Work Package 5

Installation and validation

Deliverable D5.1

Monitoring guidelines and evaluation plan

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Table of Acronyms

BOC: Building Optimization and Control

JC: Johnson Control

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1. Introduction

This document represents the first output of WP5 - "Installation and validation". It presents the results of the work done in task 5.1 - "Validation procedure definition and installation".

The main purpose of this task was:

- to complete the installation and configuration activities already started in WP2 - "Pilot's solution set data analysis";
- to set up a validation procedure to ensure measures repeatability and reliability.

Chapter 2 presents the finalization of the installation phase and the algorithm implementation.

Chapter 3 describes the guidelines that were agreed to setup the data acquisition system. The main objectives, the partners involved and their main role and the final checklist to be considered for each solution set are presented.

Chapter 4 describes the data validation procedure which can be divided into two main parts: acquired data validation and energy saving validation. The first part is more linked to ensure the measures repeatability while the second one is more focused on the reliability of the project final results in terms of savings obtained by the nine energy savings solution sets. In the same chapter specific actions aiming at ensuring the compliance of final results with ICT PSP methodology are presented. The last paragraph of this chapter presents the Web-EMCS functionalities that have been developed to support the validation process.

Chapter 5 lists the methodology agreed to ensure the measurement reliability during all the monitoring campaign.

2. Installation and algorithm implementation

Task 5.1 included activities preliminary to the test period campaign such as installation and validation procedure definition. The first activity can be seen as the finalization of the activities performed in WP2, WP3 and WP4. The list of the variables stored in the Web-EMCS has been updated adding more variables useful to optimize the management of the solution sets.

With respect to communication between Pilot hospitals and the Web-EMCS its reliability has been improved operating on:

- Connection stability
- Data queuing system (Data stored in the communication framework to avoid data loss in case of communication failure).

Furthermore the energy saving algorithms have been implemented in the Web-EMCS. Since BOC algorithms developed in WP4 need to be trained to ensure safe operation, in order to guarantee at least one year of monitoring campaign, simplified energy saving algorithms have been implemented in the pilots following the indications coming from the preliminary outputs of WP4. For this reason algorithms implementation was divided into two different main steps:

- Simplified energy saving algorithms implementation: simplified energy saving strategies implemented following the indications coming from WP4;
- BOC algorithms full implementation: BOC algorithms have been fully implemented in the Web-EMCS.

Simplified energy saving strategies implemented in each pilot hospital are presented in detail in the following paragraphs.

2.1. AOR

Smart lighting system

The smart lighting system installation has been finalized in November 2013. LED luminaries, presence and light sensors, ward and floor control panels have been installed. Moreover the system has been connected to the platform ICT architecture.

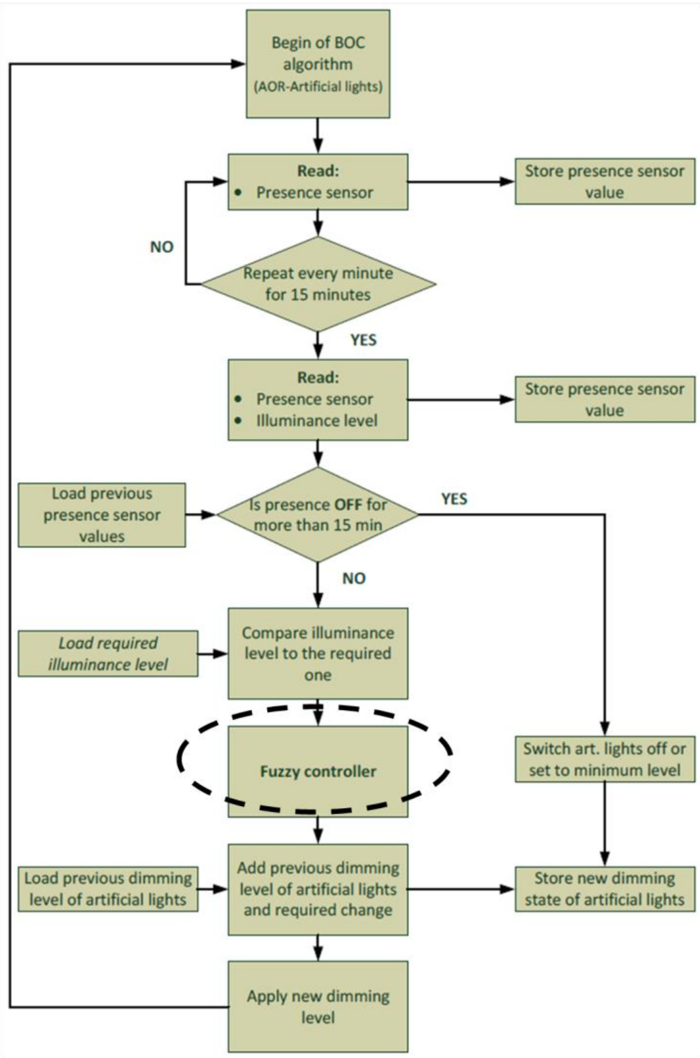

Figure 1: Lighting algorithm structure

During December 2013 and January 2014 the system has been setup and the first control strategy has been implemented. Since BOC algorithms developed in WP4 where not trained enough to ensure safe operation, a simplified control strategy has been implemented at the end of January.

With respect to Figure 1 which represents the structure of the BOC algorithm developed in the framework of WP4, the fuzzy controller has been replaced by a proportional controller while all the rest of the BOC algorithm has been implemented as described in the figure. The proportional controller regulates the dimmer output value comparing the luminance set point value and the measured illuminance. The delta obtained is multiplied by a gain set in order not to avoid light fluctuation. A dead zone of 20 lux has been set in order to make the control even more stable.

The developed fuzzy lighting controls have been tested and implemented in May 2014 replacing the proportional controller previously implemented.

Data centre cooling system

AOR data centre was already equipped with all the required monitoring equipment at the beginning of the project. For this reason no additional installation activities were needed in terms of hardware. On the contrary from a software point of view the framework has been installed in order to communicate with the Web-EMCS. This activity was already concluded in February 2013.

The optimization strategy studied in WP4 with respect to this solution set deals mainly with freecooling activation. The conditions to activate the freecooling mode have not occurred since the beginning of the test campaign fixed on the 1st February 2014. However additional energy saving strategies have been setup including pump flow and fan speed optimization.

2.1. HVN

Emergency zone Air Handling Unit Control

Electricity and heat meters installation ended in June 2013 and their connection to the Web-EMCS has been finalized in July 2013 and data are collected since that date. A free cooling control for the AHU was implemented, but the free cooling function is only available in the summer operating mode. Before the implementation of the simplified control, free cooling was not performed since conditions enabling this control were not available

Initially the algorithm was intended to provide a certain amount of recirculation air, depending on the time of day, but a specific requirement collected from the medical staff prevents from using air recirculation in the emergency area. For this reason supply air will be 100% fresh air.

Fuzzy controller was installed in July 2014. Different algorithm releases were required because part of the control needed to be installed in the hospital controller for safety reasons. In particular, the temperature prediction was installed in the framework while the valve control was installed in the hospital controller.

Surgery theaters Air Unit Control

Electricity and heat meters installation ended in June 2013 and their connection to the Web-EMCS has been finalized in July 2013 while reliable data are available since October 2013. In the same month a simplified temperature control in operating rooms and surgical areas was implemented in the new controller. Air temperature set points are manually adjusted through control panels installed in each surgical room.

