PROJECT FINAL REPORT

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4.1 Final publishable summary report

Executive summary

Buildings Operational stage represents 80% of building's life-cycle cost of which 50% is consequence of the energy use. Moreover, up to 90% of the buildings' life cycle carbon emissions occur during their operational phase, mainly as consequence of the HVAC (Heating, Ventilation and Air Conditioning), lighting and appliances' energy use[2]. Therefore, energy and cost saving strategies addressing this building operation phase will have a major impact in the building life cycle cost.

Figure 1: **Building Life-Cycle**

The buildings' energy demand and consumption is influenced by numerous factors both inherent and external to buildings. Aspects such as the constructive characteristics, climate, building usage or users' behaviour, among others, directly affect the final energy performance. Normally, these factors are strongly considered at the building design and planning stage. Buildings are usually designed to cope with the most unfavourable operating conditions (e.g. crowded room), resulting in an inefficient operation of the system and extra costs (e.g. oversized HVAC systems). Moreover, operational plans are usually based on fixed schedules, sometimes manually modified by operators, which do not use the knowledge of external conditions to take advantage of the design of more efficient plans.

Furthermore, it is important to highlight that a good energy design of the building **does not imply obtaining a good energy performance of the building**. The integration of **adequate control and operational strategies is a must** in order buildings reach to their optimal efficiency levels.

Energy IN TIME goes beyond existing building control techniques, developing an integrated Control & Operation approach, combining state of the art modelling techniques with the development of an innovative simulation-based control technique focused on automating the generation of optimal operational plans tailored to the actual building and users' requirements

Energy IN TIME started on 1st October 2013 coordinated by Acciona Construcción (Spain) and supported by 12 partners from 8 different countries: Aeroportos de Portugal S.A (Portugal), Fundación CIRCE (Spain), Cork Institute of Technology (Irland), Université de Lorraine (France), Centre Scientifique et Technique du Batiment (France), Fundación Universitaria Iberoamericana(Spain), Institutul de Cercetari Electrotehnice (Romania), Integrated Environmental Solutions Limited (United Kingdom), Stam SRL (Italy), Universidad de Granada (Spain), United Technologies Research Centre Ireland Limited (Ireland), Caverion (Finland). During the four years of project life time partners have developed several tools integrating them in the whole Energy IN TIME

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platform. The most important and challenging activities were the integration, deployment and performance evaluation of the tools in the four building demos of the project: Faro Airport in Portugal, Levi Hotel in Finland, Sanomatalo Building, also in Finland and the office building of ICPE in Romania. In particular the deployment and execution of Energy IN TIME platform at the demo-sites allowed learning more about the barriers to and benefits of such innovative technologies.

Figure 2: Energy IN TIME team, final meeting in FARO, September 2017

Summary of project context and objectives

Non-residential buildings have 40% more average specific energy consumption ($280kWh/m^2$) than the equivalent value for residential, moreover the Energy Management System in non-residential buildings renovation is more important due to their high share of electricity use[2]. The methodology for the implementation of Energy IN TIME has been defined not only for existing buildings but, as an added value, for its implementation in new buildings since its initial commissioning

Energy IN TIME project has developed a Smart Energy Simulation Based Control method to reduce the energy consumption and energy bill in the operational stage of existing non-residential buildings. This project develops new techniques based on the prediction of indoor comfort conditions and user behaviour performance to improve the Lifetime and Efficiency of Energy Equipment and Installations through continuous commissioning and predictive maintenance.

Energy IN TIME operating principle

There are different abstraction levels, or layers, in Building Energy Control.

Execution Level in which individual equipment and systems of the building are operated under the management and control of the BEMS to track the set-points stablished in upper levels. Also data acquisition is performed at this level through sensors and meters as here is where processes are directly developed. Thus, faults in actuators, systems and even in sensors are usually exposed at this level.

Supervision & Reconfiguration Level includes monitoring tools, real-time Fault Detection & Diagnosis and Simulation based Control. The real-time control module provides the optimal set-point values to be used in the lower layer by the local BEMS. At this layer of Energy IN TIME Platform, the control module uses both the planning information coming from the upper layer and the real-time data from the building provided by the lower layer. Analysis of the exchanged information can be used to detect faults and anomalous performance allowing Energy IN TIME to look for the causes and, when possible, to reduce the impact (comfort and energy) of the faults by adapting the values of set-points involved in HVAC operation.

Operational Plan Generation Level, at this level the Optimal Operational Plan for the particular building configuration is generated according to the external variables such as weather, user behavior and energy prices. By using forecasted data this Plan is generated in an anticipated way and it will be launched to the building IN TIME and operated by the energy system installed. For the Optimal Operational Plan definition, Energy IN TIME applies state of the art simulation techniques and optimization algorithms that ensure the minimum energy consumption maintaining the comfort conditions specified by the users.

To provide more robustness to the solution, Energy IN TIME is complemented with two additional tools:

Decision Support Tool, at a Decision Making level, gathering all the data related to the building operation and status and using this information Energy IN TIME offers an additional tool very useful for refurbishment, retrofitting works as well as for new buildings design.

Trying to cover the maintenance operations, Energy IN TIME has developed a **Continuous Commissioning** methodology focused on keeping the equipment at its most efficient state being reinforced by a **Predictive Maintenance** module in the Global Energy IN TIME solution.

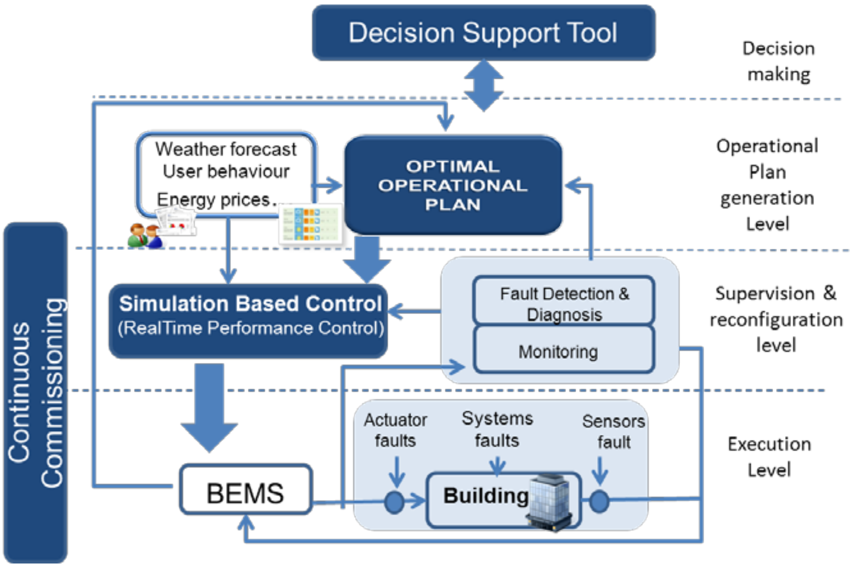

Figure 3: Energy IN TIME Control Levels

Energy IN TIME Solution is managed in a remote way, centralizing all the modules in a Central Remote Control and being automatized. This issue makes the Energy IN TIME allocation independent to the building, allowing for an external management that makes this solution suitable not only in situ for the building energy managers but for any company that provides energy management services for buildings.

Main features of Energy IN TIME solution

The most common way to handle BMS in buildings is by Facility Services Companies' maintenance operators focused on maintaining the hydraulic, mechanical and electric system working correctly and assuring the comfort conditions according to the user's demand but they do not concern for energy efficiency or for reducing the energy consumption.

By contrast, the tendencies towards an energy efficiency growth in buildings go in the direction of offering remote energy efficiency services to the users consisting in energy auditory, monitoring and generating energy consumption reports. But not managing and controlling the BMS in order to achieve an energy efficiency improvement.

Energy IN TIME offers a centralised control building platform able to communicate with Building Management Systems devices giving them the optimal operational plan according to the particular building configuration and taking into account external variables related to weather conditions, users' behaviour, building usage schedule, etc. and achieving a higher energy efficiency level in the building which will be traduced in important energy savings in consumption.

By using building energy model and simulation techniques we are able to define the building energetic behavior in different scenarios. If we add the knowledge of forecasted weather conditions and building usage stage it is possible to calculate the building energy demand in an anticipated way for a particular period of time. Knowing the building energy demand in advance it is possible to anticipate the energetic building configuration necessary for matching this demand.

Energy IN TIME calculates the optimal operational plan in order to match the expected demand, anticipating the building energy production according to this demand.

Additionally, all data gathered from sensors or measures referred to indoor and external parameters are stored and used by additional tools for **Predictive Maintenance**, **Continuous Commissioning** and **Decision support tool**.

