occupancy patterns are very simple.

For these reasons, a good solution to avoid the problems of discomfort and lack of energy efficiency would be to control the boiler with the temperatures of the rooms.

In this school, there are two circuits for the distribution of the heat generated by the boiler, and we could take in advantage the orientation of the rooms heated by the different circuits. One of the circuits heats the warmest area of the building, so an adequate control of temperature will do that the flow of heat to that area stops while the control system will keep the necessary heating to the other area.

**Uses Cases:**

1. Set point Regulation.
2. Adjust set point domestic hot water accumulation according to internal occupation and frequency of use of the system.
3. Optimization of the supply temperature set point.

## Activity Scenario: 1.2

**Activity Scenario Name:**

**Temperature and humidity control strategies**

**Actors:**

- **Offices Building**: heat and cool, variable occupancy level, HVAC system, temperature and humidity sensors, control system, distribution system,

- **Hospitals:** (traffic zone and rooms) heat and cool, variable occupancy level, HVAC system, temperature and humidity sensors, control system, distribution system,
- **Swimming Pool**: heat and cool, variable occupancy level, HVAC system, temperature and humidity sensors, control system, distribution system,

**Activities:**

In swimming pools it is very important to do a control taking into account the humidity besides the temperature.

It will be necessary to install humidity and temperature sensors and to do a control taking advantage of the outside air using a good and controlled ventilation system.

## Activity Scenario: 1.3

**Activity Scenario Name:**

**Temperature, humidity and others (air quality, stratification…) control strategies**

**Actors/Context:**

- **Shopping mall:** heat and cool, variable occupancy level, HVAC system, temperature and humidity sensors, control system, air quality, stratification, distribution system, airtightness

**Activities:**

A good control in the ventilation system of the shopping mall would solve both described problems. On one hand the ventilation will avoid the concentration of harmful substances and on the other hand it will improve the energy efficiency of the building.

The control of the stratification is also very important, because in this type of buildings, it has to be avoided during winter and it will be very good when there is cooling demand. The hot air goes up carrying inside itself contaminant particles and this hot air is renewed by fresh air.

This shopping mall is located in an area where summer nights are cold and the days are very hot. The ventilation system can take advantage of low outside temperatures at night to reduce the temperature of the building through free-cooling, which will improve the energy efficiency of the building.

**Uses Cases:**

1. Evaluate the potential of using virtual sensors

## Problem Scenario: 2

### Problem Scenario Name:

**Control Strategies not considering known future circumstances**

### Theoretical Case Studies

This is a problem that can affect to all the TCS:

- Offices Building
- School
- Hospitals
- Hotel
- Swimming Pool
- Shopping Mall

### Actors/Context:

The building has a boiler, an absorption machine and a thermal plant as generation systems and one AHU for distribution along the different offices, corridors, hall and other rooms.

The workers and other occupants have a regular timetable, from 7a.m. to 3p.m., although the facility services are in the building until 10p.m.

One relevant characteristic of the building, from point of view of thermal gains, is that it has a large glass surface.

The building has an automation system.

### Scenario:

John works in an a office building where each room have a temperature, humidity and lighting sensor but no thermostat, so people are no able to change the set points, the only entity able to manage this set points is the energy manager in charge of the buildings and/or the automation systems by means of the room-controllers.

The automation system can regulate the temperature of the rooms but this only works well in some times of year. In intermediate seasons like spring or autumn the system doesn't guarantee comfort mainly due to two reasons: on one hand there is a significant temperature difference between the early hours of the morning and noon, and on the other hand the sun has much influence on the indoor temperature due to the large glazed surfaces.

For this last reason, the temperature of these rooms with huge windows rises faster than they are able to be cooled by the chiller.

The desk where John has to work is located next to the large window so often he feels discomfort.

## Activity Scenario: 2

### Activity Scenario Name:

**Advanced control system**

### Actors/Context:

**Data gathering:** Building, weather station, historical data, data warehouse, temperature and humidity sensors, occupation level, communication system

**Weather and demand prediction tool**: Historical data, data warehouse, temperature and humidity sensors, occupancy levels, loads, HVAC systems

**Control system:** Building, weather station, historical data, data warehouse, temperature and humidity sensors, building management system, prediction tool, HVAC system, distribution system

### Activities:

To solve this problem, it is necessary to do a change in the control system.

It will be needed an outside temperature and radiation predictions. In this way, the system will start working before the inside temperature rises too.

The radiation forecast helps system to know how much solar energy is going to come in the building due to the huge windows, which produces an inside temperature rise, and it will be possible to start the chiller before expected to solve the described problem.

In this case, it will be necessary to do a weather forecasting and for this, we will need a prediction tool, a system to collect data and finally an advanced control system.

### Uses Cases:

1. Operate radiant hot water system loop to reduce energy consumption, while adjusting on uncertainties of hot water supply
2. Optimization of the operating hours of the system according to the internal conditions.
3. Optimal “Starting – stopping “actions on radiant floor valves by zone in heating operation during winter.
4. Utilisation of solar energy for energy savings, while ensuring visual and thermal comfort
5. Optimization of boiler and/or distribution starting stopping point.

## Problem Scenario: 3

### Problem Scenario Name:

**Optimize energy performance in buildings to increase the profit margin of the end user: ESCO**

### Theoretical Case Studies

This is a problem that can affect to all the TCS:

- Offices Building
- School
- Hospitals
- Hotel
- Swimming Pool
- Shopping Mall

### Actors/Context:

Building, HVAC Performance, energy meters, energy bills, temperature sensor, occupancy levels, loads, historical data, operation cost.

### Scenario:

- An ESCO has a contract energy management, are getting the expected financial ratios and wants to optimize their profit.
- An ESCO has an energy management contract, not getting the expected financial ratios and wants to optimize their profit.
- An ESCO has an energy management contract, initial energy conditions change and wants to optimize their profit.

## Activity Scenario: 3

### Activity Scenario Name:

**Energy and Economic Evaluation System**

### Actors/Context:

Building management system, Advanced control system, Energy rates.

### Activities:

To solve the problems of the ESCO, it is necessary to evaluate economically the options from Advanced Control System and choose the one that optimizes profit.

### Uses Cases:

1. Assist maintenance staff to make the best decision about the consequences of season change according to economic variables and parameters of comfort.
2. Optimisation of heating mode (weekend set back)

## Problem Scenario: 4

**Problem Scenario Name:**

**Different Building Management System in each building**

**Theoretical Case Studies:**

This is a problem that can affect to all the TCS:

- Offices
- Educational buildings
- Hospitals
- Hotels and restaurants
- Sport facilities
- Wholesale and retail trade service
- Other types of energy consuming buildings

**Actors/Context:**

Building management system, middleware, communication system, SCADA

**Scenario:**

Ivan is the responsible person for monitoring the proper functioning of several buildings, which have different BMSs.

He knows using all programs and when he goes to a building, he connects his laptop to the BMS and checks the proper functioning of the facility.

When he has to make some changes in the control strategies or modify the current set points, he has to connect his laptop to each BMS, although he has to do the same action in all buildings.

It loses a lot of time making the same thing many times, and this results in a loss of money for his company.

## Activity Scenario: 4

### Activity Scenario Name:

**Management integration system**

### Actors/Context:

Building management system, middleware, communication system, SCADA

### Activities:

Because of time lost by Ivan having to repeat the same action/change in different BMS, it detects the need for a tool that facilitates the work of connecting to different BMSs from one point.

To solve this problem, it will be necessary to develop a communication tool that is able to communicate with any building management system and translate all the information received from those systems, so the worker will have a simpler way to connect to several buildings even when each building works with a different building management system.

The workers will only have to make changes once, but the system will communicate these changes to all buildings. This will result in a time saving for the workers and thus a cost saving for the Company.

## Problem Scenario: 5

**Problem Scenario Name:**

**Lack of a fault detection and diagnosis system**

**Theoretical Case Studies:**

This is a problem that can affect to all the TCS:

- Offices
- Educational buildings
- Hospitals
- Hotels and restaurants
- Sport facilities
- Wholesale and retail trade service
- Other types of energy consuming buildings

**Actors/Context:**

The system must have control over the operation of all sensors of the building, HVAC system and distribution system, because, it must detect a wrong operation or a breakdown in these parts of the installation.

The Building Management System, will generate the alarms when a breakdown happens. In this moment, the data will be stored, the warning will be displayed in a screen and a sms or email will be sent to the responsible of the installation with the most relevant information.

**Scenario:**

David is the maintenance responsible in several facilities and he visits and reviews each of these facilities once every fortnight. When he arrives to the building, first of all, he looks a screen where he can see if some incident has happened in the last fifteen days.

If the breakdown is important, the system sends him a “sms” with information about the problem and he decides if it is necessary to go towards the installation to solve this breakdown immediately or if he can wait to repair it until the next regular visit to the facility.

David has detected that sometimes the system does not send him any “sms” although a breakdown has took place or he mistakenly decide not to go to the building because he has little information about what happened, and he think that the failure is not important, but there are situations which a small failure can trigger a great breakdown. This happens because it spends too much time from the occurrence of the incident until he makes his regular visit to the building. This situation could have been avoided if he had known the situation previously.

A month ago, David did not receive any alarm and when he made his regular visit to the building, he observed on the screen that the system had detected a minor fault in the installation that was a small water leak. However, when David went to the boiler room and he saw this room was flooded because the breakdown remained too long without being repaired.