Before the implementation of the simplified control, no automatic temperature control was available and operators could just regulate manually valves and dampers position according to users' complains.

Fuzzy controller suggesting system operation was installed in July 2014.

Data centre cold water production management

The installation of electrical and thermal energy meters was completed in June 2013. Most of the data collected are available in the Web-EMCS since July 2013 while data collected by the energy meters are available since December 2013. In this month chiller water temperature set points were adjusted according to the results of the simulations performed in WP4.

In February 2014 a further improvement was implemented: temperature and humidity set points of the AHU were modified to increase the number of hours of freecooling operation.

The fuzzy algorithm suggesting the optimal set points for the chillers have been effectively implemented in July 2014.

2.2. SGH

Fan coils management in selected rooms of the pediatric clinic

For the selected fan coils located in the pediatric department of SGH, the required equipment has been installed since March 2013.

Indoor/ outdoor air temperature, presence indication and windows position related measurements collected from the rooms and users feed-back collected using the questionnaires, led to the implementation of a simplified control which started in February 2014. Before the implementation of the simplified control, the Fan coils where controlled manually without the intervention of the central system.

The simplified controller is implemented in the FX07 controller available in each room and it prevents temperature set-points to be above 22 °C during the winter and below 24 °C during the summer. The required temperature set-point based on regulations for summer period is 26 °C and during winter period is 20 °C. Using this simplified control the Web-EMCS prevents the users to spend more energy than required in order to cover their needs.
The fuzzy controller managing the fan coil system has been implemented in June 2014.

Artificial lighting management in selected rooms of the pediatric clinic

For the artificial lights of the pediatric department of SGH, the required equipment has been installed since March 2013.

Indoor illuminance, outdoor radiation and presence indication related measurements collected from the rooms and users feed-back collected using the questionnaires, resulted in the implementation of a simplified control which started in February 2014. Before the implementation of the simplified control, the Fan coils where controlled manually without the intervention of the central system.

The simplified controller is implemented in the FX07 controller available in each room and it prevents the operation of the artificial lights when the indoor illuminance level exceeds 600 lux. Thus during the day the artificial lights cannot operate when the daylight is sufficient for the rooms.

The fuzzy controller managing the artificial lighting system has been implemented in June 2014. Control optimizations were needed to reduce the control loop time in order to respect users' requirements.

2.3. HML

Heating and cooling generation system optimized management

The system has been equipped with new meters and collected data are available since September 2013 in the Hospital BMS. Some tests have been performed since November 2013. Then according to simulation results and IFTEC expertise since February 2014 the Geothermal system management has been modified in order to reduce ground saturation: the geothermal system is used during the day when external temperature conditions are more "extreme" while traditional heat and cool generators are used during night. According to simulation results the following schedule has been setup:

- Geothermal System ON: 09:00 - 21:00

- Geothermal System OFF: 21:00 - 09:00

The fuzzy algorithms suggesting the optimal system schedule have been implemented in July 2014. System operation is planned according to the algorithm output.

Optimized control strategies for Surgery Rooms ventilation

The control strategy implemented from February 2014 affects both internal comfort conditions and ventilation rates. Three different operational conditions have been identified: USE, NO USE and CLEANING. Specific internal air requirements have been selected and are resumed in the following table.

Table 1: Surgery room operational setpoints in HML

OPERATIONAL SETPOINTS SURGERY ROOM			
SET POINT	**USE**	**NO USE**	**CLEANING**
TEMPERATURE	[18°C - 25°C]	23 °C	23 °C
T° DEADBAND	± 0,5 °C	± 5 °C	± 5 °C
HUMIDITY	50%	50%	50%
HR DEADBAND	± 1 %	± 10 %	± 10 %
PRESSURE	30 Pa	20 Pa	30 Pa
AIR FLOW	4000 m3/h	2900 m3/h	3400 m3/h

The fuzzy algorithm which optimizes the control of comfort conditions (Temperature and relative humidity in the surgery rooms has been implemented in July 2014. An additional energy saving control on ventilation rates is managed by hospital personnel.

3. Monitoring guidelines

The monitoring system implemented in the pilot hospitals is made of different layers. The lower layer is the field layer where sensors and meters measuring consumptions and parameters are located. These devices are connected by an ICT infrastructure located in the Pilot hospital which communicates towards the Web-EMCS. The Web platform stores data and presents them to the final user. The following monitoring guidelines are meant to ensure data reliability for both monitored data and energy saving calculations.

3.1. Objectives

A data set can be defined reliable if data are reasonably complete and accurate, if they meet the intended purposes and they are not subjected to inappropriate alteration. These concepts can be defined in more detail as following:

- Completeness: records are present and the fields in each record are populated appropriately.
- Accuracy: recorded data represent the real information.
- Consistency: data are clear and well defined enough to yield similar results to similar queries.

In other words data are reliable when they have a reasonable level of uncertainty; data uncertainty can be managed by controlling random errors and data bias.

Random errors are affected by the quality of the measuring equipment, the measurement techniques, and the design of the sampling procedure. Data bias, on the contrary, is affected by the quality of measurement, data assumptions and analysis.

Furthermore energy saving calculations foresees a comparison among measured energy data, and a normalization procedure needed to make the comparison among baseline and test periods meaningful.

Both measurements and normalization introduce errors. Errors may arise for example because of meter inaccuracy, sampling procedures or adjustment procedures. All physical measurement and statistical analysis are based on estimation of central tendencies, such as mean values, and quantification of variations such as range, standard deviation, standard error, and variance.

Errors can be roughly classified into: modeling, sampling, and measurement errors:

- Modeling: errors occur in mathematical modeling due to inappropriate functional form, inclusion of irrelevant variables, exclusion of relevant variables, etc.
- Sampling: error arises when only a portion of the population of actual values is measured, or a biased sampling approach is used. Representation of only a portion of the population may occur in either a physical sense (i.e., only 20 of 1,000 light fixtures are metered), or in the time sense (metering occurring for only ten minutes out of every hour).
- Measurement: errors arise from the accuracy of sensors, data tracking errors, drift since calibration, imprecise measurements, etc. The magnitude of such errors is largely given by manufacturer's specifications and managed by periodic re-calibration.

3.2. Required skills

Generally, a data reliability assessment is performed as early as possible on a project, preferably during the design phase. The assessment plan helps by reflecting data reliability issues and any additional steps that still need to be taken in assessing the reliability of critical data. The assessment team generally takes initial steps to test the data and reviews existing information about the data and the system that produces them before making the final plan. Examining this information early is also necessary to help the team to determine whether the data would be appropriate for addressing the research question in the first place.

For this reason the theme of designing an accurate monitoring system has been introduced since the beginning of the monitoring system design phase: one of the parameters identified by audit teams (Deliverable D2.2 – "Energy saving solution set description") to choose the energy saving solution set was the possibility to monitor accurately the energy consumption and the predictor variables both before and after the installation phase. Furthermore engineers responsible for the monitoring system design focused on identifying:

- Physical parameters to be measured
- Meters to be installed and their requirements
- Sampling intervals
- Formulas to assess energy savings.