Use cases

The project has been validated on a number of existing buildings where the service has been provided. These buildings have been located in different Europe locations with different climates. The concept has been tested in four buildings with different typologies and building use:

Airport in Faro (Portugal): one of the eight airports managed by ANA. It was built in 1989, with the last refurbishment performed in 2001, and has a surface of 41000 m^2 of built area. It is characterized by open spaces with big flows of people at certain times of the day, in correspondence to flight arrivals or departures. Its main energy source is electricity. High level operational plans must be implemented, aimed at maintaining pre-defined environmental conditions.

Figure 4. Faro Airport

Offices and Test Labs in Bucharest (Romania): it is property of ICPE, built in 1982 on an area of 17384 m^2. It has closed and distributed spaces with constant flow of people and scheduled occupancy. There is a strong presence of solar energy (both thermal and photovoltaic), and district heating is the base system for heating, covering 90% of the needs of the building. Fixed-schedule operational plans for indoor conditions are the only control strategy at the moment.

Figure 5. ICPE's offices in Bucharest

Commercial and office in Helsinki (Finland): managed by CAVERION, it was built in 1999 on an area of 38190 m^2. On the first floor there is a public area with commercial and restaurant usage, the rest are offices: there are open spaces and distributed spaces with varied flows of people and scheduled occupancy. The main heating source is district heating (3.000kW). Chilled beam cooling panel is used for the main cooling and double facade helps to reduce over heating in summer. Zonally fixed-schedule operational plans for indoor conditions are implemented.

Figure 6. Commercial and offices in Helsinki

Hotel in Levi (Lapland, Finland): This building is of very recent construction (2010), and has a total built area of 42500 m^2. The structure is subdivided into an hotel (170 rooms), a parking, 2 apartment buildings with seasonal and high variable occupation. The main heating source is district heating (3.630 kWh), with radiant floor installation with a heating power of 660 kW. The four different sections have four main heating distribution centres with different usages.

Figure 7. Hotel in Levi, Finland

Pilot case

Office in Montluel (France): this office building is part of the Carrier Facility in Montluel. This building has a floor area of 1052 m2, is occupied in average by 121 Carrier employees, and includes 77 Fan Coil Units, 1 Air Handler Unit, 1 Heat Pump and 1 Water Flow Pump. The building is equipped with the Carrier Aquasmart integrated solution which, in addition to the hydronic system, includes a System Manager to monitor and control the equipment in the building.

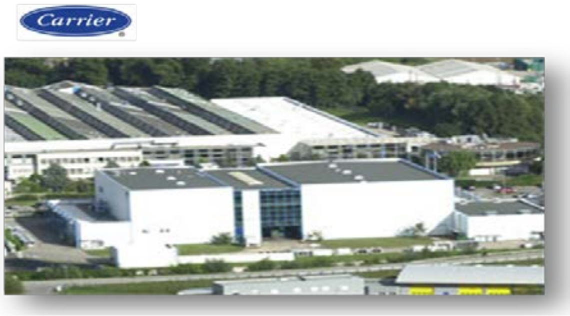

Figure 8: Office building of the Carrier facility at Montluel, France.

To achieve the objectives, the work plan was structured in 9 WPs. WP1 to WP6 devoted to research activities and corresponding technical and scientific management/coordination management, WP7 deals with the demonstration activities, WP8 dedicates to exploitation and dissemination related activities and WP9 devotes to project financial, legal and administrative management.

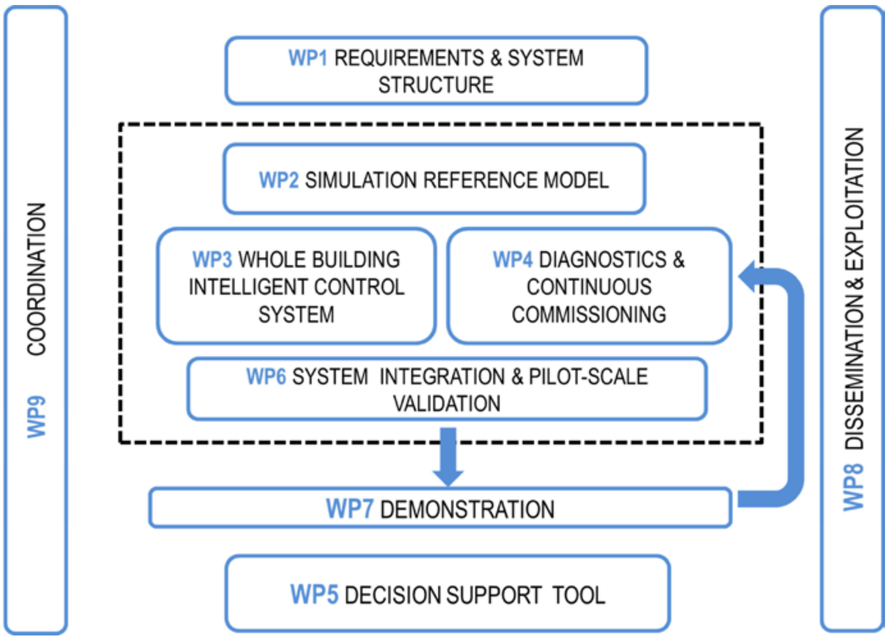

Figure 9: Project management structure, 2013

Description of the main S&T results/foregrounds

Within the 48 months of the project, the Energy IN TIME consortium completed all the activities planned for the project, resulting in the development of the different modules that compound the whole Energy IN TIME system.

The main outcome of the project is the creation of monitoring and control tools for the building energy management systems, which is automatically and remotely operated. It allows reducing the energy consumption of the building by optimizing the use of the resources: its strength lies into the fact that the building is monitored continuously and controlled according to the inputs received by the system.

The tool has a complex structure, being it made of many parts which are developed separately but interact with each other for the correct functioning of the Energy IN TIME tool. Each of those parts can be exploited on its own, and can be summarized as it follows:

Data acquisition methodology & Communications Platform. Energy IN TIME project is built upon an existing communication platform: the result is a scalable platform for time-critical processing of large amounts of data in the cloud for critical infrastructures deployed in environments such as Airports.

Dynamic simulation building models for building control use. The outputs are the development of more advanced calibration techniques, creation of automated calibrated models integrating the energy audit procedure and continuous calibration.

Simulation Based Control: buildings application. The innovative contribution is the integration of predictive methods for the periodical planning and actuation of HVAC operations, including adaptive algorithms for real-time control which reconfiguration strategies are triggered by the Fault Detection and Diagnosis module.

Fault Detection and Diagnosis. An automated fault-adaptive control platform was developed in Energy IN TIME. It includes Fault Detection and Diagnosis module to detect faults and anomalies and Simulation Based control algorithms. The interaction of the two modules allows for a reconfigurable control layer which can reconfigure HVAC operations in case of faults and anomalies, reducing the discomfort and the wasted energy consumption.

Maintenance techniques and Continuous Commissioning. The result is the creation of predictive maintenance and continuous commissioning concepts within the building day to day operation. Thanks to the information obtained from the simulations done with the calibrated models of the building and the actual information monitored from the building, it is possible to track the health degradation and to predict failure progression.

Decision support tools for building design and retrofitting. This methodology is integrated as part of a recently developed prototype decision support tool: it aims at sorting out the appropriate energy decision at level of the building envelope and the building equipment.

Centralized Remote Control. Energy IN TIME solution has been designed from a modular approach where the different tools or components (organised in modules) complement each other and collaborate with the purpose of achieving a common objective directed towards the energy efficiency, an improved performance and cost effectiveness. *Centralised Remote Control* aims to provide a unifying perspective for the global Energy IN TIME solution to facilitate the final user interaction and management of its features.