**Uses Cases:**

1. Model – based comfort monitoring
2. Occupancy faults
3. Prevent inefficient operational decisions
4. KPIs, Analytics

## Activity Scenario: 5

**Activity Scenario Name:**

**Implementation of a fault detection and diagnosis system**

**Actors/Context:**

The system must have control over the operation of all sensors of the building, HVAC system and distribution system, because, it must detect a wrong operation or a breakdown in these parts of the installation.

The Building Management System, will generate the alarms when a breakdown happens. In this moment, the data will be stored, the warning will be displayed in a screen and a sms or email will be sent to the responsible of the installation with the most relevant information.

**Activities:**

This problem would be solved with the implementation of a fault detection and diagnosis system in the building management system.

The company of David, will have to define which are the most important or relevant alarms and who will have to receive the information about these breakdowns. These will be very important decisions because the importance of a fault and the person receiving the alert, are closely related to the speed with which the problem is solved and the consequences that has the breakdown.

# Appendix B: Information to be collected from buildings

## List of contents



## Brief introduction

The following tables include the required information for the buildings definition. Since the processing and storage of data is specified in the WP2, these tables are only an orientation for data acquisition (for further information see D2.1: *Data Warehouse requirements and Extended BIM specification* and D3.1: *High-level architecture, interfaces definitions and data models extension description*).

Although all contained data would be necessary for the BaaS system operation, some missing data could be established by default. WP2 will be in charge of addressing data inconsistences in the correspondent task.

All data fields have been classified following the structure defined in D5.1: *Functional and interoperability requirements for building services*:

1. **Static data – Building Information Model (BIM)**
   a. Building geometrical data
   b. Building material data
   c. Building systems data
      i. Daylight control systems
      ii. Shading control systems
      iii. Airflow control systems
      iv. Thermal control systems
      v. Humidity control systems
      vi. Energy generation systems

2. **Dynamic data – Data warehouse (DWH)**
   a. Schedules
      i. Occupancy
      ii. Internal gains
      iii. Uncontrollable devices
      iv. Controllable devices
   b. Performance data (**PFD**)
   c. Weather data (**WTH**)
      i. Weather file data
      ii. Estimated weather data

**Table 18: Location and climate data**

| LOCATION AND WEATHER | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WHT |
| **Location** | | | | | |
| Latitude | Deg | | | | |
| Longitude | Deg | | | | |
| Time zone | Hr | | | | |
| Elevation | M | | | | |
| **Climate conditions** | | | | | |
| Climatic area | | | | | |
| Heating degree days (HDD 18ºC based) | | | | | |
| Cooling degree days (CDD 20ºC based) | | | | | |
| Maximum dry-bulb temperature | ºC | | | | |
| Dry-bulb temperature range | ΔºC | | | | |
| Relative humidity | % | | | | |
| Barometric pressure | Pa | | | | |
| Wind speed | m/s | | | | |
| Wind direction | Deg | | | | |
| Total solar radiation | $W/m^2$ | | | | |
| Diffuse solar radiation | $W/m^2$ | | | | |
| Sunshine hours | Hr | | | | |
| Daylight saving time indicator | | | | | |
| Water mains temperature | | | | | |
| Annual average outdoor temperature | ºC | | | | |
| Precipitation model type | | | | | |
| Design level for total annual precipitation | $m^3/yr$ | | | | |
| Average total annual precipitation | $m^3/yr$ | | | | |
| Daily wet-bulb temperature range | ΔºC | | | | |
| **Weather data** | | | | | |
| Outside dry-bulb temperature | ºC | | | | |
| Outside dew point temperature | ºC | | | | |
| Outside wet-bulb temperature | ºC | | | | |
| Sky temperature | ºC | | | | |
| Ground temperature | ºC | | | | |
| Outside atmospheric pressure | Pa | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Wind direction | deg | | | | |
| Wind speed | m/s | | | | |
| Humidity ratio of outside air | | | | | |
| Relative humidity | % | | | | |
| Weather codes | | | | | |
| Rain index | | | | | |
| Sky IR radiation | W | | | | |
| Direct solar irradiance | W/m$^2$ | | | | |
| Diffuse solar irradiance | W/m$^2$ | | | | |
| Cloud cover index | | | | | |
| Direct clearness factor | | | | | |
| Diffuse clearness factor | | | | | |
| Albedo | | | | | |
| Density of dry air | kg/m$^3$ | | | | |
| Density of air | kg/m$^3$ | | | | |
| Specific heat of air | J/(kg·K) | | | | |
| **Weather forecast** | | | | | |
| Outside dry-bulb temperature | ºC | | | | |
| Outside dew point temperature | ºC | | | | |
| Outside wet-bulb temperature | ºC | | | | |
| Sky temperature | ºC | | | | |
| Ground temperature | ºC | | | | |
| Outside atmospheric pressure | Pa | | | | |
| Wind direction | deg | | | | |
| Wind speed | m/s | | | | |
| Humidity ratio of outside air | | | | | |
| Relative humidity | % | | | | |
| Rain index | | | | | |
| Sky IR radiation | W | | | | |
| Direct solar irradiance | W/m$^2$ | | | | |
| Diffuse solar irradiance | W/m$^2$ | | | | |
| Cloud cover index | | | | | |

**Table 19: Building geometry and construction elements definition**

| FIELD | UNITS | BIM | DWH | | |
|---|---|---|---|---|---|
| **BUILDING GEOMETRY DEFINITION (geometrical information included in CAD file whether it's possible)** | | | | | |
| **FIELD** | **UNITS** | **BIM** | **SCH** | **PFD** | **WTH** |
| Site (oriented and with surroundings definition) | | | | | |
| Floor plans | | | | | |
| Elevations | | | | | |
| Sections | | | | | |
| Windows and doors detailing plans | | | | | |
| Construction systems details | | | | | |
| HVAC system schemes (generation and distribution) | | | | | |
| Lighting and electrical systems schemes | | | | | |
| Plumbing schemes | | | | | |
| Monitoring and control system scheme (geometrical scheme) | | | | | |
| Energy on-site production schemes | | | | | |
| **CONSTRUCTION ELEMENTS (provide the as-build documentation whether it's possible)** | | | | | |
| **FIELD** | **UNITS** | **BIM** | **DWH** | | |
| | | | **SCH** | **PFD** | **WTH** |
| **Average envelopment transmittances** | | | | | |
| Average opaque elements transmittances | $W/m^2 \cdot K$ | | | | |
| Average windows and doors transmittances by orientation | $W/m^2 \cdot K$ | | | | |
| Percentage of glazed area by orientation | | | | | |
| **Opaque elements (walls, roofs, etc.)** | | | | | |
| **Construction** | | | | | |
| Airtightness | | | | | |
| Material layer bedding | | | | | |
| **Materials** | | | | | |
| Roughness | | | | | |
| Thickness | m | | | | |
| Thermal conductivity | $W/m \cdot K$ | | | | |
| Density | $kg/m^3$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Specific heat | J/kg·K | | | | |
| U-value | $W/m^2 \cdot K$ | | | | |
| Short-wave absorption coefficient | | | | | |
| Long-wave emittance coefficient | | | | | |
| Solar transmittance | | | | | |
| Heat gain coefficient | | | | | |
| **Phase change materials** | | | | | |
| Roughness | | | | | |
| Thickness | m | | | | |
| Conductivity | W/m·K | | | | |
| Density | $kg/m^3$ | | | | |
| Specific heat | J/kg·K | | | | |
| U-value | $W/m^2 \cdot K$ | | | | |
| Short-wave absorption coefficient | | | | | |
| Long-wave emittance coefficient | | | | | |
| Solar transmittance | | | | | |
| Heat gain coefficient | | | | | |
| **Green roof materials** | | | | | |
| Height of plants | m | | | | |
| Leaf area | $m^2$ | | | | |
| Leaf reflectivity | | | | | |
| Leaf emissivity | | | | | |
| Minimum stomata resistance | s/m | | | | |
| Roughness | | | | | |
| Thickness | m | | | | |
| Conductivity of dry soil | W/m·K | | | | |
| Density of dry soil | $kg/m^3$ | | | | |
| Specific heat of dry soil | J/kg·K | | | | |
| U-value | $W/m^2 \cdot K$ | | | | |
| Short-wave absorption coefficient | | | | | |
| Long-wave emittance coefficient | | | | | |
| Solar transmittance | | | | | |
| Heat gain coefficient | | | | | |
| Saturation volumetric moisture content of soil | | | | | |
| Residual volumetric moisture content of soil | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Initial volumetric moisture content of soil | | | | | |
| **Windows-glazing doors** | | | | | |
| **Opaque area construction** | | | | | |
| Airtightness | | | | | |
| Glazing material and gas layer bedding | | | | | |
| **Frame and divider** | | | | | |
| Frame Width | m | | | | |
| Frame Outside projection | m | | | | |
| Frame Inside projection | m | | | | |
| Frame Conductance | $W/m^2{\cdot}K$ | | | | |
| Ratio of frame-edge glass conductance to centre-of-glass conductance | | | | | |
| Frame Solar absorptance | | | | | |
| Frame Visible absorptance | | | | | |
| Frame Thermal hemispherical emissivity | | | | | |
| **Glazing** | | | | | |
| Thickness | m | | | | |
| Solar transmittance at normal incidence | | | | | |
| Solar diffusing | | | | | |
| **Gas** | | | | | |
| Gas type | | | | | |
| Thickness | m | | | | |
| **Windows shading elements control and schedules** | | | | | |
| Shading type (interior/exterior shade, exterior screen, interior/exterior blind, between glass shade or blind, switchable glazing) | | | | | |
| Shading control type (always on, always off, solar radiation, zone temperature…) | | | | | |
| Shading elements operation schedule | | | | | |
| **Windows – glazing doors Air flow control** | | | | | |
| Source (indoor/outdoor) | | | | | |
| Destination (indoor, outdoor, return air) | | | | | |
| Maximum flow rate | $m^3/s{\cdot}m$ | | | | |
| Control type (always on, always off…) | | | | | |
| Windows opening angle schedule | | | | | |
| **Doors** | | | | | |
| **Construction** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Material layer bedding | | | | | |
| **Materials** | | | | | |
| Roughness | | | | | |
| Thickness | m | | | | |
| Conductivity | W/m·K | | | | |
| Density | kg/m$^3$ | | | | |
| Specific heat | J/kg·K | | | | |
| Thermal absorptance | | | | | |
| Solar absorptance | | | | | |
| Visible absorptance | | | | | |
| **Doors Air flow control** | | | | | |
| Source (indoor/outdoor) | | | | | |
| Destination (indoor, outdoor, return air) | | | | | |
| Maximum flow rate | m$^3$/s·m | | | | |
| Control type (always on, always off…) | | | | | |
| Doors opening angle schedule | | | | | |
| **External shading surfaces** | | | | | |
| **Trees – high fences – other buildings** | | | | | |
| Trees – high fences – other buildings transmittance schedule | | | | | |
| Geometry description | | | | | |
| **Overhangs – fins** | | | | | |
| Overhangs – fins transmittance schedule | | | | | |
| Geometry description | | | | | |