Different expertise of the project partners is required to perform this activity, such as:

- **Hospital technical personnel**: they contributed with their deep knowledge of the hospital plants architecture. A good knowledge not only of the plant itself but also of its modifications over time and of its connection to other systems is required to ensure that meters are installed correctly in order to collect all the information required to evaluate the system energy performance.
- **Academic partners**: they contributed sharing their competence on metrics and metering systems. The work done in the framework of WP2 and presented in Chapter 4 of Deliverable D2.1 – "Standard energy audit procedure" was the base to choose the physical parameters to be monitored and to define the characteristics of the meters to be integrated in the monitoring architecture.
- **Technical partners**: their expertise in the management of monitoring system was useful to integrate and manage meters correctly.

3.3. Checklist

Assessing data reliability can entail reviewing existing information about the data, including conducting interviews with the stakeholders, performing tests on the data, including advanced electronic analysis, tracing to and from source documents and reviewing selected system controls.

A review of existing information helps to determine what is already known about the data and the computer processing. The related information collected can indicate both the accuracy and completeness of the entry and processing of the data, as well as how data integrity is maintained. This information can be in the form of reports, studies, or interviews with individuals who are knowledgeable about the data and the system.

Data testing can be done by applying logical tests to electronic data files or paper copies of reports. For raw electronic data, computer programs can be used to test all entries of key data elements in an entire data file.

The same types of tests to the data can be applied also on electronic data file, paper copy report or summary.

The tests will vary for each assessment and can include the following actions:

- check the total number of records provided;
- look for missing data, either entire missing records or missing values in key data elements;
- look for duplicate records;
- look for values outside a designated range;
- look for dates outside valid time periods or following an illogical progression;
- test relationships between data elements (sometime by merely doing a cross tabulation);
- verify that computer processing is accurate and complete, such as testing a formula used in generating specific data elements, or testing to ensure that edit checks are working correctly.

This checklist has to be transformed in a list of specifications in order to enable the implementation of these controls in the platform which becomes the main actor in the data validation process. Chapter 3 describes these requirements and how these functions will be implemented in the Web-EMCS.

4. Data validation requirements and tools

Data quality can be assessed more easily if record-level (i.e. raw) data are analyzed. Data validation is particularly important for those data which represent key project outputs.

Furthermore, it is important that raw data remain available: this would increase the traceability during the validation procedure making it reversible.

The same concept can be applied to calculate or summarize data: if only summary-level data were available the repeatability of the validation procedure would not be granted Below the main requirements to be respected by the data validation tool are described with respect to both monitored data validation and energy saving validation.

4.1. Monitored data validation requirements

The term monitored data refers to the raw log data collected in the database. To ease the process to check the reliability of a data set each stored measure needs to have a validation state associated. The validation state is determined running specific validation algorithms. These algorithms should be both scheduled during specific parts of the day or manually triggered by users. Scheduled algorithms can be used to validate data associated to a physical parameter whose behavior is easy to predict. On the contrary validation algorithms can be run manually when specific data acquisition problems are encountered such in case of unexpected missing data.

Validation algorithms and associated parameters should vary according to the physical measured variable and according to the selected channel in order to make the validation process more accurate.

In each case the possibility to re-import raw data and their state should be granted in order to ensure the access to the original data and change the validation process according to new needs.

Furthermore the user should be allowed to manually change the validation state of a measure. The available algorithms should be able to identify and delete out of scale data, zeros and undesired spikes.

4.2. Energy savings validation requirements

Since the energy saving solution sets are very different one from another and it is necessary to calculate energy savings starting from different measured values the Web-EMCS should support the configuration of customized formulas. The validity of the results of these formulas should depend on the validity of the data used by the formulas: the calculated data should inherit the worst validation state from the factors.

Furthermore data collected during the test period has to be compared to data collected during the baseline in order to assess the energy savings obtained through the implemented solution set. For this reason it should be possible to load baseline channels and to compare through customized formulas different datasets.

Finally another option useful to state the reaction of a system to the change of the control algorithms parameters is the possibility to compare data acquired in different periods.

4.2.1. Compliance with ICT PSP methodology

The document "Methodology for energy-efficiency measurements applicable to ICT in buildings (eeMeasure) – D1.2 Non-residential methodology" is intended to promote good practice and consistency in the reporting of ICT-PSP project results. The use of a common methodology should also assist all the projects to more clearly identify significant future energy saving opportunities including the development of local and national policy.

The high level process flow shown below is created to be used by each ICT-PSP projects. The first five steps are those normally taken by a project to report results. The final step helps policy makers and project managers to determine potential Energy Savings in other properties.

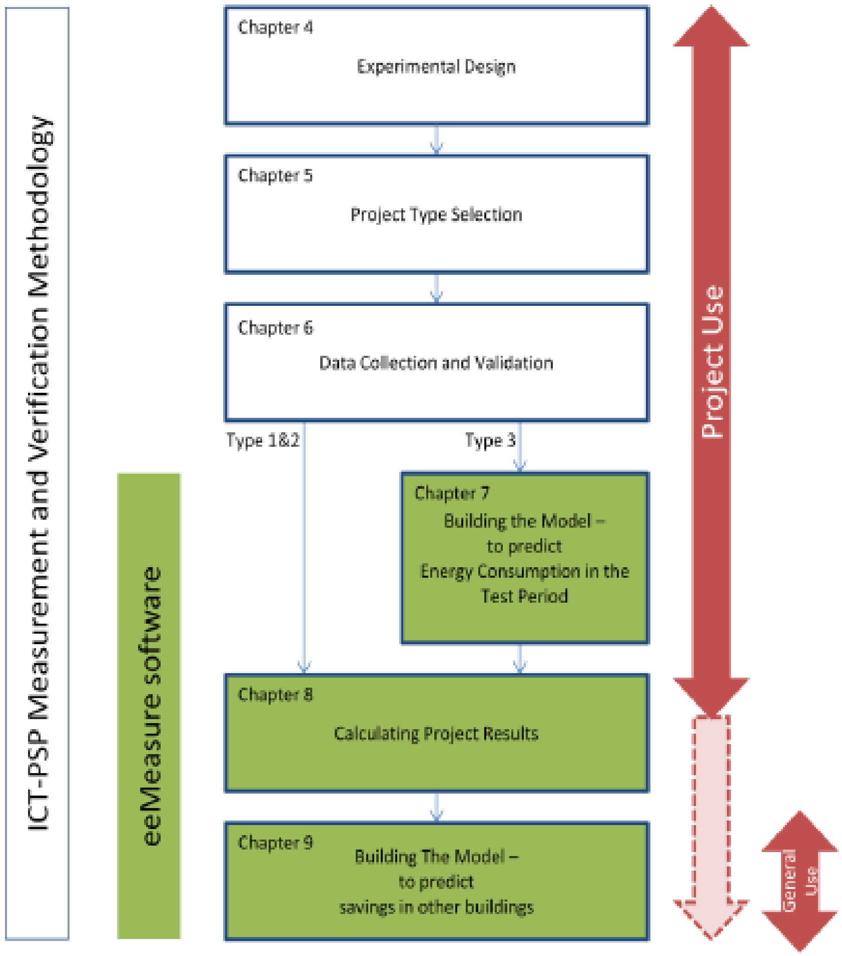

Figure 2: ICT-PSP measurement and verification methodology flowchart - (eeMeasure) – D1.2 Non-residential methodology

Concerning step 2, all Green@Hospital solutions fall under Type 3 which is defined as follows:

Type3: Energy Consumption is significantly impacted by Predictor Variables (e.g. external temperature, daylight hours, occupancy variations, equipment failure) that cannot be fully compensated for by a Control Group.