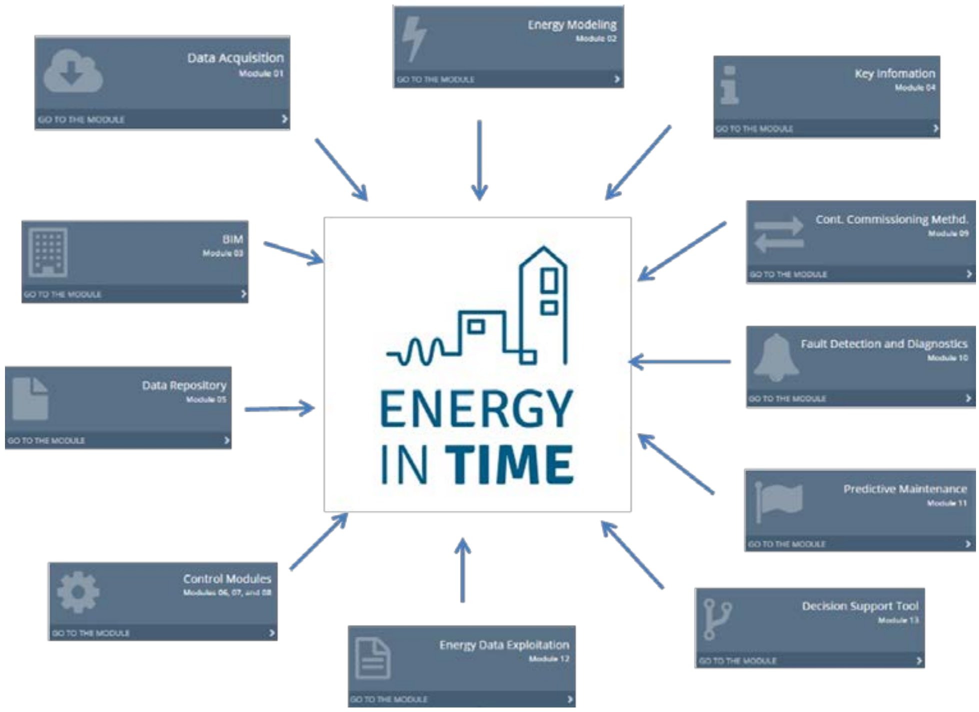

Figure 10: Energy IN TIME System

Some of the results in each of the modules developed within the Energy IN TIME project have been:

<u>Data acquisition methodology & Communications Platform</u>

Most modern buildings are equipped with an abundance of sensors facilitating a variety of different tasks. Although some standards exist the market for building automation and management systems is quite vertical with different vendors providing end-to-end solutions that only allow for a limited amount of interoperability. While each such system is deployed with a specific task in mind one of the goals of Energy IN TIME has been to utilise as much information as possible from the building therefore an abstract and unified access to all this information is desirable.

Within Energy IN TIME it has been taken a layered view on the data acquisition methodology starting on the lowest level in the building infrastructure layer that describes the physical deployment of sensors in the building and the communication protocols that are used to transmit the sensor readings to the building management layer. As these systems are proprietary, usually closed and special purpose built Energy IN TIME partners have described how to interface them on the building management layer using well established industry standards and implemented a dedicated Energy IN TIME middleware layer on top of this, thereby abstracting from the various different building management systems in a typical scenario. This abstraction enables a unified sensor data stream to be generated across the whole platform and allows subsequent Energy IN TIME modules to make use of the data regardless of the actual underlying physical infrastructure and specific building management system vendors.

In each of the demo building where Energy IN TIME system has been validated the communication platform, particular connection structure has been implemented. They are described in the following figures has been implemented in a different way. In the following figures they are described.

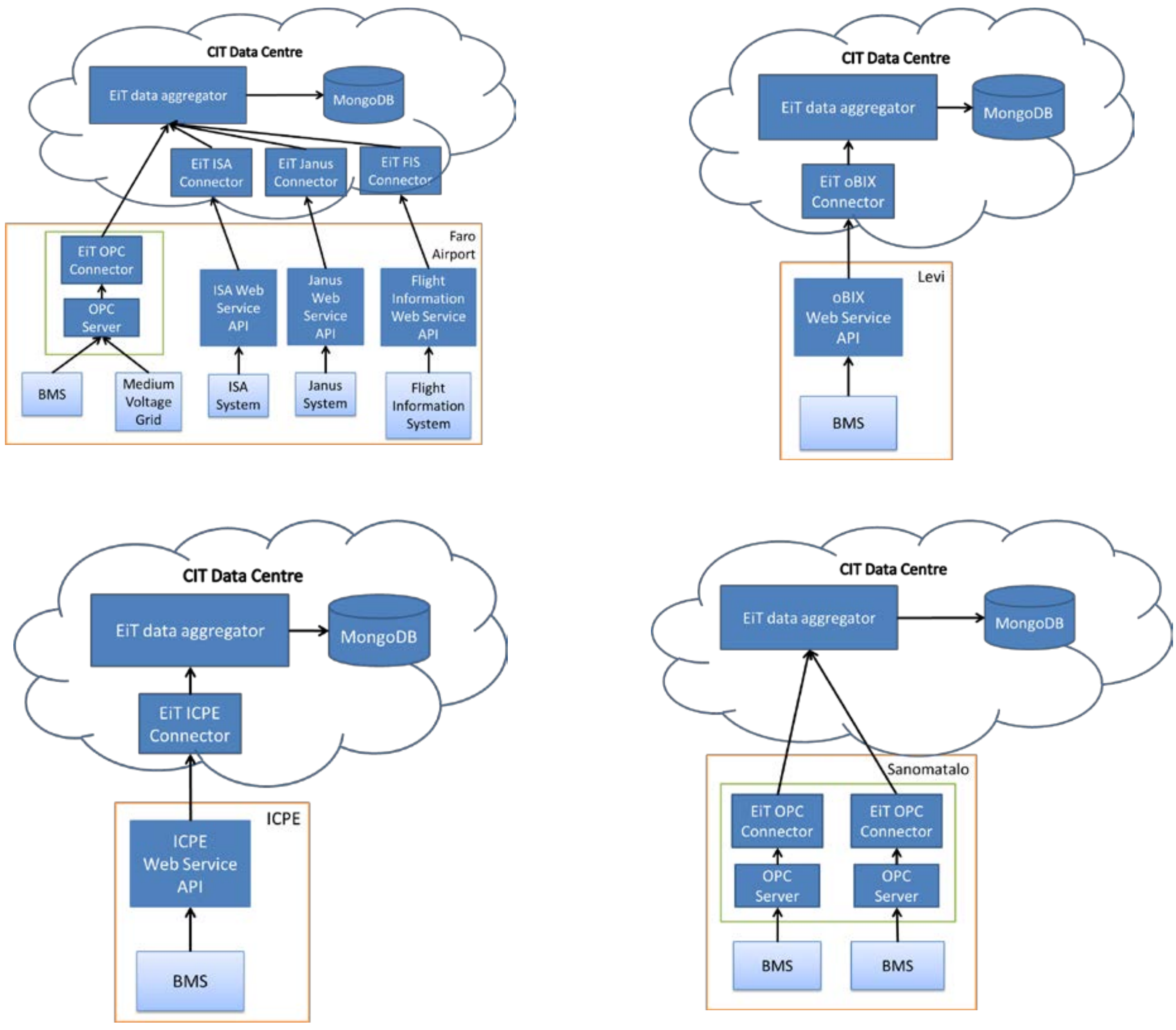

Figure 11: Energy IN TIME Communication Platform in Energy IN TIME demos

<u>Dynamic simulation building models for control use</u>

In achieving the key building information for building simulation, implementing an appropriate environment and structure for the optimising of the collection of data required for building simulation and energy auditing, it was determined that the development of a Tablet based application was the most efficient method to achieve this, both from a data collection and mobility point of view. After assessing the viability and advantages of this approach, a novel purpose build Tablet application, named the Virtual Auditing App (VAA) was developed in the project. The VAA ties together a number of ideas to create an enhanced auditing application in which the user can carry out a full Energy Audit of all relevant building components and systems in a user–friendly and structured manner. The VAA initially drives the users to answer a series of questions about the building, which relate to the input parameters. The user is then presented with a fully prioritised list of parameters derived from the simulation results.

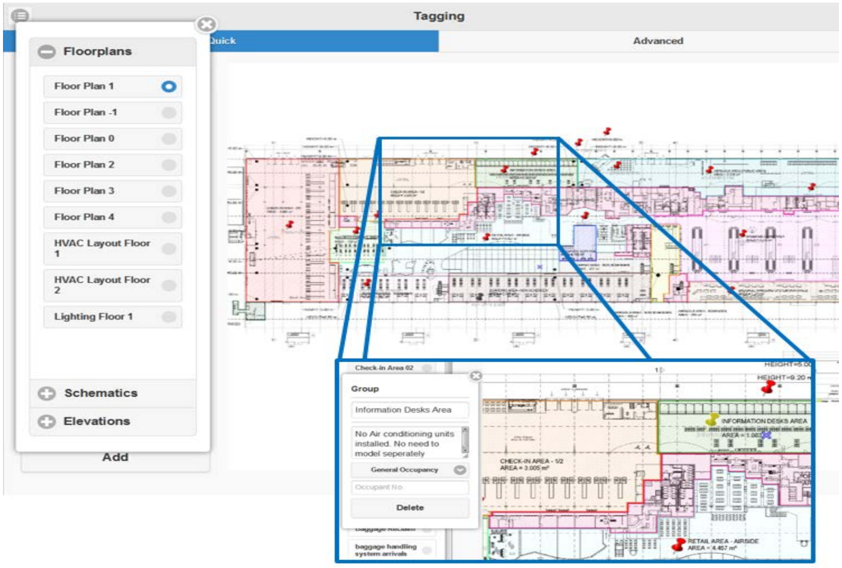

Figure 12: VAA Tagging Functionality Example

In the Energy IN TIME project has been created a Simulation Reference Model in the IES <Virtual Environment> software for each of the four test sites located across Portugal, Romania and Finland. The IES <VE> software is a suite of building performance-modelling tools incorporated into a single integrated data model. These modelling tools (or modules) can be used to model and simulate multiple aspects of building design and operation at different building life-cycle stages, as illustrated in the figure bellow.