**Table 20: Thermal zones, internal gains and exterior energy equipment**

| THERMAL ZONES | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DHW | | |
| | | | SCH | PFD | WTH |
| **Thermal zone geometry** | | | | | |
| Area | $m^2$ | | | | |
| Volume | $m^3$ | | | | |
| Virtual bounds of thermal zones | | | | | |
| Walls consisting the thermal zone | | | | | |
| Windows – glass door consisting the thermal zone | | | | | |
| Doors consisting the thermal zone | | | | | |
| **Internal gains per zone** | | | | | |
| People internal gains | | | | | |
| Lighting equipment internal gains | | | | | |
| Electric equipment internal gains | | | | | |
| Gas equipment internal gains | | | | | |
| Steam equipment internal gains | | | | | |
| Other equipment internal gains | | | | | |
| **Internal thermal mass** (walls located inside the thermal zone and furnitures) | | | | | |
| Internal thermal mass objects | | | | | |
| Total area per internal thermal mass object type | $m^2$ | | | | |
| **HVAC system** | | | | | |
| Forced air unit objects | | | | | |
| Radiative/convective unit objects | | | | | |
| Air loop terminal unit objects | | | | | |
| Zone HVAC equipment connection objects | | | | | |
| **Zone airflow** | | | | | |
| Design infiltration flow rate | $m^3/s$ | | | | |
| Infiltration air changes per hour | | | | | |
| Effective air leakage area | $cm^2$ | | | | |
| Design ventilation flow rate | $m^3/s$ | | | | |
| Ventilation air changes per hour | | | | | |
| Ventilation type (natural, intake, exhaust, balance) | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Fan pressure rise | Pa | | | | |
| Fan total efficiency | | | | | |
| Maximum and minimum indoor temperature set points | ºC | | | | |
| Maximum and minimum outdoor temperature set points | ºC | | | | |
| Other ventilation systems definition (earth tube, cool tower, thermal chimney…) | | | | | |
| Design infiltration flow rate | $m^3/s$ | | | | |
| **INTERNAL GAINS (defined by the occupation profiles and the systems schemes and documentation)** | | | | | |
| **FIELD** | **UNITS** | **BIM** | **DWH** | | |
| | | | **SCH** | **PFD** | **WTH** |
| **People** | | | | | |
| Maximum number of people per zone | people | | | | |
| Occupancy schedule | | | | | |
| Fraction radiant | 0-1 | | | | |
| Sensible heat fraction | 0-1 | | | | |
| Carbon dioxide generation rate | $m^3/s\cdot W$ | | | | |
| **Comfort evaluation parameters** | | | | | |
| Work efficiency (metabolic rate) | $W/m^2$ | | | | |
| Clothing insulation ◊ | clo | | | | |
| **Lights** | | | | | |
| Lighting level | W | | | | |
| Lighting operation schedule | | | | | |
| Return air fraction | 0-1 | | | | |
| Fraction radiant | 0-1 | | | | |
| Fraction visible | 0-1 | | | | |
| Fraction replaceable | 0-1 | | | | |
| **Daylight controls** | | | | | |
| Luminance set points at reference point | | | | | |
| Luminance set points schedule | | | | | |
| **Electric equipment** | | | | | |
| Design level | W | | | | |
| Electric equipment operation schedule | | | | | |
| Fraction latent | 0-1 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Fraction radiant | 0-1 | | | | |
| Fraction lost | 0-1 | | | | |
| **Gas equipment** | | | | | |
| Design level | W | | | | |
| Gas equipment operation schedule | | | | | |
| Fraction latent | 0-1 | | | | |
| Fraction radiant | 0-1 | | | | |
| Fraction lost | 0-1 | | | | |
| **Hot water equipment** | | | | | |
| Design level | W | | | | |
| Hot water equipment operation schedule | | | | | |
| Fraction latent | 0-1 | | | | |
| Fraction radiant | 0-1 | | | | |
| Fraction lost | 0-1 | | | | |
| **Steam equipment** | | | | | |
| Design level | W | | | | |
| Steam equipment operation schedule | | | | | |
| Fraction latent | 0-1 | | | | |
| Fraction radiant | 0-1 | | | | |
| Fraction lost | 0-1 | | | | |
| **Other equipment** | | | | | |
| Design level | W | | | | |
| Other equipment operation schedule | | | | | |
| Fraction latent | 0-1 | | | | |
| Fraction radiant | 0-1 | | | | |
| Fraction lost | 0-1 | | | | |

| EXTERIOR ENERGY EQUIPMENT | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WTH |
| **Exterior lights** | | | | | |
| Design level | W | | | | |
| Exterior lights operation schedule | | | | | |
| **Exterior fuel equipment** | | | | | |
| Design level | W | | | | |
| Fuel type | | | | | |
| Exterior fuel equipment operation | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| schedule | | | | | |
| **Exterior water equipment** | | | | | |
| Design level (maximum volumetric flow) | $m^3/s$ | | | | |
| Exterior water equipment operation schedule | | | | | |