In this case the Methodology requires that for each solution Periodic Baseline period consumption and predictor variables are collected to build a predictor model.

In other words, in order to assess energy savings the Non residential methodology requires to create a model to predict what the Energy Consumption would be during the Test Period if there had been no Intervention. The Model is based on regression analysis.

Below, for each of the solution sets, a list of parameters needed to assess energy savings together with the predictor variables related to each solution is presented.

AOR

Table 2: AOR Smart lighting system: energy measurements and predictor variables

	Description	**Channels and formulas**
Energy measurements	Lighting energy	(Dimmer*Lamps power)*Time
Predictor variables	Solar radiation Occupancy	Solar radiation Occupancy
KPI	Light level	Luminance
Note: the same variables are collected for all the involved rooms Lamps power and time are not variables, but fixed parameters.		

Table 3: AOR Data centre cooling optimization: energy measurements and predictor variables

	Description	**Channels and formulas**
Energy measurements	Cooling energy	(Total power AVG-IT power AVG)*Time
Predictor variables	IT load Outdoor temperature Cold corridor temperature	IT power AVG Outdoor average temperature Cold corridor temperature AVG
KPI	PUE	PUE AVG

HVN

Table 4: HVN Emergency zone Air Handling Unit Control: energy measurements and predictor variables

	Description	Channels and formulas
Energy measurements	Cooling energy Heating energy Electrical energy	Thermal cooling energy (Final-initial) Thermal heat energy (Final-initial) Electrical Active Energy (Fans)
Predictor variables	Outdoor temperature Return temperature	Outside air temperature Return air temperature
KPI	Supply air temperature	Supply air temperature (to calculate its deviation compared to the setpoint)
Note: Fan electricity is constant regardless of the control		

Table 5: HVN Surgery theaters Air Unit Control: energy measurements and predictor variables

	Description	Channels and formulas
Energy measurements	Cooling energy Heating energy Electrical energy	C1:Thermal cooling energy (Final-initial) + C2:Thermal cooling energy (Final-initial) C1:Thermal heat energy (Final-initial) + C3:Thermal heat energy (Final-initial) Electrical Active Energy (Fans)
Predictor variables	Outdoor temperature	Outside air temperature (variable not available in this AHU. Use reading from the previous solution)
KPI	Room air temperatures	Room X temperature (X=1,2,3,4)

Table 6 HVN Data centre cold water production management: energy measurements and predictor variables

	Description	**Channels and formulas**
Energy measurements	Cooling Energy (Electricity)	In_active_energy_Chiller1 (final-initial) + In_active_energy_Chiller2 (final-initial) + In_active_energy_Chiller3 (final-initial) + DC_In_active_energy_AHUs (final-initial)
	IT Energy	IT Load * time
Predictor variables	Outdoor temperature	DC_Outside_temperature_AHU3
	Outdoor humidity	DC_Outside_humidity_AHU3
	IT Load	Sum (UPS1_upsOutputPercentLoad1 + UPS1_upsOutputPercentLoad2 + UPS1_upsOutputPercentLoad3 + UPS2_upsOutputPercentLoad1 + UPS2_upsOutputPercentLoad2 + UPS2_upsOutputPercentLoad3) * 0,773 * 1000 / 3
PUE	PUE	Cooling Energy / IT Energy + 1,14

SGH

Table 7 SGH Fan coils management: energy measurements and predictor variables

	Description	**Channels and formulas**
Energy measurements	Cooling/ heating energy	NVE_Heatmeter1nvoE3_Cool, NVE_Heatmeter1nvoE1_HeatV1,
Predictor variables	Outdoor temperature Outdoor humidity Solar radiation	AIR_TEMP AIR_HUM Solar radiation
KPI	Indoor temperature	202_AD2, 201_AD2, 203_AD2
Note: the same variables are collected for all the involved rooms		

Table 8 SGH Artificial lighting: energy measurements and predictor variables

	Description	**Channels and formulas**
Energy measurements	Energy (electricity)	(NVE_PowerMeter1nvoPowerL1 + NVE_PowerMeter2nvoPowerL1)*Time
Predictor variables	Solar radiation Occupancy	Solar radiation
KPI	Light level	202_AD4, 201_AD4, 203_AD4
Note: the same variables are collected for all the involved rooms		

HML

Table 9 HML Heating and cooling generation system optimized management: energy measurements and predictor variables.

	Description	Channels and formulas
Energy measurements	Cooling / heating supplied energy Electricity / Gas Consumption	Analizador_electrico_N2_Sala_Geotermia__BCA.Energia_activa_total Analizador_electrico_N3_Sala_Geotermia__BCB.Energia_activa_total Analizador_electrico_N4_Enfriadora_1.Energia_activa_total Analizador_electrico_N5_Enfriadora_2.Energia_activa_total Analizador_electrico_N6_Enfriadora_3.Energia_activa_total Caldera_1_Consumo_total Caldera_2_Consumo_total Boiler_1_heat_energy_meter.BOI1_HE Boiler_2_heat_energy_meter.BOI1_HE Geothermal_system_heat_energy_meter.BOI1_HE Geothermal_system_cold_energy_meter.BOI1_HE Geothermal_system_ground_energy_meter_Calor_BOI1_HE Geothermal_system_ground_energy_meter_Frio_BOI1_HE Chiller_3_cold_energy_meter.BOI1_HE Chiller_1_cold_energy_meter.BOI1_HE Chiller_2_cold_energy_meter.BOI1_HE
Predictor variables	Outdoor temperature Outdoor humidity	Temperatura_exterior Humedad_relativa_exterior
KPI	Chillers efficiency Boilers efficiency Heat pumps efficiency	Formulas

Table 10 HML Optimized control strategies for Surgery Rooms ventilation: energy measurements and predictor variables

	Description	Channels and formulas
Energy measurements	Electricity Consumption Cooling/ heating energy	Analizador.Energia_activa Air_unit_surgery_room_heat_1_energy_meter.BOI1_HE Air_unit_surgery_room_cold_energy_meter.BOI1_HE Air_unit_surgery_room_heat_2_energy_meter.BOI1_HE
Predictor variables	Air flow Indoor temperature Indoor relative humidity Indoor pressure	Cl62_S1_D9.mando_variador_impulsion Cl62_S1_D9.mando_variador_retorno Quirofano_5.Tempeatura_ambiente Quirofano_5.Humedad_ambiente Quirofano_5.Sobrepresion_sala
KPI	Chillers efficiency Boilers efficiency Heat pumps efficiency	Formulas

4.3. Web-EMCS functions

A back-office section will be specifically developed for platform administrators and energy managers. Since it will be an area targeted to technical users its layout will be customized following the specific requirements.