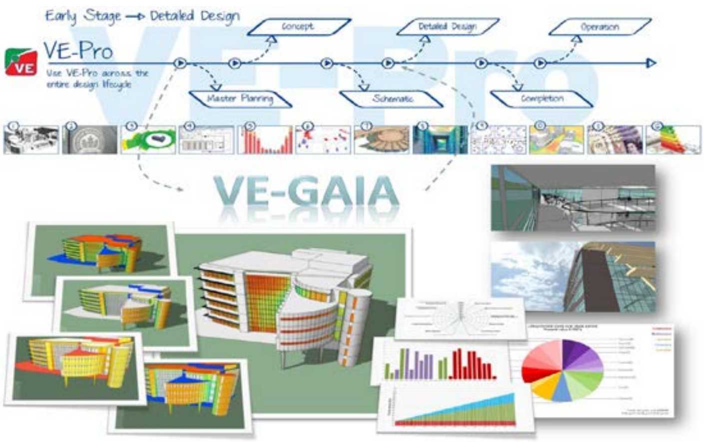

Figure 13 Overview of the IES Software

The simulation reference models developed in Energy IN TIME are complex, dynamic models which incorporate all of the passive elements of the building structures, all plant/HVAC equipment and design, as well as internal and external factors such as lighting, occupancy, weather variables, energy tariffs etc. to create a real-time representative simulation model of each test site.

The IES <VE> system provides high quality simulation based information required to design, build and operate better performing sustainable buildings that maintain comfort levels and can incorporate low-carbon and renewable technologies. It is comprised of a series of individual modules including climate, geometric modelling, solar shading, energy and carbon, lighting, airflow, value/cost and egress modules that are linked by a single Integrated Data Model (IDM) through a Common User Interface (CUI) which allows data to be easily exchanged between the different applications; the integration of all of these modules means all aspects of a building's construction, location, geometry, climate, usage, systems and thermal performance can be modelled, and in turn, simulated. The IES <VE> Main Modules are shown in following figure:

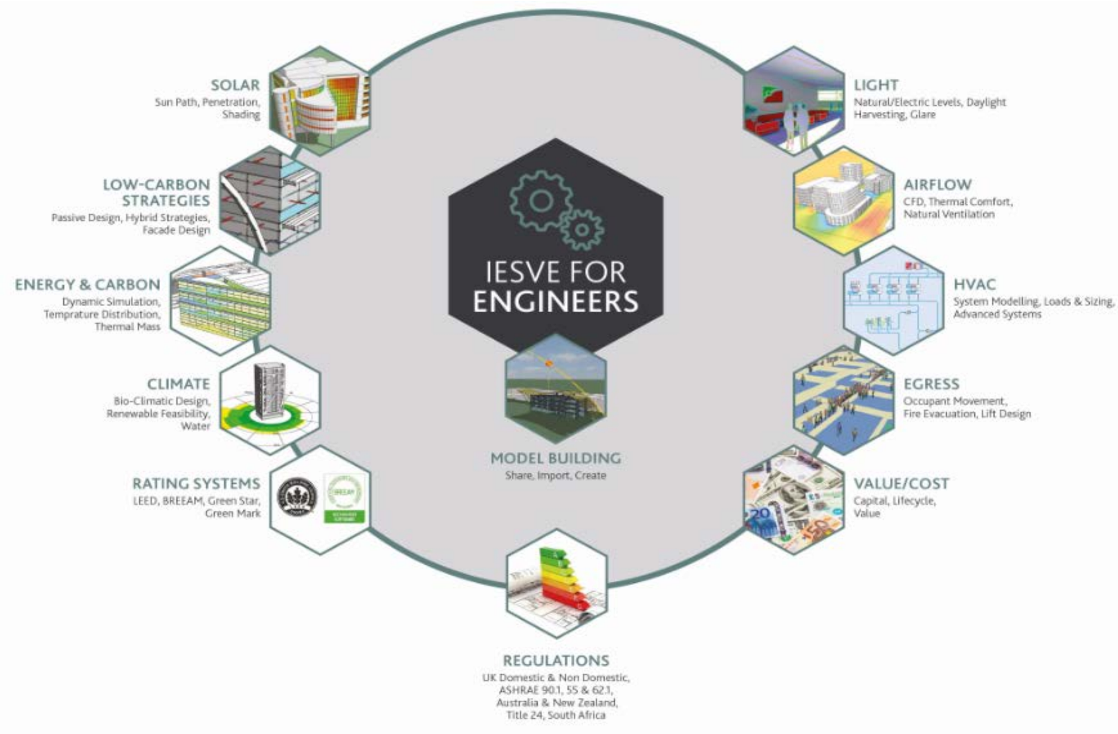

Figure 14 IES <VE> Main Modules Overview

There are several modules that have been used in the Energy IN TIME project for creating the Simulation Reference Models of the demo buildings.

The passive model is the first step required in building simulation in the IES <VE> software and incorporates all "passive" elements such as building geometry, construction materials, u-values, framework, façade, claddings, location, orientation etc.

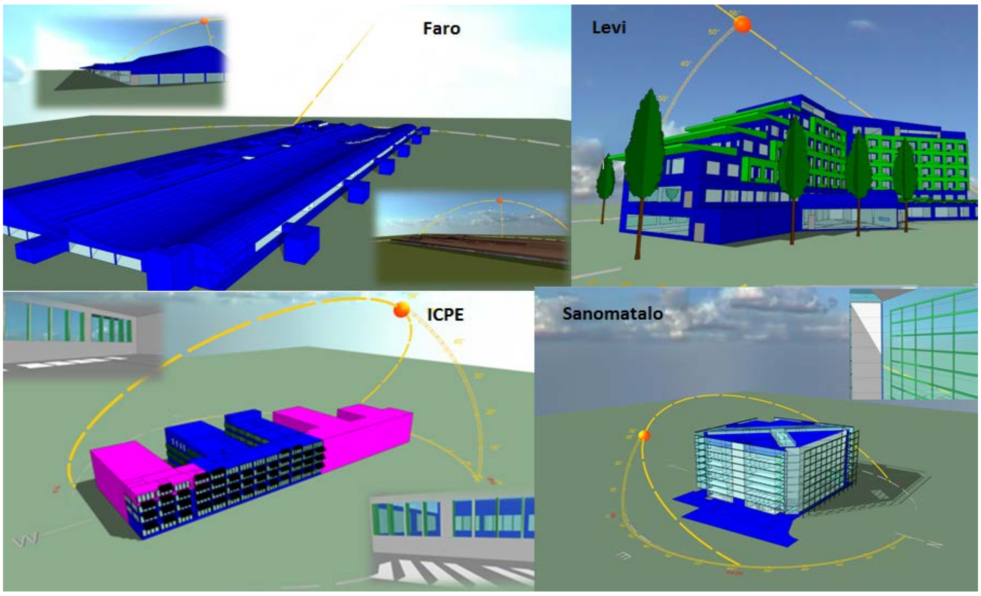

Figure 15: Passive Model's

The modules used for the development of the passive energy models were:

- **ModelIT** to create the 3D geometry models required by the other components of the <VE>.
- **SunCast** to perform shading and solar insolation studies. Suncast can generate images and animations quickly and easily from a model created by the IES ModelIT.

Together with the passive models the active models were developed for the Energy IN TIME demo building. The active model takes into account all “active” elements of the building in the development of the simulation reference model. The active systems relate to anything producing or consuming electricity with the buildings and require significant modelling, especially in relation to the HVAC system installed on each of the sites.