**Table 21: HVAC systems**

| HVAC SYSTEM | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WTH |
| **Zone HVAC forced air units** | | | | | |
| **Four Pipe fan coil** | | | | | |
| Supply air maximum flow rate | $m^3/s$ | | | | |
| Four pipe fan coil availability schedule | 0-1 | | | | |
| Outdoor air flow rate | $m^3/s$ | | | | |
| Supply fan total efficiency | % | | | | |
| Pressure rise al full flow | Pa | | | | |
| Supply fan motor efficiency | % | | | | |
| Four pipe FC chilled water availability schedule | 0-1 | | | | |
| Four pipe FC hot water availability schedule | 0-1 | | | | |
| **Packaged terminal air conditioner** | | | | | |
| Cooling supply air flow rate | $m^3/s$ | | | | |
| Heating supply air flow rate | $m^3/s$ | | | | |
| Outdoor air flow rate | $m^3/s$ | | | | |
| Supply fan total efficiency | % | | | | |
| Pressure rise al full flow | Pa | | | | |
| Supply fan motor efficiency | % | | | | |
| Packaged terminal AC cooling coil availability schedule | 0-1 | | | | |
| Packaged terminal AC heating coil availability schedule | 0-1 | | | | |
| Cooling coil rated capacity | W | | | | |
| Heating coil rated capacity | W | | | | |
| Cooling coil rated COP | | | | | |
| Heating coil rated COP | % | | | | |
| **Packaged terminal heat pump** | | | | | |
| Cooling supply air flow rate | $m^3/s$ | | | | |
| Heating supply air flow rate | $m^3/s$ | | | | |
| Outdoor air flow rate | $m^3/s$ | | | | |
| Supply fan total efficiency | % | | | | |
| Pressure rise al full flow | Pa | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Supply fan motor efficiency | % | | | | |
| Packaged terminal HP cooling coil availability schedule | 0-1 | | | | |
| Packaged terminal HP heating coil availability schedule | 0-1 | | | | |
| **Water to air heat pump** | | | | | |
| Cooling supply air flow rate | $m^3/s$ | | | | |
| Heating supply air flow rate | $m^3/s$ | | | | |
| Outdoor air flow rate | $m^3/s$ | | | | |
| Supply fan total efficiency | % | | | | |
| Pressure rise al full flow | Pa | | | | |
| Supply fan motor efficiency | % | | | | |
| Water to air HP cooling coil availability schedule | 0-1 | | | | |
| Water to air HP heating coil availability schedule | 0-1 | | | | |
| Cooling coil rated capacity | W | | | | |
| Heating coil rated capacity | W | | | | |
| Cooling coil rated COP | | | | | |
| Heating coil rated COP | % | | | | |
| **Dehumidifier** | | | | | |
| Dehumidifier availability schedule | | | | | |
| Rated water removal | | | | | |
| Rated energy factor | | | | | |
| Rated air flow rate | | | | | |
| Water removal curve | | | | | |
| Energy factor curve | | | | | |
| **Energy recover ventilator** | | | | | |
| Energy recover ventilator availability schedule | | | | | |
| Heat exchanger | | | | | |
| Supply air flow rate | $m^3/s$ | | | | |
| Supply air fan | $m^3/s$ | | | | |
| Exhaust air fan | | | | | |
| Ventilation rate | $m^3/s$ | | | | |
| **Terminal unit: variable refrigerant flow** | | | | | |
| Terminal unit: VAV availability schedule | | | | | |
| Supply air flow rate during cooling | $m^3/s$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| operation | | | | | |
| Supply air flow rate when no cooling is needed | $m^3/s$ | | | | |
| Supply air flow rate during heating operation | $m^3/s$ | | | | |
| Supply air flow rate when no heating is needed | $m^3/s$ | | | | |
| Outdoor air flow rate during cooling operation | $m^3/s$ | | | | |
| Outdoor air flow rate during heating operation | $m^3/s$ | | | | |
| Outdoor air flow rate when no heat/cooling is needed | $m^3/s$ | | | | |
| Supply air fan | | | | | |
| Outside air mixer | | | | | |
| DX cooling coil | | | | | |
| DX heating coil | | | | | |
| **Zone HVAC radiative/convective units** | | | | | |
| **Radiant/convective water** | | | | | |
| Rated average water temperature | ºC | | | | |
| Rated water mass flow rate | kg/s | | | | |
| Rated capacity | W | | | | |
| Fraction radiant | $m^3/s$ | | | | |
| **Radiant/convective steam** | | | | | |
| Degree of subcooling | ºC | | | | |
| Maximum steam flow rate | $m^3/s$ | | | | |
| Fraction radiant | | | | | |
| **Radiant/convective electric** | | | | | |
| Nominal capacity | W | | | | |
| Efficiency | | | | | |
| Fraction radiant | | | | | |
| **Low temperature radiant** | | | | | |
| Hydronic tubing inside diameter | m | | | | |
| Hydronic tubing length | m | | | | |
| Temperature control type | | | | | |
| Maximum hot water flow | $m^3/s$ | | | | |
| Heating control throttling range | ΔºC | | | | |
| Maximum cold water flow | $m^3/s$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Condensation control type | | | | | |
| Condensation control dew point offset | ºC | | | | |
| **Ventilated slab** | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Outdoor air control type | | | | | |
| Minimum outdoor air flow rate | $m^3/s$ | | | | |
| Maximum outdoor air flow rate | $m^3/s$ | | | | |
| Hollow core inside diameter | | | | | |
| Hollow core length | | | | | |
| Number of cores | | | | | |
| Temperature control type | | | | | |
| **Zone HVAC air loop terminal units** | | | | | |
| **Single duct: constant volume** | | | | | |
| Single duct: constant volume availability schedule | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Reheat Coil | | | | | |
| Maximum Reheat Air Temperature | ºC | | | | |
| **Single duct: VAV reheat** | | | | | |
| Single duct: VAV reheat availability schedule | $m^3/s$ | | | | |
| Damper Air Outlet Node | | | | | |
| Unit Air Inlet Node | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Reheat Coil | | | | | |
| Reheat Outlet Node | | | | | |
| Damper Heating Action | | | | | |
| Maximum Reheat Air Temperature | ºC | | | | |
| **Single duct: VAV variable speed fan** | | | | | |
| Single duct: VAV variable speed fan availability schedule | | | | | |
| Maximum cooling air volume flow rate | $m^3/s$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Maximum heating air volume flow rate | $m^3/s$ | | | | |
| Zone Minimum Air Flow Fraction | 0-1 | | | | |
| Terminal unit's air inlet node | | | | | |
| Terminal unit's air outlet node | | | | | |
| Heating Coil's air inlet node | | | | | |
| Fan | | | | | |
| Heating coil | | | | | |
| **Single duct: VAV heat and cool – reheat** | | | | | |
| Single duct: VAV heat/cool – reheat availability schedule | | | | | |
| Damper Air Outlet Node | | | | | |
| Unit Air Inlet Node | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Reheat Coil | | | | | |
| Unit Air Outlet Node | | | | | |
| **Single duct: VAV – no reheat** | | | | | |
| Single duct: VAV – no reheat availability schedule | | | | | |
| Unit Air Outlet Node | | | | | |
| Unit Air Inlet Node | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| **Single duct: Series PIU – reheat** | | | | | |
| Single duct: Series PIU – reheat availability schedule | | | | | |
| Total volume flow rate through ATU | $m^3/s$ | | | | |
| Unit Supply Air Inlet Node | | | | | |
| Unit Secondary Air Inlet Node | | | | | |
| Unit Outlet Node | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Mixer | $m^3/s$ | | | | |
| Fan | | | | | |
| Reheat coil Air Inlet Node | | | | | |
| Reheat Coil | | | | | |
| **Single duct: Parallel PIU – reheat** | | | | | |
| Single duct: Parallel PIU – reheat availability schedule | | | | | |
| Maximum primary air flow rate | $m^3/s$ | | | | |
| Maximum secondary air flow rate | $m^3/s$ | | | | |
| Unit Supply Air Inlet Node | | | | | |
| Unit Secondary Air Inlet Node | | | | | |
| Unit Outlet Node | | | | | |
| Reheat coil Air Inlet Node | | | | | |
| Mixer | | | | | |
| Fan | | | | | |
| Reheat Coil | | | | | |
| **Single duct: constant volume – four pipe induction** | | | | | |
| Single duct: constant volume – four pipe induction availability schedule | | | | | |
| Maximum total air flow rate | $m^3/s$ | | | | |
| Induction ratio | % | | | | |
| Unit Supply Air Inlet Node | | | | | |
| Unit Induced Air Inlet Node | | | | | |
| Unit Outlet Node | | | | | |
| Heating coil Air Inlet Node | | | | | |
| Cooling coil Air Inlet Node | | | | | |
| Mixer | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Heating Coil | | | | | |
| Cooling Coil | | | | | |
| **Single duct: constant volume – cooled beam** | | | | | |
| Single duct: constant volume – cooled beam availability schedule | | | | | |
| Cooling Beam Type | $m^3/s$ | | | | |
| Induction ratio | % | | | | |
| Unit Supply Air Inlet Node | | | | | |
| Unit Induced Air Inlet Node | | | | | |
| Unit Outlet Node | | | | | |
| Chilled Water Inlet Node | | | | | |
| Cooling coil Air Inlet Node | | | | | |
| **Dual duct: VAV** | | | | | |
| Dual duct: VAV availability schedule | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Induction ratio | $m^3/s$ | | | | |
| Cold Air Inlet Node | | | | | |
| Hot Air Inlet Node | | | | | |
| Air Outlet Node | | | | | |
| **Dual duct: VAV – outdoor air** | | | | | |
| Dual duct: VAV – outdoor air availability schedule | | | | | |
| Maximum air flow rate | $m^3/s$ | | | | |
| Induction ratio | % | | | | |
| Outdoor Air Inlet Node | | | | | |
| Air Outlet Node | | | | | |
| **Zone HVAC equipment connections** | | | | | |
| Ducts (length, section, material…) | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Pipes (length, diameter, material…) | | | | | |
| **Fans** | | | | | |
| Fan efficiency | | | | | |
| Pressure rise | Pa | | | | |
| Maximum flow rate | $m^3/s$ | | | | |
| Motor efficiency | | | | | |
| **Coils** | | | | | |
| Design water flow rate | $m^3/s$ | | | | |
| Design air flow rate | $m^3/s$ | | | | |
| Design inlet water temperature | ºC | | | | |
| Design inlet air temperature | ºC | | | | |
| Design outlet air temperature | ºC | | | | |
| Design inlet air humidity ratio | kg $H_2O$/kg air | | | | |
| Design outlet air humidity ratio | kg $H_2O$/kg air | | | | |
| Rated total cooling capacity | W | | | | |
| Rated COP | | | | | |
| **Humidifiers and dehumidifiers** | | | | | |
| Rated capacity | $m^3/s$ | | | | |
| Rated power | W | | | | |
| Rated fan power | W | | | | |
| Standby power | W | | | | |
| **Heat recovery units** | | | | | |
| Heat exchanger type (air to air: flat plate or sensible and latent; desiccant) | | | | | |
| Nominal supply air flow rate | $m^3/s$ | | | | |
| Nominal supply air inlet temperature | ºC | | | | |
| Nominal supply air outlet temperature | ºC | | | | |
| Nominal secondary air flow rate | $m^3/s$ | | | | |
| Nominal secondary air inlet temperature | ºC | | | | |
| Nominal electric power | W | | | | |
| **Pumps** | | | | | |
| Rated flow rate | $m^3/s$ | | | | |
| Rated pump head | Pa | | | | |
| Rated power consumption | W | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Motor efficiency | | | | | |
| Control type (continuous/intermittent) | | | | | |
| Pump curve | | | | | |
| **Solar collectors** | | | | | |
| Gross area | $m^2$ | | | | |
| Test fluid | | | | | |
| Test flow rate | | | | | |
| Test correlation type (inlet, average, outlet) | | | | | |
| Maximum flow rate | $m^3/s$ | | | | |
| Coefficient of efficiency | $W/m^2{\cdot}K$ | | | | |
| Incident angle | deg | | | | |
| Orientation | deg | | | | |
| **Boilers** | | | | | |
| Nominal capacity | W | | | | |
| Nominal thermal efficiency | | | | | |
| Design water outlet temperature | ºC | | | | |
| Design water flow rate | $m^3/s$ | | | | |
| **Chillers** | | | | | |
| Nominal capacity | W | | | | |
| Nominal COP | | | | | |
| Design chilled water outlet temperature | ºC | | | | |
| Design water flow rate | $m^3/s$ | | | | |
| **Chiller-heat: absorption** | | | | | |
| Nominal cooling capacity | W | | | | |
| Heating to cooling capacity ratio | | | | | |
| Design entering condensed water temperature | ºC | | | | |
| Design leaving chilled water temperature | ºC | | | | |
| Design water flow rate | $m^3/s$ | | | | |
| Design condenser water flow rate | $m^3/s$ | | | | |
| Design hot water flow rate | $m^3/s$ | | | | |
| **Heat pump** | | | | | |
| Nominal capacity | W | | | | |
| Nominal COP | | | | | |
| Load side flow rate | $m^3/s$ | | | | |
| Source side flow rate | $m^3/s$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Load side heat transfer coefficient | W/K | | | | |
| Source side heat transfer coefficient | W/K | | | | |
| **District heating** | | | | | |
| Nominal capacity | W | | | | |
| **District cooling** | | | | | |
| Nominal capacity | W | | | | |
| **Condenser equipment and heat exchangers (include equipment parameters)** | | | | | |
| Cooling tower | | | | | |
| Evaporative fluid cooler | | | | | |
| Fluid cooler | | | | | |
| Ground heat exchanger | | | | | |
| Heat exchanger (hydraulic, plate, water side economizer) | | | | | |
| Water heaters and thermal storage | | | | | |