The back-office will include different areas enabling different services for system administrators and energy managers. These areas will be accessible from a drop down menu and each area will enable specific services. Below areas and related services are presented:

Dashboard

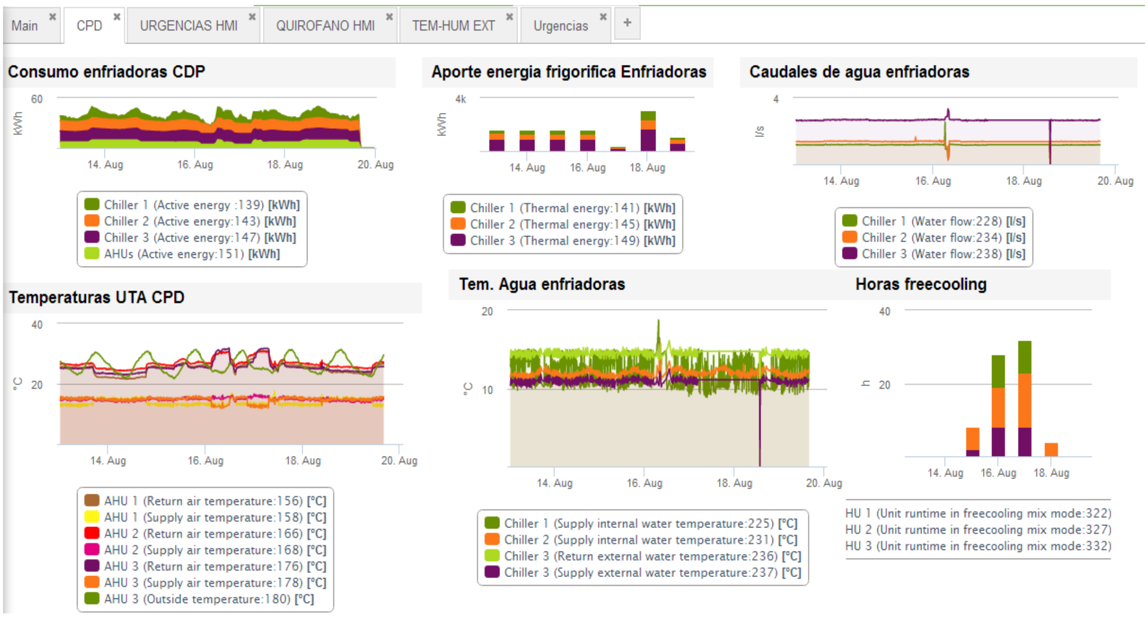

Figure 3: Dashboardtool: example for HVN

Each administrator or energy manager entering the back-office with his own credentials will be able to create his own dashboard and to populate it with graphs presenting the data he wishes to see each time he enters the back-office. Graphs are loaded as widgets which can be configured in terms of:

- Displayed data
- Time window
- Size
- Position

Configuration

The access to this area will be restricted to system administrators: they will be the only personnel allowed to access the functionalities of this area which will be used to create and configure channels. Channels can read physical variables or calculated logical variables according to customized formulas. A configuration mask allows to:

- Chose a channel name
- Chose the channel category
- Set the unit to be used to store data
- Set measure type (instant or period)
- Set the channel configuration
- Sampling time
- Channel active period
- Channel type (formula or rawdata)
- Channel rule (physical measure reference or formula)

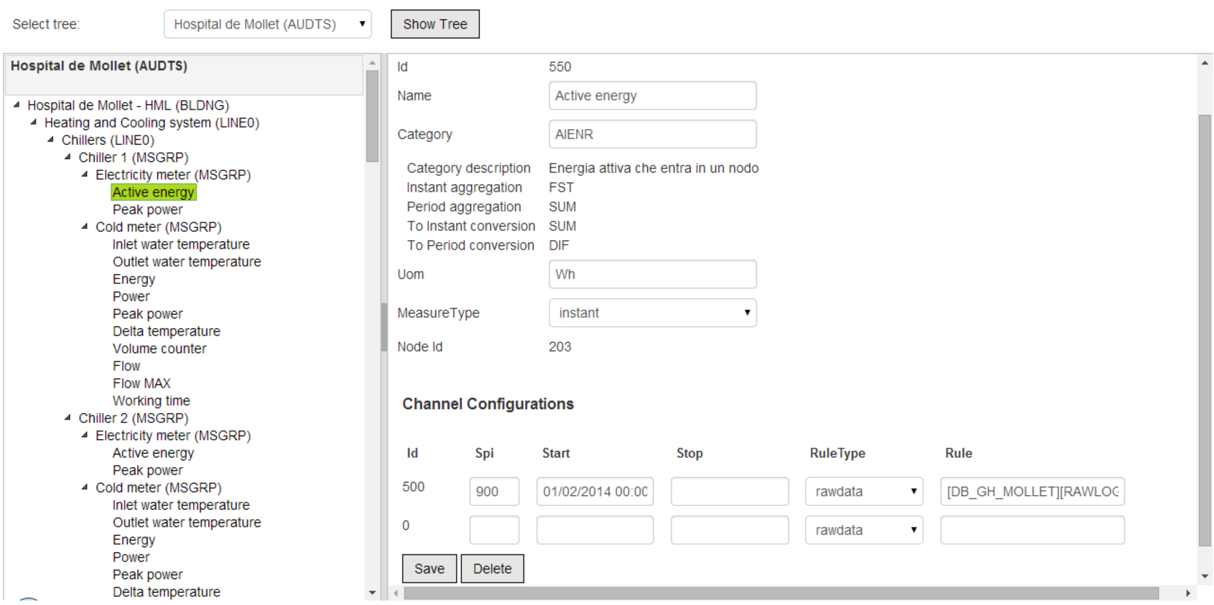

Figure 4: Channel configuration tool: example for HML

Workbench

This area will enable working on measured data selecting specific trees and specific channels among the list of available trees and channels. Once one or more channels have been selected, the user will be able to display them both in graphical and table form. The user will be able to visualize for each timestamp the value, quality (real or reconstructed) and status (valid or not valid). The user will be able to manually change the measure status forcing it to be valid or invalid or he will be empowered to use specific validation algorithm to validate data automatically.

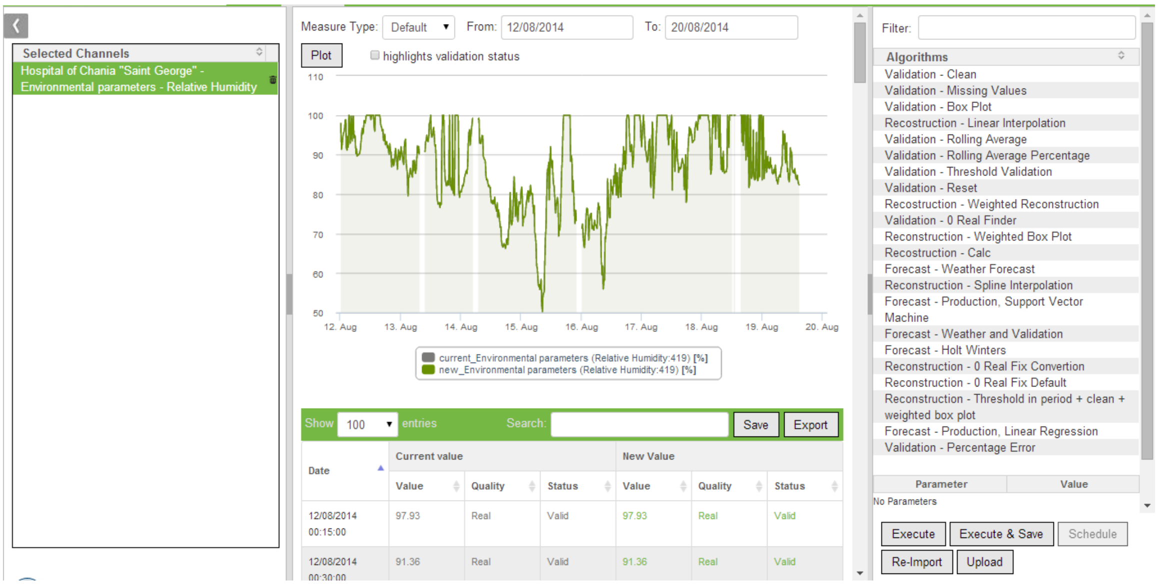

Figure 5: Workbench tool: example for SGH

Different algorithms will be developed and will be available, such as:

- Threshold validation
- Rolling average
- Box plot

Once the algorithms have been tested on a specific channel they can be scheduled to be run on a specific scheduled calendar. A specific session will allow the user to search and filter the scheduled algorithms. For each schedule the user will be able to verify, and eventually modify, schedule target channels, algorithm parameters, the last execution time and the result of the algorithm execution process.