The modules utilised in the active model development (*ApacheSim*, *ApacheHVAC*, *MacroFlo* and *Vista*) comprise the dynamic thermal applications of the <Virtual Environment>. In common with other Virtual Environment applications, the dynamic thermal applications derive their geometrical data from *ModelIT*. When the active models are completed the first simulation of the models are run in the *ApacheSim* module which dynamically simulates the interaction between all of the active and passive elements, with external influences (e.g. weather) over a selected period of time. The results of the simulation can be viewed in the *VistaPro* module for analysis of heating and cooling loads, energy consumption, internal temperatures, thermal comfort etc. Active models are based on static design information or assumptions derived from data provided by project partners at a point in time. They can only be updated manually by a user via the user interface of the IES <VE> desktop software. Active models typically have many assumptions and do not reflect the building as it changes through its life-cycle.

Simulation reference models are cloud based models which allow automated continuous updating of dynamic model parameters like BMS control settings, user occupancy data or actual weather data. As model-updating is an automated process, no dedicated graphical user interface is required. Interaction with the simulation reference models for the four Energy IN TIME demo sites will be enabled through IES SCAN, a web-based data acquisition and analysis tool. For this, a dedicated 3rd party API scripting API has been specified and is currently being implemented by IES. Other Energy IN TIME modules can connect to the simulation reference models via this API using python scripts (see schematic below).

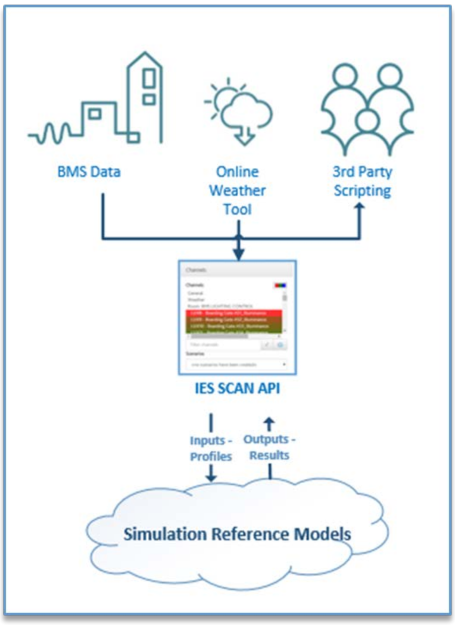

Figure 16: Connection schema

Simulation Based Control

This functionality of Energy IN TIME is given by two types of controls: one aimed on the generation of the optimal operational plan in advance taking into account weather and occupation forecasts (Operational Plan Generator) and a second one, Model on Demand Control that coordinates in real time the relevant equipment set-points by seeking the HVAC optimal behaviour. This last control module is supported by two additional tools: Fault detection and diagnosis and Fault adaptive control.

Operational Plan Generator, OPG

The intelligent control system, developed in Energy IN TIME, for whole-building energy optimization adjusts HVAC set points continuously to be adapted to occupancy and weather loads and their predictions, minimizing HVAC energy consumption and peak demand while maintaining the indoor environment within user preferred comfort conditions. This results in the generation of the operational plan in advance to be implemented in the existing energetic systems in the building.

The procedure for the generation of operational plans uses information about: (a) the current building status (i.e., sensor and actuators readings –encapsulated in the simulation model); (b) the operation restrictions (i.e., allowed strategies –defined by energy experts and building operators); and (c) forecasted future conditions (i.e., weather predictions, users' behaviour, etc. –from the Key Information Platform), to simulate the building's energy behaviour under those conditions (by relying on the simulation reference model), and to consequently generate an optimal operation plan for a given period of time (typically, one day).

The Operational Plan (OP) is a list of timestamped setpoint values which describe the actions to be performed on the building equipment at each interval. The optimized strategies provided by the OPG have been evaluated in order to analyze whether this system is able to provide better cost-effective functionalities to the current facilities in buildings.

Control strategies and algorithms are responsible for maintaining a controlled variable to operate within acceptable ranges and to fulfill the desired functions. The strategies have been defined aiming the energy consumption optimization. Different options were possible within the installations focused on production/generation or distribution/consumption sides.

From the point of view of production/generation option, the possibilities of optimization would come from the optimization of the temperature production in the central equipment operation. This fact could increase the seasonal performance in around 5% per ºC increased or decreased (depending whether it is operating in Summer or Winter mode). It is possible to improve the energy efficiency from the production/generation side by increasing the use of renewable systems or other high efficiency sources (e.g. geothermal instead fuel based). This option has the limitation of availability, since not all the locations have the same exploitation potential. On the other side, a new installation should be needed and this option was out of scope of the Energy IN TIME project.

Analysing the optimization strategies from the distribution/consumption side, two main possibilities are found: the optimization of timetables and the maximization of freecooling/heat recovery. The optimization of timetables would reduce the pumping consumption and the wasted energy as well, making the installation to operate just when it is necessary and, at the same time, maintaining the internal comfort and satisfaction of the people inside the building.

A better use of efficient technics such as the freecooling and the heat recovery reduces the energy consumption of the central production satisfying the comfort and energy requirements from the final users.

After the analysis of the different options for defining energy efficient strategies, individual evaluation was done in each particular demo building in order to finally define which strategies would be followed and applied.

The final step of the project has been a period of demonstration where OPG has been integrated in the building energy management system in ICPE, SANOMATALO and FARO and as Decision Support Tool in LEVI. The demonstration period has been different for each building, depending on the kind of control strategies (Summer/Winter strategies) and the weather of each location in order to fulfil the proper demonstration activity.

In order to evaluate the savings achieved, the International Performance Measurement and Verification Protocol (IPMVP)[3] have been applied. The IPMVP is not a standard and thus there is no formal compliance mechanism, however it is based on calculate savings following a procedure. Particularly, savings are determined by comparing measured use or demand before and after implementation of a program (in this case OPG), making suitable adjustments for changes in conditions.

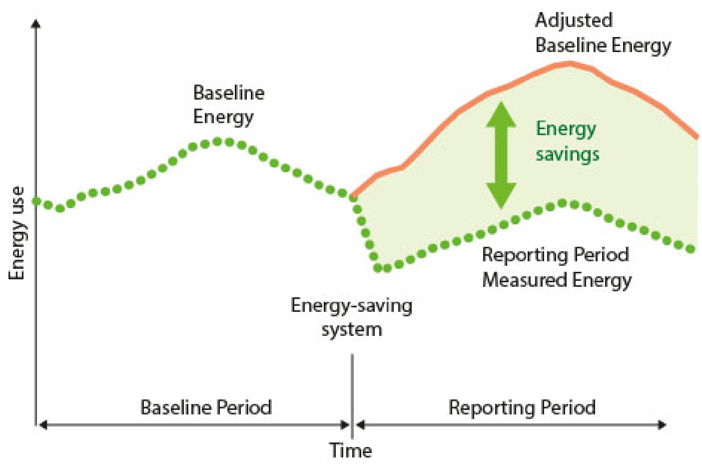

Figure 17. Energy savings evaluation.

In order to evaluate a more fruitful period after the demonstration phase, a yearly analysis has been carried out, taking into account both the demonstration results and the information obtained in the simulation phase. Furthermore, since most of the demo buildings (ICPE, Sanomatalo and Faro) have been evaluated in one part the building, a projection to the whole building has been performed.

Results of the analysis in each demo building are described below:

ICPE Office Building: This demo was the first to be operated with the OPG since winter in Romania ended at the beginning of April and the district heating was going to be cut off in consequence. The demonstration period in ICPE covered from March 29th until April 10th. Unfortunately, winter season was ending and the OPG application could not show a great potential, nevertheless, some savings were achieved.

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[3] http://www.evo-world.org/

In order to elaborate the baseline, a lineal regression line was stablished with data from January 2016 till March 2016 for the evaluation of the heat demand as function of the weather (Heat Degree Days with 18 ºC as reference). In this case, occupancy was not taken into account since there was not any variation. The equation is the following:

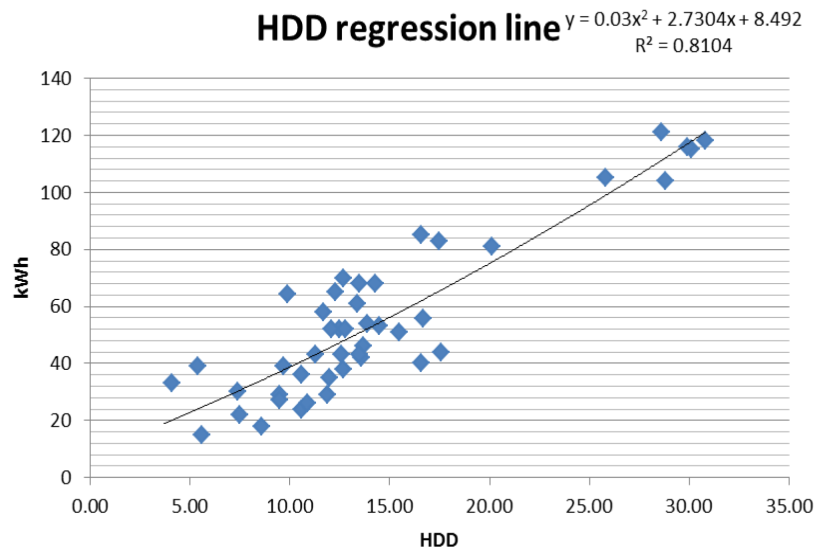

Figure 18. ICPE HDD regression line.