**Table 22: On-site energy generation from renewable sources**

| ON-SITE ENERGY GENERATION FROM RES | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WTH |
| **Photovoltaic system** | | | | | |
| **Electric load inverter** | | | | | |
| Electric load inverter availability Schedule | | | | | |
| Performance curve | | | | | |
| Maximum DC power input | W | | | | |
| Maximum AC power produced | W | | | | |
| **Electric load storage battery** | | | | | |
| Electric load storage battery availability Schedule | | | | | |
| Number of battery modules in parallel | | | | | |
| Number of battery modules in series | | | | | |
| Maximum module capacity | W | | | | |
| Charge performance curve | | | | | |
| Discharge performance curve | | | | | |
| **Photovoltaic array** | | | | | |
| Location-surface attached | | | | | |
| Number of PV modules in parallel | | | | | |
| Number of PV modules in series | | | | | |
| **Photovoltaic module** | | | | | |
| Number of cells | | | | | |
| Rated current | A | | | | |
| Rated voltage | V | | | | |
| Short circuit current | A | | | | |
| Open circuit voltage | V | | | | |
| Rated power | W | | | | |
| Module efficiency | % | | | | |
| Maximum forward current | A | | | | |
| Maximum system voltage | V | | | | |
| **Wind turbine** | | | | | |
| Wind turbine availability schedule | | | | | |
| Rotor orientation | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Rated rotor speed | rev/min | | | | |
| Rotor diameter | m | | | | |
| Overall height | m | | | | |
| Number of blades | | | | | |
| Rated power | W | | | | |
| Rated wind speed | m/s | | | | |
| **Combined heat and power** | | | | | |
| Combined heat and power availability schedule | | | | | |
| Maximum electric power | W | | | | |
| Minimum electric power | W | | | | |
| Minimum cooling water flow rate | kg/s | | | | |
| Maximum cooling water temperature | ºC | | | | |
| Electrical efficiency curve | | | | | |
| Thermal efficiency curve | | | | | |
| Cooling water flow rate curve | | | | | |
| Heat exchanger U-factor | W/K | | | | |
| Cooling water flow rate curve | W/K | | | | |
| **Geothermal heat pump** | | | | | |
| **Heat pump** | | | | | |
| Heat pump heating/cooling availability schedule | | | | | |
| Nominal heating/cooling COP | | | | | |
| Nominal heating/cooling capacity | W | | | | |
| Load side heat transfer coefficient | W/K | | | | |
| Source side heat transfer coefficient | W/K | | | | |
| Piston displacement | $m^3/s$ | | | | |
| Compressor clearance factor | | | | | |
| Loss factor | | | | | |
| Pressure drop | Pa | | | | |
| Superheat | ºC | | | | |
| **Ground loop heat exchanger** | | | | | |
| Number of boreholes | | | | | |
| Borehole length | m | | | | |
| Borehole radius | m | | | | |
| Ground thermal conductivity | W/m·K | | | | |
| Ground heat capacity | $kJ/m^3 \cdot K$ | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Fluid specific heat | J/kg·K | | | | |
| Far field temperature | ºC | | | | |
| Grout conductivity | W/m·K | | | | |
| Pipe conductivity | W/m·K | | | | |
| Fluid conductivity | W/m·K | | | | |
| Fluid density | kg/m$^3$ | | | | |
| Dynamic viscosity | m$^2$/s | | | | |
| Pipe outer diameter | m | | | | |
| U-tube shank distance | m | | | | |
| Pipe wall thickness | m | | | | |

**Table 23: Energy monitoring and control systems**

| BUILDING CONTROLS AND MANAGEMENT SYSTEM | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WTH |
| **Building controls system** | | | | | |
| Building control type (adaptive/non adaptive) | | | | | |
| System availability manager | | | | | |
| Set point managers | | | | | |
| **EMS scheme (topology, addressing and communication protocols definition)** | | | | | |
| Sensors | | | | | |
| Actuators | | | | | |
| Communication protocols | | | | | |
| **Demand limiting controls** | | | | | |
| Exterior lights | | | | | |
| Lights | | | | | |
| Electric equipment | | | | | |
| Thermostats | | | | | |
| Thermostat temperature set points schedule | | | | | |
| Thermostat humidity set points schedule | | | | | |
| **HVAC controllers** | | | | | |
| Water pipes valves | | | | | |
| Water pipes valves operation schedules | | | | | |
| Outdoor air valves | | | | | |
| Outdoor air valves operation schedules | | | | | |
| Mechanical ventilation valves | | | | | |
| Mechanical ventilation valves operation schedules | | | | | |
| Switch on/off (pumps, boilers, chillers, lighting system…) | | | | | |
| Pumps, boilers, chillers, etc. operation schedules | | | | | |

| ENERGY METERS AND SENSORS | | | | | |
|---|---|---|---|---|---|
| FIELD | UNITS | BIM | DWH | | |
| | | | SCH | PFD | WTH |
| **Resources (energy and others) meters** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Gas consumption | $m^3$ and € | | | | |
| Other fossil fuels consumption | $m^3$ and € | | | | |
| Total electrical energy consumption | kWh or € | | | | |
| Electrical energy generation | $kWh/m^2$ | | | | |
| Electrical energy usage | $kWh/m^2$ | | | | |
| Electrical energy sales/export | $kWh/m^2$ | | | | |
| Thermal energy total generation | $kWh/m^2$ | | | | |
| Thermal energy usage | $kWh/m^2$ | | | | |
| Water consumption | l | | | | |
| **Outdoor climate conditions sensors** | | | | | |
| Weather station (variables defined in table 1) | | | | | |
| **Indoor climate sensors and comfort parameters** | | | | | |
| Occupancy sensor | 0-1 | | | | |
| Air temperature | ºC | | | | |
| Relative humidity | % | | | | |
| Carbon dioxide concentration (IAQ-$CO_2$) | ppm | | | | |
| Volatile organic compounds (IAQ-VOC) | ppm | | | | |
| Light sensor | lux | | | | |
| Air velocity | m/s | | | | |
| Surfaces temperature | ºC | | | | |
| Critical construction points temperature | ºC | | | | |
| Critical construction points relative humidity | % | | | | |
| Dew point sensor | ºC | | | | |
| Heat flux sensor | $W/m^2$ | | | | |
| **Thermal comfort** | | | | | |
| Operative temperature | ºC | | | | |
| Fanger Predicted Mean Vote (PMV) | % | | | | |
| Fanger Predicted Percentage of Dissatisfied People | % | | | | |
| Optical comfort index | | | | | |
| Air quality | $CO_2$ em. | | | | |
| **Equipment and systems sensors** | | | | | |
| Supply temperature | ºC | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Return temperature | ºC | | | | |
| Flow meter | $m^3/s$ | | | | |
| Electrical energy meter | kWh | | | | |
| Thermal energy meter | kWh | | | | |
| Equipment state (on/off): pumps, boilers, chillers… | 0-1 | | | | |
| Reed contacts (windows/doors state) | 0-1 | | | | |
| Air velocity on ducts (laminar flow sensor) | m/s | | | | |
| $CO_2$ sensor for ducts | ppm | | | | |

# Appendix C: Functional and non-functional requirements

## List of contents



## Brief introduction

The following tables present the requirements collected from an end user and a technical point of view. Every table has been defined in order to capture the requirements related to a specific aspect of the BaaS system, for example data management, APO modules, and so on. These requirements have been divided in functional and non-functional requirements. Functional ones present the main functionality expected by the BaaS platform users, and the non-functional ones complement the functional requirement in order to assure the performance and security of the system.

So as to measure the relevance of the requirements for the behaviour of the system, an "Importance" field has been defined with three levels of importance: *critical, high,* and *standard*:

- Critical – These requirements are indispensable for the operation of the BaaS system.
- High – Without these requirements, only limited functionality can be achieved.
- Standard – These requirements have an impact on the quality of service but are not crucial for the operation of the BaaS system itself, i.e. they add value to the overall system.