5. Methodology to make data reliability durable

Data reliability is essential for the validation of the work: if only one value is not reliable also the algorithms results are not reliable.

It is important to schedule a set of periodic tests for ensuring that data remains reliable during the monitoring period and also for years after the commissioning of the solution.

The following tables report, for each solution set, the list of the variables involved in the process of energy saving calculation and validation.

For each variable the following characteristics are shown:

- Type of sensor: type of meter, brand and model, kind of power supply
- Type of connection: wired or unwired, dedicated network
- Control algorithms: suggested automatic control algorithms for data validation (e.g. threshold validation, rolling average, box plot, ….)

It should be noticed that for all the parameters the threshold validation automatic control algorithm has been suggested as default. Furthermore for almost all the meters a backup measure is not available: for this reason the reliability of the monitoring system is a key factor to be accounted.

Table 11: AOR Data Centre cooling optimization: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
IT load meter for normal supply	APC, Rack PDU metered AP8853	Wired SNMP	Threshold
IT load meter for UPS supply	APC, Rack PDU metered AP8854	Wired SNMP	Threshold
Cooling loads	Beckhoff KL3403	Wired Proprietary	Threshold
Outdoor average temperature	PT100	Wired Analogical	Threshold
Cold aisle air temperature	PT100	Wired Analogical	Threshold

Table 12: AOR Smart lighting system: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Dimmer average value	Analogical output from the lamp	DALI-wired	Threshold
Luminance	Schneider Electric DALI Multi- Sensor MTN880641	DALI-wired	Threshold
Occupancy	MTN880641	DALI-wired	Threshold
Power meter	Indirect measure from Dimmer average value	/	Threshold
Solar radiation	Imported from another plant located in the same area	/	Threshold

Table 13: HVN Emergency zone Air Handling Unit Control: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
AHU3 Outside air temperature	STD100 TAC	Thermistor	Threshold
AHU3 Supply air temperature	STD100-200 TAC	Thermistor	Threshold
AHU3 Return air temperature	STD100-200 TAC	Thermistor	Threshold
Thermal cooling energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold
Thermal heat energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold
Electrical energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold

Table 14: HVN Surgery theaters Air Unit Control: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Indoor air temperature zone 1	STR350 TAC	LonWorks	Threshold
Indoor air temperature zone 2	STR350 TAC	LonWorks	Threshold
Indoor air temperature zone 3	STR350 TAC	LonWorks	Threshold
Indoor air temperature zone 4	STR350 TAC	LonWorks	Threshold
Supply air temperature Zone 1	STD100-200 TAC	Thermistor	Threshold
Supply air temperature Zone 2	STD100-200 TAC	Thermistor	Threshold
Supply air temperature Zone 3	STD100-200 TAC	Thermistor	Threshold
Supply air temperature Zone 4	STD100-200 TAC	Thermistor	Threshold
Outside air temperature	STD100-200 TAC	Thermistor	Threshold
C1 Thermal cooling energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold
C2 Thermal cooling energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold
C1 Thermal heat energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold

C3 Thermal heat energy	MULTICALL 602 KAMSTRUP	LonWorks	Threshold
Electrical energy	EDMK-MC-ITF-RS485-C2 CIRCUTOR	Modbus	Threshold

Table 15: HVN Data centre cold water production management: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Data Center AHU3 Outside humidity	SHR100 + STR350 TAC	LonWorks	Threshold
Chiller 1 Active energy	EDMK-MC-ITF-RS485-C2 CIRCUTOR	Modbus	Threshold
Chiller 1 Supply external water temperature	PT500 + MULTICALL 602 KAMSTRUP	PT 500	Threshold
Chiller 1 Water flow	ULTRAFLOW 65 + MULTICALL 602 KAMSTRUP	LonWorks	Threshold
AHU 1 Opening grade valve 1	3WAY VALVE + ASD320CW STULZ	Modbus	Threshold
Chiller 2 Active energy	EDMK-MC-ITF-RS485-C2 CIRCUTOR	Modbus	Threshold
Chiller 2 Supply external water temperature	PT500 + MULTICALL 602 KAMSTRUP	PT 500	Threshold
Chiller 2 Water flow	ULTRAFLOW 65 + MULTICALL 602 KAMSTRUP	LonWorks	Threshold
AHU 2 Opening grade valve 1	3WAY VALVE + ASD320CW STULZ	Modbus	Threshold
Chiller 3 Active energy	EDMK-MC-ITF-RS485-C2 CIRCUTOR	Modbus	Threshold
Chiller 3 Supply external water temperature	PT500 + MULTICALL 602 KAMSTRUP	PT 500	Threshold
Chiller 3 Water flow	ULTRAFLOW 65 + MULTICALL 602 KAMSTRUP	LonWorks	Threshold
AHU 3 Opening grade valve 1	3WAY VALVE + ASD320CW STULZ	Modbus	Threshold
AHU active energy	EDMK-MC-ITF-RS485-C2 CIRCUTOR	Modbus	Threshold
UPS1_upsOutputPercentLoad1	Measure from UPS	/	Threshold
UPS1_upsOutputPercentLoad2	Measure from UPS	/	Threshold

UPS1_upsOutputPercentLoad3	Measure from UPS	/	Threshold
UPS2_upsOutputPercentLoad1	Measure from UPS	/	Threshold
UPS2_upsOutputPercentLoad2	Measure from UPS	/	Threshold
UPS2_upsOutputPercentLoad3	Measure from UPS	/	Threshold

Table 16: SGH Fan coils management: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Indoor temperature 202_AD4	Pt100	JC protocol N1 & N2	Threshold
Indoor temperature 201_AD4	Pt100	JC protocol N1 & N2	Threshold
Indoor temperature 203_AD4	Pt100	JC protocol N1 & N2	Threshold
CO2 concentration	Non-Dispersive Infrared Technology (NDIR)	JC protocol N1 & N2	Threshold
Presence indication	PIR Occupancy sensor	JC protocol N1 & N2	Threshold
Outdoor temperature	Pt100	JC protocol N1 & N2	Threshold
Energy consumption of coils	Temperature: Pt100 Flow: ULTRAFLOW (static flow sensor based on the ultrasonic measuring principle)	LON network	Threshold
Outdoor Humidity	Collected from the Web	/	Threshold