The comparison of the adjusted baseline (in red colour) and the real measurements gathered by the monitoring system (in blue colour) is represented in the next figure:

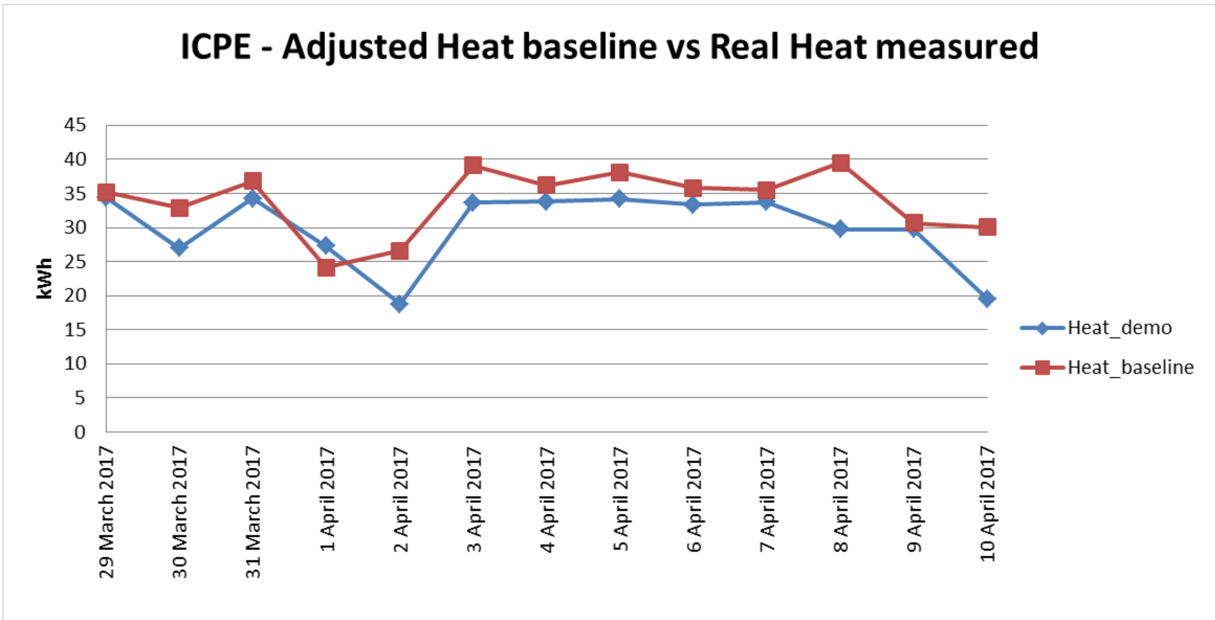

Figure 19. ICPE comparison.

Below, the numerical numbers of the energy savings achieved each day (weekends are not taken into account since the office is closed):

	Heat (kWh)	Savings (kWh)		Heat (kWh)	Savings (kWh)
29/03/2017	34.4	0.75	**04/04/2017**	33.8	2.33
30/03/2017	27.0	5.91	**05/04/2017**	34.2	3.96
31/03/2017	34.3	2.55	**06/04/2017**	33.3	2.48
01/04/2017	-	-	**07/04/2017**	33.7	1.76
02/04/2017	-	-	**08/04/2017**	-	-
03/04/2017	33.7	5.46	**09/04/2017**	-	-
			10/04/2017	19.5	10.49

Table 1. ICPE savings.

The total amount of thermal energy savings achieved in the demonstration period were 11.2%.

The electrical consumption was not analyzed because there were not available measurements; however, in order to evaluate the benefits of the VSD installation based on the electrical consumption, the following calculation has been done:

1) For the OLD pump:

The pump flow was 70m3/h with a power of 4kW. The running time for 2016-2017 cold season (Nov 2016 – Apr 2017) was 3648 hours. So based on that the potential energy that would have been consumed with the old pump would be:

OLD pump		
flow	70,00	m3/h
power	4,00	kW
period	3.648,00	hours/year
Total	**14.592,00**	**kWh/year**

Table 2. ICPE old pump.

2) VSD pump:

For the VSD pump, based on the BEMS monitored data the average flow for the entire winter period of 40.5m3/h witch correspond to 1.05kW power (from the pump power to flow profile) was 40,50 m3/h . With the same number of hours the value of the energy consumed by the VSD pump would be:

VSD pump

flow	40,50	m3/h
power	1,05	kW
period	3.648,00	hours/year
Total	**3.830,40**	**kWh/year**

Table 3. ICPE new pump.

Therefore, the new pump means 73% of electricity savings in pumping.

Icpe – Projection study

It is shown the District Heating consumption in 2016 for the pilot area and whole building, the energy prices and the average energy savings obtained for the different winter periods:

Month	District Heating consumption 2016 PAN(kWh)	District Heating consumption 2016 TOTAL(kWh)	Winter period	Energy savings average	District heating (€/kWh)
Jan	2,336	196,435	Harsh	20%	0.04071
Feb	989	97,413	Standard	10%	
Mar	1,040	88,316	Intermediate	10%	
Apr	0	0			
May	0	0			
Jun	0	0			
Jul	0	0			
Aug	0	0			
Sep	0	0			
Oct	0	0			
Nov	1,265	151,427			
Dec	1,354	152,627			
Total	6,984	686,219			

Table 4. ICPE heating savings.

The distribution of thermal savings hypothetically achieved in 2016 thanks to the OPG installation for optimizing the consumption in the whole building is shown in the next figure:

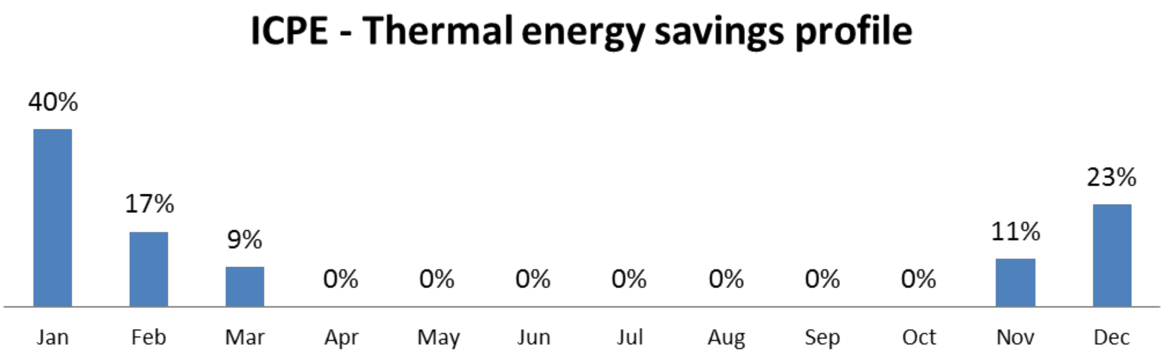

Figure 20. ICPE thermal energy savings profile.

The yearly savings in the whole building for DH consumption implementing the OPG module would be 16%. This energy savings would mean around 5000 €/year.

The optimization potential in this building is higher in the colder months where it is possible to adjust better the comfort temperature in the building as well as the water supply temperature from the district heating network. Thanks to the improvements done within the project, a more accurate set points have been instituted for an energy optimization of the heat consumption.