**Table 24: Human-Machine Interaction Requirements (functional)**

| | |
|---|---|
| **Name** | **FR-01:** Human-Machine Interaction Requirements |
| **WPs affected** | WP 3 & WP 5 |
| **Description** | The system should be able to allow the communication with the users through several graphical-user-interfaces in order to manage and operate the system.<br>• The system should offer different access to the content and views of the BaaS system, according to the privileges of a user:<br>  ○ Administrators (e.g. technical staff) should have control over the configuration of the system related to both user management and specific system configuration (alarm configuration, scheduler configuration, KPI calculation configuration, etc.).<br>  ○ BaaS users should be able to access to the whole functionality of the system, execute optimization (in case of being manually or at any moment even if the optimization has been scheduled) and control orders and view the results of the operation executed.<br>  ○ External users should be able to access monitoring values and results of optimization calculations executed over the BaaS buildings (only monitoring, and without privileges for the execution of any control or optimization tasks).<br>• User access should be controlled by managing permissions.<br>• The system should provide a user-friendly human-computer interface (HCI). The HCI should be intuitive and easy to use.<br>• The HCI should reflect the users' role (i.e. privileges). This includes different screens for administration of the system, monitoring values, control and optimisation, etc.<br>• The functionality offered by the system should be available from any device via a web browser. So the system should guarantee ubiquity in the access to its functionality.<br>• The user interface should be refreshed automatically in order to show the latest data collected by the system (live data). The update interval should be defined in the design phase. |
| **Importance** | High |
| **Rationale** | Providing structured access to the system and its functionality |

**Table 25: System Management Requirements: System Configuration (functional)**

| | |
|---|---|
| **Name** | **FR-02.1:** System Configuration |
| **WPs affected** | WP3 |
| **Description** | The system should allow the **configuration of the main parameters for the proper behaviour of the system**.<br>• The system should provide the administrator with the privileges to manage (create, delete, modify) users and their privileges. This configuration should be stored in a persistent storage medium (file, DB, DWH …).<br>• The system should allow the BaaS users (possibly automatically through the APO service modules) to configure the needed parameters for the schedulers: start time, finish time, timer, etc. for all the activities which need a planning.<br>• The system should allow alarm configuration:<br>  o The BaaS user should be able to configure the set-points below/above which an alarm must be triggered.<br>  o The administrator should be able to configure customised system alarms.<br>  o The BaaS user should be able to configure the mailing list, phone number list, etc. to which must alarms are sent. |
| **Importance** | Standard |
| **Rationale** | The configuration is an added value in order to increase the functionalities of the system. |

**Table 26: System Management Requirements: Interoperability (functional)**

| | |
|---|---|
| **Name** | **FR-02.2:** Interoperability |
| **WPs affected** | WP 2 & WP 3 & WP 5 |
| **Description** | The system **should interwork in heterogeneous networks**.<br>• The BaaS system should guarantee an appropriate interconnection among all their internal pieces of software (APO services, modules, components) as well as with external data sources and tools (BMS/BACN (Building Automation and Control Network), BIM server, DWH, external systems and services, and external tools). The whole distributed "eco"-system (regardless of being deployed locally, in a cloud, or a mix thereof) should communicate transparently and maintain coherence and consistency of data transferred.<br>• The BaaS system should be able, if necessary, to communicate (read |

| | |
|---|---|
| | & write access) with the existing BMS and/or BACN at the BaaS testbeds and demonstration buildings. The interface (connector) implementing the protocols provided by the aforementioned BMSs and/or BACNs should be developed.<br>• The BaaS system should be able, if necessary, to communicate (read & write access) with existing Data Warehouse(s), maintaining the consistency of data. The interface (connector) implementing the protocols provided by the DWH should be developed. In case that more than one DWH will be used by the BaaS system, the BaaS system should be able to communicate in a homogeneous and coherent way with all of them. The BaaS system should maintain the coherency of data.<br>• The BaaS system should be able to communicate (read & write access) with existing building information model (BIM) repositor(y/ies). The interface (connector) implementing the protocols provided by the BIM repositories should be developed. In case that more than one BIM repository will be used by the BaaS system, the BaaS system should be able to communicate in a homogeneous and coherent way with all of them. The BaaS system should maintain the coherency of data.<br>• The BaaS system should be able to retrieve data from external (third-party) service(s) (i.e. weather forecast service, occupancy forecast service, etc.). The interface (connector) implementing the protocols provided by the aforementioned external services should be developed.<br>• The BaaS system should be able to communicate with external tools (Matlab, E+, etc.) providing data and getting results. The interface (connector) implementing the protocols provided by the aforementioned external tools should be developed.<br>• The BaaS system should be able to communicate (read & write access) with existing ICT (external to the BMS/BACN such as metering system, access control, weather station and so on) systems used at BaaS testbeds and demonstration buildings. The interface (connector) implementing the protocols provided by the aforementioned ICT external systems should be developed.<br>• The BaaS system should be able to communicate (read & write access) with the APO Services, providing this layer with all the data needed from the Data Layer (BMS, BIM, DWH, etc.).<br>• The BaaS system should be cloud-enabled. The BaaS system should implement (or use from external servers/providers) those *Platform*, *Infrastructure*, and *Software as a Service* (PaaS, IaaS, SaaS) models needed in a "cloud environment" in order to guarantee the interoperability among all the components which make up the BaaS |

| | |
|---|---|
| | system. |
| **Importance** | Critical |
| **Rationale** | The communication amongst all the components is necessary for the properly behaviour of the whole system. |

**Table 27: System Management Requirements: Openness (functional)**

| | |
|---|---|
| **Name** | **FR-02.3:** Openness |
| **WPs affected** | WP 2 & WP 3 |
| **Description** | The system **<u>should work with open systems where possible based on SOA (Service Oriented Architecture)</u>**.<br>• Solutions based on FLOSS (free/libre open source software) should be used. Use of FLOSS components should be encouraged and promoted (e.g. OpenBIM Server; LON- or BACnet- based BMSs; open and relational DWHs; M-BUS based meters). If the use of FLOSS is impossible, then the BaaS platform should use proprietary software (proprietary BIM server; proprietary BMS, etc.).<br>• The BaaS system should implement open or standardized protocols for the communication with the BMS/BACN system (LON, BACnet, etc.). If this is not possible, we should try to include a commercial gateway mapping the proprietary protocol to BACnet, LON, or any other open or standard protocol. If it is not possible, the BMS/BACN proprietary protocol should be implemented in one connector.<br>• The BaaS system should implement any communication with the database repositories based on SQL queries or other open database standards. Transparency between the BaaS system and these repositories should be provided (i.e. interface based on Hibernate technology in order to make the database independent of the BaaS platform).<br>• The BaaS system should implement open or standardized protocols for the communication with the BIM Server. The system should be able to query the BIM Server using different kind of filters (site, building, storey, room, system/subsystem objects, object types, object properties).<br>• The BaaS system should implement open or standardized protocols for the communication with the external services (SOAP, REST).<br>• The BaaS system should implement open or standardized protocols for the communication with the external ICT system (i.e. M-BUS from energy meters). If this is not possible, proprietary protocols should be implemented in one connector. |

| | |
|---|---|
| **Importance** | Standard |
| **Rationale** | BaaS activities should foster openness and the adoption and use open standards |

**Table 28: Data Management Requirements (functional)**

| | |
|---|---|
| **Name** | **FR-03:** Data Management |
| **WPs affected** | **WP 2** |
| **Description** | The system should be able to maintain data consistency and to ensure high availability of the data<br>• The system should be able to securely backup data and restore it if needed. Multi-level incremental backups are preferred.<br>• The system should be able to keep historical records / logs of access, modification, deletion, etc. of data.<br>• The BaaS system should be able to read/write data from/to the BMS/BACN working on the BaaS testbeds and demonstration buildings. The BaaS system should be able to read:<br>a) live (on-line/near-real time/time response minor than predetermined time) data from devices (sensor/actuator states and values, parameters, properties, setpoints, etc.),<br>b) temporary storage structures as data logs (for example, some BMSs are able to create a file containing data in a temporal "window" of several days), and<br>c) other structured information like schedules, list of devices, etc.<br>• The BaaS system should be able to write data to:<br>a) Actuators (setpoints, actuation commands)<br>b) Controllers (update parameters and control laws)<br>• The BaaS system should be able to retrieve and store data from/to the databases/DWHs which support the data storage in the BaaS testbeds and demonstration buildings.<br>• The BaaS system should be able to read and write information from/to the BIM repository, including:<br>a) the entire BIM model,<br>b) specific information (object properties, list of sensors, etc.) of the BIM repository.<br>• The system should be able to write, update, or delete information into/from the BIM repository. For instance, sensors/actuators malfunctions could be detected by the BaaS system (*fault detection and diagnostics service*), so this new state of the sensor/actuator should be able to be updated in the BIM repository; as well as new |

| | |
|---|---|
| | sensors could be commissioned in the BMS/BACN system, so this new object should be added in the BIM repository.<br>• The BaaS system should be able to retrieve data from external services and – if desired – to store these data in the DWH(s). Some examples of data served by external services are weather forecasting, historical weather data, and properties of materials.<br>• The BaaS system should be able to retrieve and write data of external ICT system – if desired – to store these data in the DWH(s). Some examples of data served by external ICT systems could be in-building weather station, access control system, meters (gas, water, electricity). |
| **Importance** | Critical |
| **Rationale** | Good data management is crucial for the resilience and fault tolerance of the entire system. |