Table 17: SGH Artificial lighting: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Luminance level 202_AD4	Ambient brightness in rooms	JC protocol N1 & N2	Threshold
Luminance level 201_AD4	Ambient brightness in rooms	JC protocol N1 & N2	Threshold
Luminance level 203_AD4	Ambient brightness in rooms	JC protocol N1 & N2	Threshold
Presence indication	PIR Occupancy sensor	JC protocol N1 & N2	Threshold
Energy consumption of art. Lights -1	One-phase current measurements by shunt One-phase voltage measurements by voltage division	LON network	Threshold
Energy consumption of art. Lights -2	One-phase current measurements by shunt One-phase voltage measurements by voltage division	LON network	Threshold
Outdoor radiation	Solar pyranometer	Manually transferred	Threshold

Table 18: HML Heating and cooling generation system optimized management: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Heat pump hot energy	KAMSTRUP 65-5-FDCN	M-BUS	Threshold
Heat pump cold energy	KAMSTRUP 65-T-FDCN	M-BUS	Threshold
Heat pump - energy delivered to the ground	KAMSTRUP 65-T-FCCN	M-BUS	Threshold
Heat pump electrical meter N2	CIRCUTOR CVM NRG 96 (2)	M-BUS	Threshold
Heat pump electrical meter N3	CIRCUTOR CVM NRG 96 (2)	M-BUS	Threshold
Gas Boiler 1 - gas meter	ITRON MZ 002-099-4115	ANALOGIC	Threshold
Gas Boiler 1 - energy meter	KAMSTRUP 65-5-FACL	M-BUS	Threshold
Gas Boiler 2 - gas meter	ITRON MZ 002-099-4115	ANALOGIC	Threshold
Gas Boiler 2 - energy meter	KAMSTRUP 65-5-FACL	M-BUS	Threshold
Chiller 1 - cold energy	KAMSTRUP 65-T-FBCL	M-BUS	Threshold
Chiller 1 - electrical meter	CIRCUTOR CVM NRG 96	M-BUS	Threshold
Chiller 2 - cold energy	KAMSTRUP 65-T-FBCL	M-BUS	Threshold
Chiller 2 - electrical meter	CIRCUTOR CVM NRG 96	M-BUS	Threshold
Chiller 3 - cold energy	KAMSTRUP 65-T-CMBH	M-BUS	Threshold
Chiller 3 - electrical meter	CIRCUTOR CVM NRG 96	M-BUS	Threshold
External air temperature	NA	Analog	Threshold
External air relative humidity	NA	Analog	Threshold

Table 19: HML Optimized control strategies for Surgery Rooms ventilation: list of variables

Variable name	Type of sensor	Connection	Implemented control algorithms
Energy meter Heat 1	KAMSTRUP 65-68-63	M-BUS	Threshold
Energy meter Heat 2	KAMSTRUP 65-68-63	M-BUS	Threshold
Energy meter Cold	KAMSTRUP 65-68-63	M-BUS	Threshold
Electrical meter	CIRCUTOR EDMK	M-BUS	Threshold
Airborne particle counter	LIGHTHOUSE 5012	ANALOGIC	Threshold
Indoor Temperature	NA	ANALOGIC	Threshold
Indoor Humidity	NA	ANALOGIC	Threshold
Indoor Pressure	NA	ANALOGIC	Threshold
Inlet Air flow	NA	ANALOGIC	Threshold
Return Air flow	NA	ANALOGIC	Threshold

5.1. Maintenance program

A maintenance program has been developed with the purpose of maintaining the reliability of the system over time. These maintenance actions should be scheduled at least monthly and are classified into four sessions:

- System maintenance.
- Sensors maintenance.
- Web-EMCS data manual control.
- Web-EMCS automatic data validation algorithms.

A fifth section is a System Logbook, where all hardware and software changes and improvements should be recorded.

5.1.1. System maintenance

A set of actions are planned to maintain the efficiency of the control systems in the hospitals. These checks involve the monitoring infrastructure ensuring its reliability and a prompt maintenance in case of failure.

Server

This section includes a list of activities useful to check the overall functionality of the system and of the devices. The database consistency is also verified and a copy of the data is saved.

Network

The reliability of the network where instruments are connected is basic: a reliable instrument with an unreliable connection is not useful.

For wired instruments it is important to ensure that, in case of retrofit, the new instruments that will be connected to the same network will have a different address.

For un-wired instruments (i.e. Wi-Fi probes) it is important to ensure that other Wi-Fi instruments and systems are not causing interferences.

Clients and terminals

This section includes a list of activities useful to check the overall functionality of clients and terminals, including the communication with the server and the presence of alarms.

DDC system

In case of malfunctions or failures there is a list of activities to be done to check the functionality. Other actions to be periodically performed are listed in the table below, that presents as an example the planned checks to be performed for AOR pilot hospital. The equivalent tables for the other hospitals are available in Annex I.

Table 20: Example of system maintenance table for AOR hospital

AOR HOSPITAL - system maintenance					
Activity		Date	Result	Name	Signature
Server	System overview for overall functionalities analysis				
	Analysis of the database and possible optimizations				
	General check on the devices, gateways , modems, and network				
	Saving of Data Base and application program				
Network	Analysis of data network				
Client and terminals for the access to the server	System overview for overall functionalities analysis				
	Check communication with the Server				
	Check the overall quality of the graphics				
	Check for possible acoustic signals from terminals				
DDC system	Check power supplies and fuses (in case of malfunctions)				
	Check field electrical connections (in case of failure)				
	Check by sample of control parameters directly from the server				
	Check by sample of the operation and / or simulation forinputs and outputs , directly from the server				
	Performing diagnostic tests (in the case of incorrect feedback)				
	Check communication bus and connecting terminals (in case of failure)				
	Check coherence of the date and time of the calendar				
	Check the response of the regulation systems (in case of malfunctions)				
	Check by sample the proper functioning of the start-up and shutdown sequences of the systems				

5.1.2. Sensors maintenance

For each device gathering data from the field, a set of inspections should be scheduled monthly. For some instruments (e.g. temperature probes, flow meters, etc.) a yearly calibration should be carried out to guarantee reliability over years.

Monthly checks planned for AOR are presented as an example. The equivalent tables for the other hospitals are available in -Annex I.

Table 21: sensors maintenance for AOR

AOR HOSPITAL - sensors maintenance							
SENSORS							
Solution	**Variable name**	**Type of sensor**	**Scheduled manual inspections**	**Date**	**Result**	**Name**	**Signature**
Smart lighting system solution	Dimmer average value	Analogic output from the lamp					
	Luminance	Schneider Electric DALI Multi- Sensor MTN880641					
	Occupancy	MTN880641					
	Power meter						
Data Centre cooling solution	IT load meter for normal supply	APC, Rack PDU metered AP8853					
	IT load meter for UPS supply	APC, Rack PDU metered AP8854					
	Cooling loads	Beckhoff KL3403					
	Outdoor average temperature	Pt100					
	Cold aisle air temperature	Pt100					

5.1.3. Web-EMCS manual control

For each solution set the operator must lead some manual control on the Web-EMCS to ensure the data presence and consistency and also the reliability of the energy saving calculation results.

For each solution a set of periodic controls have to be planned in the Web-EMCS. The flowchart below represents the validation process to be carried on manually.