SANOMATALO Office Building: For the development of the baseline (that was studied with monitored data in 2016), two variables were taken into account in this building: the weather (in Heating Degree Days with 18ºC as reference) and the number of people inside the building (Occupancy). Therefore, the linear regression was multiple and its representation is shown in the following image:

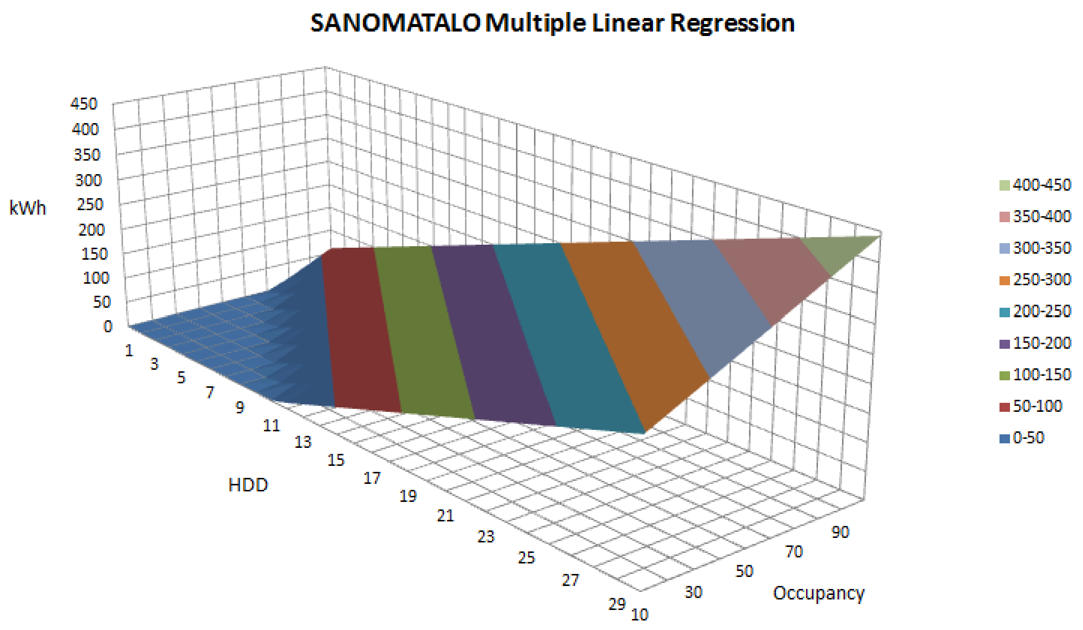

Figure 21. Sanomatalo multiple linear regression.

It can be observed that, according to the graph, there are some combinations where there is no energy requirement. This information would have been very useful for its utilization in the control strategies in that period (before the implementation of Energy IN TIME measures).

The demonstration activity started in April 2017 and was extended until the end of May 2017. The comparison of the heating consumption in the pilot area during the demonstration is shown in the next figure:

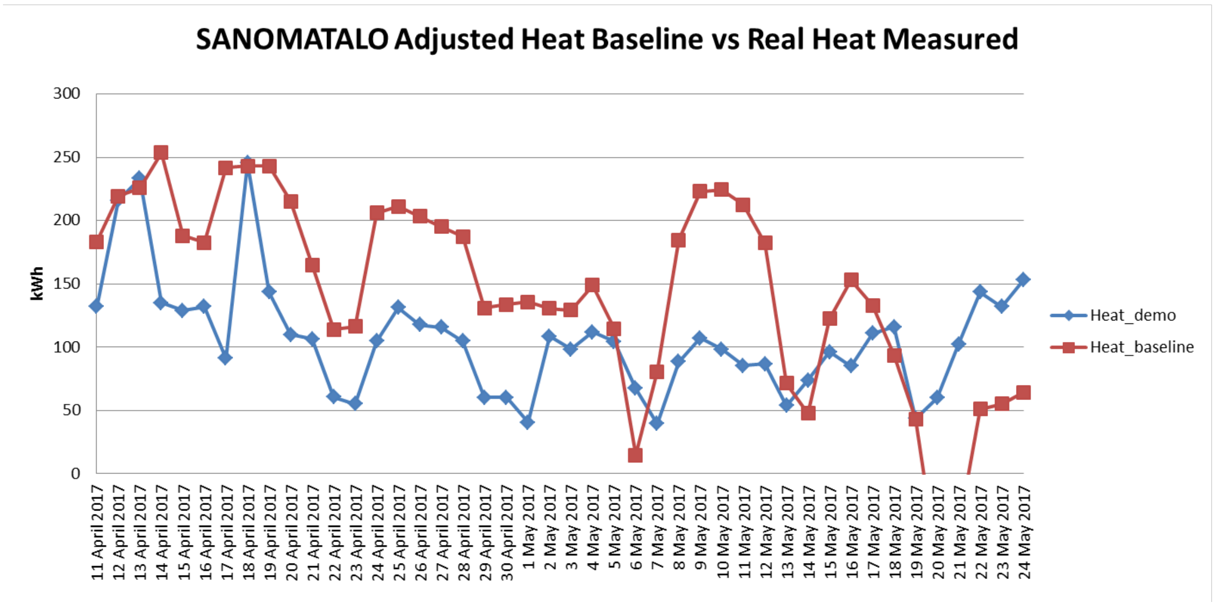

Figure 22. Sanomatalo comparison.

Below, the numerical numbers of the energy savings achieved each day:

	Heat (kWh)	Savings (kWh)		Heat (kWh)	Savings (kWh)
11/04/2017	131.9	51.5	**03/05/2017**	98.3	30.9
12/04/2017	215.9	3.2	**04/05/2017**	112.0	37.0
13/04/2017	233.3	-7.5	**05/05/2017**	104.6	10.1
14/04/2017	134.9	118.7	**06/05/2017**	67.3	-52.7
15/04/2017	129.1	58.9	**07/05/2017**	39.4	41.4
16/04/2017	132.0	50.6	**08/05/2017**	88.6	96.2
17/04/2017	91.1	150.5	**09/05/2017**	107.3	115.8
18/04/2017	245.4	-2.4	**10/05/2017**	98.3	126.2
19/04/2017	143.7	99.3	**11/05/2017**	85.4	127.2
20/04/2017	109.9	105.3	**12/05/2017**	86.9	95.3
21/04/2017	106.6	58.4	**13/05/2017**	54.0	17.6
22/04/2017	60.5	53.4	**14/05/2017**	73.7	-26.0
23/04/2017	55.1	61.4	**15/05/2017**	96.5	26.1
24/04/2017	104.7	101.2	**16/05/2017**	85.1	67.9
25/04/2017	131.3	79.9	**17/05/2017**	111.0	22.2
26/04/2017	117.7	85.6	**18/05/2017**	116.0	-22.5
27/04/2017	115.7	79.6	**19/05/2017**	43.6	-0.4
28/04/2017	104.7	82.7	**20/05/2017**	59.9	-129.9
29/04/2017	60.4	70.7	**21/05/2017**	102.4	-146.0
30/04/2017	60.2	73.5	**22/05/2017**	143.6	-92.4
01/05/2017	40.4	95.4	**23/05/2017**	131.8	-76.7
02/05/2017	108.5	22.1	**24/05/2017**	153.5	-89.2

Table 5. Sanomatalo daily energy savings.

The energy savings achieved in the demonstration period compared to the baseline were 26%. However, it is important to point out that this percentage of energy savings does not correspond only to the application of the OPG system but a combination of different energy efficiency measures (particularly MODC and OPG modules).

Sanomatalo – Projection study

It is shown the District Heating consumption in 2016 for the pilot area and the whole building, the energy prices and the average energy savings obtained for the different season periods.

Table 6. Sanomatalo energy savings.

Month (WHOLE BUILDING)	District Heating consumption 2016 (kWh)	District Heating consumption 2016 (kWh)[1]	Winter period	Energy savings average	District heating period	2016 Price (€/MWh)
Jan	721,400	9,894	Harsh	29%	Jan – Feb	49.89
Feb	381,300	8,099	Standard	32%	Mar – Apr	46.84
Mar	367,300	8,696	Intermediate	26%	May – Oct	27.78
Apr	212,000	5,186	Summer	26%	Nov - Dec	43.18
May	58,400	686				
Jun	48,600	419				
Jul	32,800	121				
Aug	38,200	222				
Sep	58,600	1,057				
Oct	220,900	4,181				
Nov	430,400	9,320				
Dec	428,000	9,135				
Total	2,997,900	57,016				

[1] January and February consumptions correspond to 2017 instead of 2016 in order to complete a whole year.