**Table 29: APO Modules General Requirements (functional)**

| | |
|---|---|
| **Name** | **FR-04:** APO Modules |
| **WPs affected** | WP 5 |
| **Description** | APO modules are basic software modules, providing the business intelligence of the BaaS system at the APO Service Layer. A transparent and generic mechanism for development, deployment and configuration of such modules should be provided within the BaaS system.<br>• An APO kernel service will be in charge of registering and managing modules as well as making them available to the system.<br>• Should APO modules require parameters, they should be passed when the module is executed (by access through the middleware layer to the BIM, DW other external providers).<br>• APO modules should propagate detected anomaly events for storing, logging, visualization, automated corrective actions, etc. to the BaaS system.<br>• At the kernel level, time-control mechanisms (scheduling) should be in place to allow for controlling of execution of modules at user-defined time intervals.<br>• A user- and service-permission mechanism should control access to system resources and data.<br>• The system should support Error- and event-handling through properly defined mechanisms and interfaces<br>• The system should communicate events and errors with the middleware layer. |

| | |
|---|---|
| | • Simulation models should be available to modules. Binding to these simulation modules should be achieved with the help of the APO kernel.<br>• The BaaS user should be able to configure what modules (performing APO tasks) must be scheduled and periodically launched.<br>• The system must provide a bi-directional interface between the middleware and the APO layer. |
| **Importance** | Critical |
| **Rationale** | This is key BaaS functionality, a part of APO services |

**Table 30: FDD general requirements (functional)**

| | |
|---|---|
| **Name** | **FR-05:** APO services: Fault and Detection Diagnostics |
| **WPs affected** | WP 5 |
| **Description** | The BaaS system should detect abrupt changes in the monitored system (building), where the changes relate to difference from expected behaviour (correct one).<br>• Each fault definition contains its required data points.<br>• A fault present in the system must be detected if all required data points are available and the FDD module is triggered.<br>• FDD APO services provide actionable recommendations for the end user if appropriate. |
| **Importance** | Standard |
| **Rationale** | This is a BaaS functionality, which is a part of APO services |

**Table 31: Energy and Comfort Management general requirements (functional)**

| | |
|---|---|
| **Name** | **FR-06:** APO services: Energy and Comfort Management |
| **WPs affected** | WP 5 |
| **Description** | The BaaS system should calculate KPIs describing the monitored system (i.e. building) in terms of its energy performance and user comfort. Note: calculated KPIs are listed in the deliverable 1.1<br>• Each KPI definition contains its required data points.<br>• If monitored system (or its part) degrades it must be captured by deteriorating relevant KPI values.<br>• Energy & comfort management services provide actionable recommendations for the end user if appropriate. |

| | |
|---|---|
| **Importance** | High |
| **Rationale** | This is key BaaS functionality, a part of APO services |

**Table 32: Control and Optimization general requirements (functional)**

| | |
|---|---|
| **Name** | **FR-07:** APO services: Control Optimization |
| **WPs affected** | WP 5 |
| **Description** | The system should support supervisory control and control optimization functionalities. For design and optimization purposes access to simulation might be required.<br>• The system should be able to automatically generate control actions to optimize selected KPIs.<br>• Control actions should respect thermal comfort constraints.<br>• The system should support rule-based and model-based control strategies.<br>• The system should be able to store the optimization results and make them available upon request. |
| **Importance** | High |
| **Rationale** | This is key BaaS functionality, a part of APO services |

**Table 33: Modelling and Simulation general requirements (functional)**

| | |
|---|---|
| **Name** | **FR-08:** Modelling and Simulation |
| **WPs affected** | WP 4 & WP 5 |
| **Description** | The system should be able to provide multiple simulation approaches: on the (whole) building level and, if needed, at the component level (e.g. HVAC system). These simulations should be exposed to the other system components and be made available upon request. A platform for providing "simulation as a service" to be consumed by other services is necessary.<br>• These simulation capabilities should support multiple uses: FDD, Control Design and Optimization (CDO).<br>• The system should be able to simulate the behaviour or the building and interface with the control algorithms. The system should be able to run simulation tasks by means of the APO Services, with the data provided by the middleware, in order to optimize the control algorithms.<br>• The whole building simulation models should have co-simulation capabilities.<br>• Simulation using sensed (historical) data and forecasts should be possible. |
| **Importance** | Critical |
| **Rationale** | Simulation is needed for support of APO Services |

**Table 34: Performance requirements (non-functional)**

| | |
|---|---|
| **Name** | **NFR-01:** Performance |
| **WPs affected** | WP 3 |
| **Description** | The systems should provide a sufficiently high availability (--> service level agreement) and be scalable as well as fault-resilient. Scalability, replicability, reliance and robustness concepts should be taken into account.<br>• Scalability: New functions of the BaaS system, as well as further external systems (BMSs, data sources), should be easy to add. In order to assure the BaaS system's scalability, the documentation to code interfaces between the BaaS system and other modules should be provided, e.g.:<br>o BMS/BACNs,<br>o BIM repositories,<br>o DWHs, DBs,<br>o third-party web services |

| | |
|---|---|
| | ○ external tools,<br>○ external ICT systems/devices<br>○ new modules of the BaaS system<br>• Reliability: A malfunction of the system should not affect the operability of the building.<br>○ The system should have a fall-back mode with reduced functionality in case of local errors (e.g. in the communication channels or in individual components). The building should have an emergency fall-back mode in case of total failure to maintain vital functions.<br>• The system should be able to detect and ideally also predict internal faults.<br>• Response time: The system should be able to respond in a limited time in order to allow a fluent activity.<br>• Replicability: The system should be able to operate in different typologies of buildings. |
| **Importance** | Standard |
| **Rationale** | Reliable operation of the system crucial for the success of the entire project. |

**Table 35: Security requirements (non-functional)**

| | |
|---|---|
| **Name** | **NFR-02:** Security |
| **WPs affected** | WP 3 |
| **Description** | The system should be able to ensure confidentiality and integrity of collected data, particularly of personally identifiable data as well as ensure privacy of people affected by the operation of the system.<br>• Authentication and authorisation: The system should provide appropriate interfaces to support different access profiles to different users.<br>• Integrity: The system should provide meta-information about origin and trust of the gathered data and protect the data against malicious or accidental modification.<br>• Confidentiality: The system should ensure the confidentiality of information which might leak sensitive information about building users and tenants. |
| **Importance** | High |
| **Rationale** | Meeting legal requirements on both a local and European level is crucial for liability reasons and to achieve maximum acceptance of the BaaS system. |

# Appendix D: Key Performance Indicators

**Table 36: Summary of BaaS KPIs**

| ENERGY INDICATORS | | | |
|---|---|---|---|
| Key Performance Indicator | | Reference | Unit |
| NECE | Net Energy Consumed Electric | Eq. 2 | $kWh_e$ |
| NECT | Net Energy Consumed Thermal | Eq. 3 | $kWh_t$ |
| SCL | Summer Cooling demand | Section 7.1.4.1 | kWh |
| WHL | Winter Heating demand | Section 7.1.4.2 | kWh |
| NFEC | Net Fossil Energy Consumed | Eq. 4 | kWh |
| NEP | Net Energy Performance | Section 7.1.4 | kWh |
| $\eta$ | Efficiency | Eq. 6 | % |
| DEP | Dependence from external sources | Eq. 7 | % |
| PEC | Primary Energy Consumed | Eq. 5 | kWh |
| PES | Primary Energy Savings | Eq. 9 | kWh |
| PESP | Primary Energy Savings Percentage | Eq. 10 | % |
| $NECE_{norm}$ | Net Energy Consumed Electric / normalisation criteria | Eq. 2 / norm. | kWh/HDD<br>kWh/CDD<br>$kWh/m^2$<br>kWh/person |
| $NECT_{norm}$ | Net Energy Consumed Thermal / normalisation criteria | Eq. 3 / norm. | |
| $SCL_{norm}$ | Summer Cooling demand / normalisation criteria | Section 7.1.4.1 | |
| $WHL_{norm}$ | Winter Heating demand / normalisation criteria | Section 7.1.4.2 | |
| $NEP_{norm}$ | Net Energy Performance / normalisation criteria | Section 7.1.4 | |
| $PEC_{norm}$ | Primary Energy Consumed / normalisation criteria | Eq. 5 / norm. | |
| $PES_{norm}$ | Primary Energy Savings / normalisation criteria | Eq. 9 / norm. | |

| | | | |
|---|---|---|---|
| HDD | Heating Degree Days | Eq. 12 | ºC DD |
| CDD | Cooling Degree Days | Eq. 13 | ºC DD |
| **ENVIRONMENT INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| $CO_2$ | $CO_2$ Emitted to the ambient | Eq. 14 | $TonCO_2$ |
| $CO_2^{extra}$ | Extra emissions | Eq. 8 | % |
| $CO_{2\ norm}$ | $CO_2$ Emitted to the ambient / normalisation criteria (HDD, CDD, area, person) | Eq. 14 / norm. | $TonCO_2$/HDD<br>$TonCO_2$/CDD<br>$TonCO_2/m^2$<br>$TonCO_2$/person |
| HDD | Heating Degree Days | Eq. 12 | ºC DD |
| CDD | Cooling Degree Days | Eq. 13 | ºC DD |
| **COMFORT INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| POR | Percentage outside range | Section 7.3.1 | % |
| DHC | Degree hours criterion | Section 7.3.1 | ºC |
| - | Temperature indoor | Section 7.3.1 | ºC |
| CPAV | Comfort parameter average value | Eq. 16 | % |
| UPT | Underperformance Time | Eq. 17 | n.a. |
| UPR | Underperformance Ratio | Eq. 18 | n.a. |
| UPP | Proportional Underperformance | Eq. 19 | n.a. |
| PMV | Predicted Mean Vote | Eq. 21 | n.a. |
| PPD | Predicted Percentage of Dissatisfied | Eq. 22 | % |
| **ECONOMIC INDICATORS** | | | |
| **Economic** | **Key Performance Indicator** | **Reference** | **Unit** |
| - | Operating Costs | Section 7.4.1 | € |
| NEB | Net Expected Benefit | Section 7.4.2 | € |

| | | | |
|---|---|---|---|
| GCEI | Generation Consumption Effectiveness Index | Eq. 24 | n.a. |
| BPBP | BaaS Payback Period | Section 7.4.4 | n.a. |
| NPVB | Net Present Value of BaaS | Eq. 25 | € |
| IRRB | Internal Rate of Return of BaaS | Eq. 26 | n.a. |
| **DATA QUALITY INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| $DQ_C$ | Completeness of data | Eq. 27 | n.a. |
| $DQ_{TS}$ | Technical significance of data | Eq. 28 | n.a. |
| $DQ_{SS}$ | Systemic significance of data | Eq. 29 | n.a. |
| **SYSTEMS' PERFORMANCE INDICATORS** | | | |
| **Key Performance Indicator** | | **Reference** | **Unit** |
| $\rho_{occup}$ | Occupant density | Eq. 30 | n.a. |
| $UI_a$ | Absolute use intensity | Section 7.6.2 | n.a. |
| $UI_{a,\ comp}$ | Component level absolute use intensity | Eq. 33 | n.a. |
| $UI_{a,\ subsys}$ | Subsystem level absolute use intensity | Eq. 32 | n.a. |
| $UI_{a,\ sys}$ | System level absolute use intensity | Eq. 33 | n.a. |
| $UI_{c,\ subsys}$ | Compared use intensity | Section 7.6.2 | n.a. |