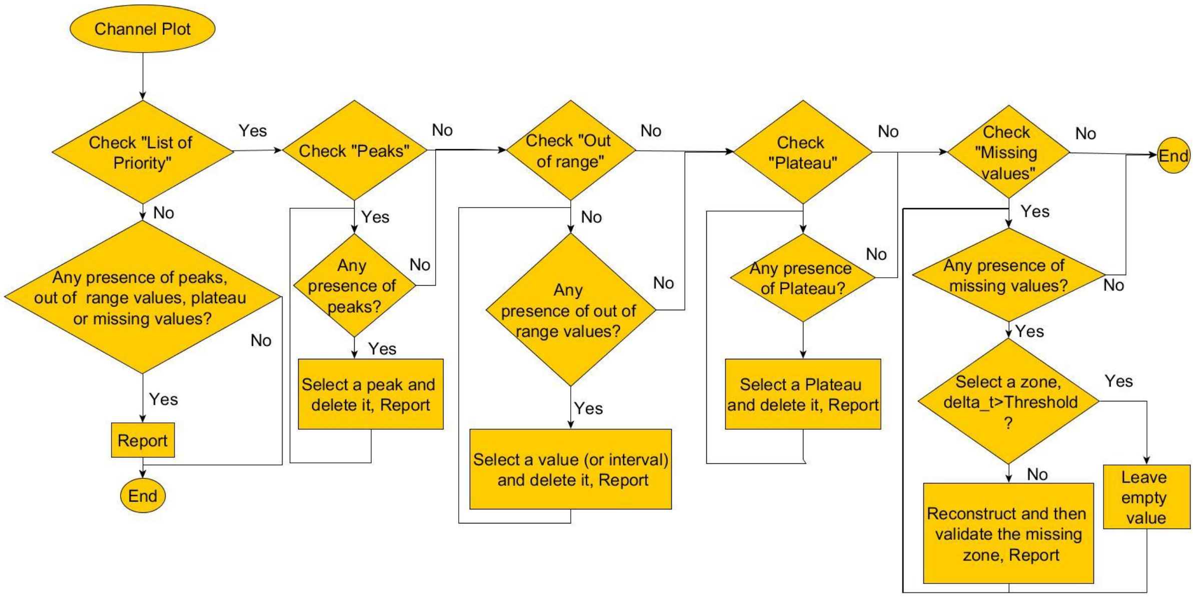

Figure 6: Validation process

Detailed data validation and reconstruction is needed particularly for key parameters affecting energy saving calculations: these parameters have been already identified in paragraph 4.2.1. For the other parameters a brief check is enough to identify incorrect operation but a detailed and precise reconstruction is not strictly needed for the project purposes.

Three categories of invalid values are highlighted in the flowchart (peaks, out of range values and plateau).

- Peaks: they can be found wherever there is an unexpected increment/decrement inside the series;
- Out of range values: they can be found when a value out of the sensor's range is detected or when the value is out of the physical range of the variable;
- Plateaus: they can be identified whenever there is an interval of time in which the signal is unexpectedly constant.

Obviously, some variables are not affected by these kinds of problems: for example, digital signals don't need to be analyzed with reference to peaks or plateaus.

For each of these categories it has been created a different label and one or more of them have been assigned to the various channels depending on whether it is important or not (for any of them) to verify the presence of abnormalities, which are indicated in those labels.

Concerning the last section of the flowchart two questions are raised for each label: the first one asks, using the label check, if it's generally useful to find any anomaly of the label's class (for the considered channel): if the answer is yes, then the presence of any of them is checked, otherwise the algorithm goes to the next label check.

Different validation algorithms address these errors and these errors are typical of different variables.

As highlighted in the flowchart if the algorithm reports an error, this has to be reported leading to a maintenance operation for the replacement or the re-calibration of the probe or to a data reconstruction. In the latter case the data should be labeled as "reconstructed data" in order to highlight the changes.

In the event of data loss or unreliable data, data have to be reconstructed manually or with automatic algorithms, using historical data, other probes value, etc.

Monthly manual checks planned for AOR are presented as an example. The equivalent tables for the other hospitals are available in Annex I.

Table 22: WEB EMCS manual controls for AOR hospital

AOR HOSPITAL - Web-EMCS manual control					
Solution	**Action**	**Date**	**Result**	**Name**	**Signature**
Smart lighting system solution	Check of data presence				
	Check of data consistency				
	Check of historical data available in archive				
	Check of energy saving calculation results				
Data Centre cooling solution	Check of data presence				
	Check of data consistency				
	Check of historical data available in archive				
	Check of energy saving calculation results				

5.1.4. Web-EMCS automatic data validation algorithms

If similar invalid errors occur for the same channel in different period validation algorithm can be automatically triggered, thus saving time and effort from the operators. Also in case of automatic data validation algorithms application, data should be labeled as "reconstructed data" in order to highlight the changes.

In the table below an example of report table for AOR is presented. The equivalent tables for the other hospitals are available in Annex I.

Table 23: Web-EMCS automatic control algorithms for AOR

AOR HOSPITAL - PRIORITY LIST			
Parameter		**Label**	**Threshold**
Wheather Forecast	Solar Radiation	Plateau, Out of range values	Range = 0 - 1000 [W/m^2]
Lighting	Oncology - Visitors waiting room corridor - Occupancy	No automatic control	
	Oncology - Visitors waiting room corridor - Luminance	Out of range values	Range = 0 - 1016 [lx]
	Oncology - Visitors waiting room corridor - Dimmer	Out of range values	Range = 0 - 100 [%]
Thermal Power Plant	Outdoor average temperature	Peaks, out of range values, Plateau	Peak's increase/decrease = 10°/ 1 hour, range = -10 - 45 [°C], Plateau = 30 min
Data Center	PUE AVG	Peaks, out of range values, Plateau	Range = 1,5 - 2 [], Plateau = 30 min, Peak's increase/decrease = 0,1 / 30 min
	Environmental parameters - Cold corridor temperature AVG	Peaks, out of range values, Plateau	Peak's increase/decrease = 5°/ 1 hour, range = 10 - 40 [°C], Plateau = 30 min
	IT Room - Total power AVG	Peaks, out of range values	Range = 30 - 45 [kW], Peak's increase/decrease = 1kW / 10 hours
	IT Room - IT Power AVG	Peaks, out of range values	Peak's increase/decrease = 4kW / 24 hours, Range = 20 - 25 [kw]

5.1.5. System logbook

Any hardware or software changes on the solution set (e.g. probe replacement, parameter improvement) or in the Web-EMCS (e.g. data reconstruction) must be recorded in the following form.

Table 24: System logbook for AOR

AOR HOSPITAL - system logbook		Green@Hospital	
Date	**Operation**	**Name of the operator**	**Signature**

6. Conclusion

The monitoring guidelines described in this document and the maintenance program detailed in Chapter 5 represent not only a key tool to ensure the reliability of data collected during the test phase but also a procedure useful to maintain optimal energy performances after the end of the project.

Each pilot hospital, supported by the technical partners, will be responsible for applying the proposed methodology and for presenting a monthly report according to the proposed template. The reports will be useful to track key events such as:

- Devices failures
- System failures
- Improvement realized
- Data losses

These data, analyzed at the end of the project, will provide an overview about the reliability of the system and will provide all the information needed for a precise understanding of the monitored energy savings.

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