# Appendix E: Energy Parameters

### Production Parameters

### Primary energy

The transformation parameter to relate final with primary energy must be provided by the ESCO. The appendix of EN 15603 contains tables of national energy factors for European countries (see extract shown in Table 11). "RE = 0" corresponds to the non-renewable primary energy factor, "RE = 1" to the total primary energy factor.

**Table 37. National primary energy factors PEF [EN15063]**

| EU-Country | %Renewable (RE) | PEF | PEF (RE=0) | PEF (RE = 1) |
|---|---|---|---|---|
| France | 12.8 | 2.58 | 2.63 | 2.77 |
| Germany | 10.3 | 2.6 | 2.54 | 2.65 |
| Netherlands | 4.2 | 2.56 | 2.3 | 2.35 |
| Poland | 2.7 | 3.00 | 3.23 | 3.26 |
| Spain | 22.3 | 2.6 | 1.78 | 2.01 |
| Sweden | 50.2 | 2.00 | 1.6 | 2.14 |
| United Kingdom | 4.7 | 2.92 | 2.43 | 2.48 |

### *$CO_2$Emissions*

As explained in [SEAP2010] to calculate the $CO_2$ emissions to be attributed to electricity consumption it is necessary to determine the emission factor.

$$EFE = \frac{(TCE - LPE - GEP) * NEEFE + CO_2LPE + CO_2GEP}{TCE}$$

**Where:**

EFE: Local emission factor for electricity [t/MWhe]

TCE: Total electricity consumption in the local authority [MWhe]

LPE: Local electricity production [MWhe]

GEP: Green electricity purchases by the local authority [MWhe]

NEEFE: National or European emission factor for electricity [t/MWhe]

$CO_2$LPE: $CO_2$ emissions due to the local production of electricity [t]

$CO_2$GEP: $CO_2$ emissions due to the production of certified green electricity [t]

Table 38 shows national emission factors for 25 European countries and the average value for whole EU, i.e. the standard emission factor (in tons of $CO_2$/MWh electricity) and the emission factor including Life Cycle Assessment LCA (in tons of $CO_2$-equivalents/MWh electricity), which take into consideration the overall lifecycle of the energy carrier. This approach includes not only the emissions of the final combustion, but also all emissions of the supply chain. It includes emissions from exploitation, transport and processing (e.g.refinery) steps in addition to the final combustion. This hence includes also emissions that take place outside the location where the fuel is used.

**Table 38. National and European emission factors for consumed electricity [IPCC2006]**

| EU-Country | Standard Emission Factor ($tCO_2$/MWhe | LCA emission factor (tCO2-eq&MWhe) |
|---|---|---|
| Austria | 0.209 | 0.31 |
| Belgium | 0.285 | 0.402 |
| Germany | 0.624 | 0.706 |
| Denmark | 0.461 | 0.760 |
| Spain | 0.440 | 0.639 |
| Finland | 0.216 | 0.418 |
| France | 0.056 | 0.146 |
| United Kingdom | 0.543 | 0.658 |
| Greece | 1.149 | 1.167 |
| Ireland | 0.732 | 0.870 |
| Italy | 0.483 | 0.708 |
| Netherlands | 0.435 | 0.716 |
| Portugal | 0.369 | 0.750 |
| Sweden | 0.023 | 0.079 |
| Bulgaria | 0.819 | 0.906 |

| | | |
|---|---|---|
| Cyprus | 0.874 | 1.019 |
| Czech Republc | 0.950 | 0.802 |
| Estonia | 0.908 | 1.593 |
| Hungary | 0.566 | 0.678 |
| Lithuania | 0.153 | 0.174 |
| Latvia | 0.109 | 0.563 |
| Poland | 1.191 | 1.185 |
| Romania | 0.701 | 1.084 |
| Slovenia | 0.557 | 0.602 |
| Slovakia | 0.252 | 0.353 |
| EU-27 | 0.460 | 0.578 |

The national and European emission factors fluctuate from year to year due to energy mix used in electricity generation. These fluctuations are caused by the heating/cooling demand, availability of renewable energies, energy market situation, import/export of energy and so on. These fluctuations occur independently of the actions taken by the local authority.

In the case of the local renewable electricity production (other than biomass/biofuels), the emissions can be estimated by using the emission factors in Table 39. The table contains emission factors for local renewable electricity production or green electricity purchases for solar photovoltaic, wind power and hydropower. Emission factors for local renewable heat/cold production (geothermal or AHU exchanger) are not available in this study.

**Table 39. Emission Factor for local renewable electricity production [IPCC2006]**

| Electricity source | Standard Emission Factor ($tCO_2$/MWhe | LCA emission factor (tCO2-eq/MWhe) |
|---|---|---|
| Solar PV | 0 | 0.020-0.050 |
| Windpower | 0 | 0.007 |
| Hydropower | 0 | 0.024 |

Depending on the fuels composition, each mass unit of fuel produces a different amount of $CO_2$.The emission factors for the fuels which are most commonly used are presented in the

Table 40, based on 2006 IPCC Guidelines and European Reference Life Cycle Database (ELCD). The emission factors for fuel combustion are expressed as $t/MWh_{fuel}$

**Table 40. Standard $CO_2$ emission factors for most common fuel types [IPCC2006].**

| Type | Standard Emission Factor ($tCO_2/MWhe$) | LCA emission factor (tCO2-eq/MWh) |
|---|---|---|
| Motor Gasoline | 0.249 | 0.299 |
| Gas oil, diesel | 0.267 | 0.305 |
| Residual Fuel oil | 0.279 | 0.310 |
| Anthracite | 0.354 | 0.393 |
| Other Bituminous Coal | 0.341 | 0.380 |
| Sub-Bituminous Coal | 0.346 | 0.385 |
| Lignite | 0.364 | 0.375 |
| Natural Gas | 0.202 | 0.237 |
| Municipal Waste (non – biomass fraction) | 0.330 | 0.330 |
| Wood | 0 – 0.403 | 0.002 – 0.405 |
| Plant Oil | 0 | 0.182 |
| Biodiesel | 0 | 0.156 |
| Bioethanol | 0 | 0.206 |
| Solar thermal | 0 | - |
| Geothermal | 0 | - |

**In building distribution**

The "in building distribution" includes the cooling production caused by free ventilation cooling and evaporative cooling effects, not evaluated in the "production layout". This effect normally occurs in an AHU (Air Handling Unit) that is fed by hot/cold water previously produced. The air from the AHU is distributed inside the building, so the AHU has been considered in this example as a distribution piece with internal energy production.

**Building demands**

The building has a combination of demands that must be provided by the heating and cooling system, but cannot always be evaluated in a precise mode. So, in some of the following cases, the building demand will be considered as the energy delivered to the system (considering that the final element, as radiator, radiant floor, etc. gives the building the exact energy needed to cover the demands, and it is never more than the building needs).

***Domestic Hot Water Demand***

The total domestic hot water demand of the building can be considered as the sum of all partial demands of the building.

The measuring of the hot water demand considers the temperatures and flows at the water plug of the circuit.

***Sensible demand***

Sensible demand is the result of all the sensible inputs and outputs occurring inside the building zones. Heat gains provided by lamps and electrical components, solar gains through the windows and people occupancy deliver heat to the building.

Other loads due to the temperature difference between the external and internal temperature, as can be convective and radiative losses to the ambient, sensible ventilation and infiltration of air through the façade, etc. The combination of all this loads creates the sensible demand of heating and cooling, depending on the sign obtained from the instantaneous sum.

It is nearly economically impossible to measure all these values independently in normal buildings, so the sensible building demand will be considered as the difference between the internal characteristics of the zone and the set points that should be reached for an optimum control that can be different from the energy provided by the heat delivering systems to the building. This energy can be higher or smaller, dependent on the delivering efficiency.

***Latent demand***

Total latent load, as the sensible was, is the sum of the different loads where the humidity effects vary the hydro parameters of the air inside the building.

Occupation loads and water evaporation due to the activity of inhabitants, e.g. cooking or bathing, increase the humidity level and -as a consequence -the latent load. Ventilation and air renovation change the characteristics of the system.

The latent demand will be measured and controlled in the AHU that treat the complete air flows moving in the building in the case of centralized treatment. If there is no AHU installed, it is almost impossible to measure all ventilation and infiltration flows.