The distribution of thermal savings hypothetically achieved in 2016 thanks to the OPG installation for optimizing the consumption in the whole building is shown in the next figure:

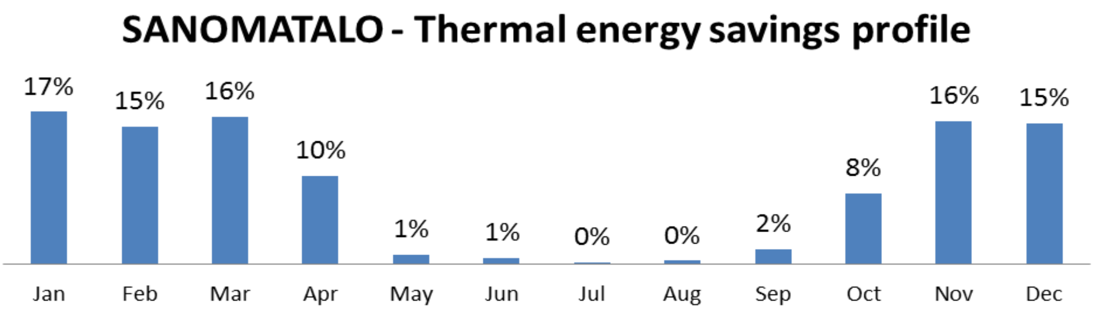

Figure 23. Sanomatalo thermal energy savings.

The yearly savings in the whole building for DH consumption implementing the OPG and MODC modules would be 30%. This energy savings would mean around 40000 €/year.

The energy savings are quite shared among the months in winter season, therefore, the OPG+MODC modules offer a high optimization potential in this case. The difference in this demo building relies on the optimization focus which is not only distribution and terminal units but also the generation system. Acting at the beginning of the installation, it is possible to obtain much higher energy savings.

LEVI Hotel Building: In this demo building two different zones were studied. First, the zone called "Rooms" (which contains DHW, under floor heating - hotel and -AHUs 301, 303, 304 networks) and "7th Floor" (which contains DHW, under floor heating - restaurant and - AHUs 306, 307, 308 networks). The baseline period was studied with data from 2016 and the demonstration activity was carried out during the month of May 2017.

Firstly, the multiple regression line obtained for the "Rooms" package is shown in the next image:

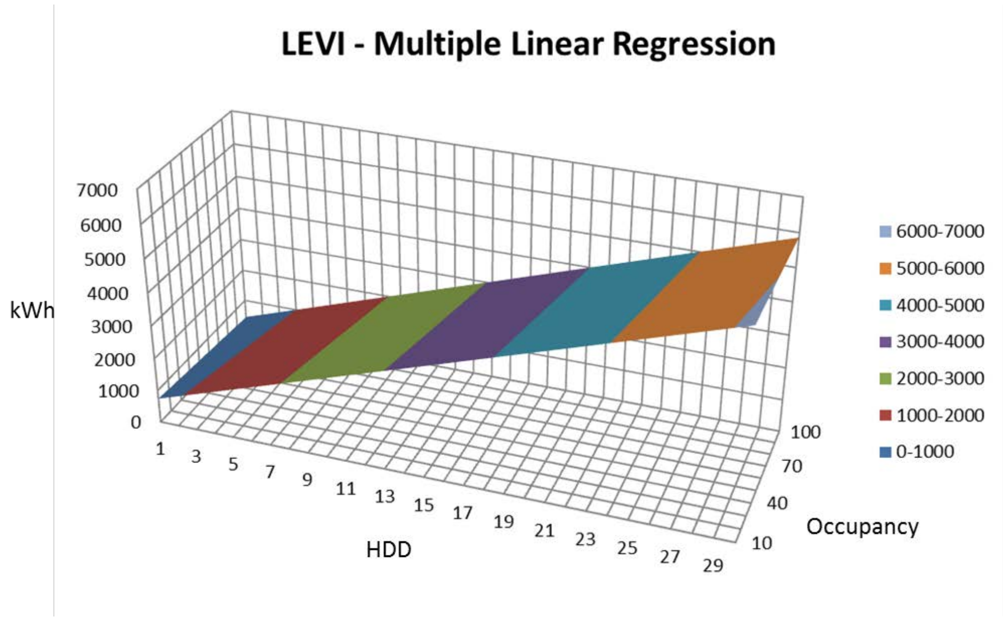

Figure 24. Levi multiple linear regression.

From the graph, it can be observed that, even with comfortable weather outside, there is some thermal energy consumption due to the DHW (domestic hot water).

The comparison of the heating consumption in the pilot area during the demonstration is shown in the next figure:

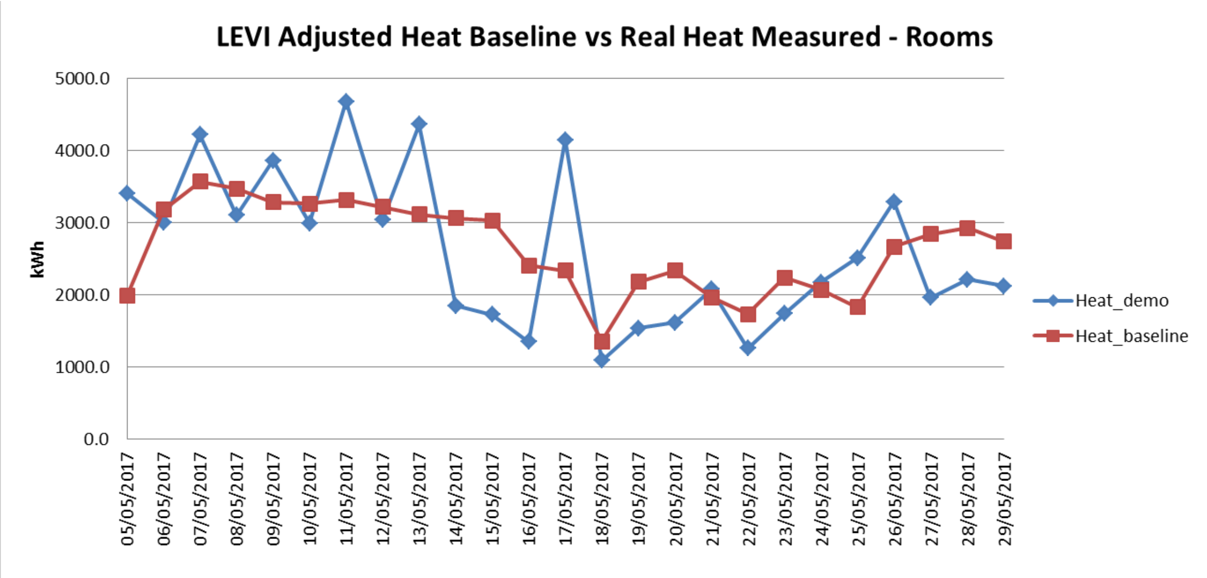

Figure 25. Levi comparison.

Below, the numerical numbers of the energy savings achieved each day:

	Heat (kWh)	Savings (kWh)		Heat (kWh)	Savings (kWh)
05/05/2017	3407.3	-1421.1	**17/05/2017**	4149.7	-1817.1
06/05/2017	3002.7	179.0	**18/05/2017**	1083.2	270.6
07/05/2017	4218.4	-653.0	**19/05/2017**	1532.0	648.5
08/05/2017	3100.3	371.7	**20/05/2017**	1615.7	716.9
09/05/2017	3858.2	-578.1	**21/05/2017**	2071.3	-104.8
10/05/2017	2987.5	276.3	**22/05/2017**	1252.5	474.0
11/05/2017	4680.8	-1368.3	**23/05/2017**	1736.4	501.5
12/05/2017	3036.1	178.6	**24/05/2017**	2172.6	-108.2
13/05/2017	4361.1	-1246.0	**25/05/2017**	2509.7	-682.4
14/05/2017	1845.8	1218.8	**26/05/2017**	3287.7	-624.0
15/05/2017	1724.4	1306.3	**27/05/2017**	1956.0	885.0
16/05/2017	1346.1	1061.4	**28/05/2017**	2207.3	720.6
			29/05/2017	2117.1	618.1

Table 7. Levi daily energy savings.

Although during the demonstration period some thermal savings were achieved (2%) the OPG does not offer a clear benefit since there are many days were the energy demand has been higher than expected (it can be clearly seen in the first days of the demonstration). This effect can be explained by two reasons:

- The OPG plan was not automatically used in the hotel but it was used as a “suggestion” for the maintenance personnel in the hotel. This fact could mean that not all the actions sent by the OPG were applied in the local BMS.

- Rooms comfort temperature cannot be controlled by the OPG (or externally) since the client who is hosted in the hotel decides which the temperature that they prefer is. Therefore, to give an optimized plan for this part of the hotel is not possible because the comfort temperature can be different from one person to other and, as a consequence, the thermal consumption of the zone will depend on the predilection of the people in each moment.

The other zone analyzed is different because in this case it is mostly a common zone. Therefore, the thermal comfort can be fixed externally by the maintenance of the hotel (or the OPG). The lineal regression obtained with data from 2016 is the following:

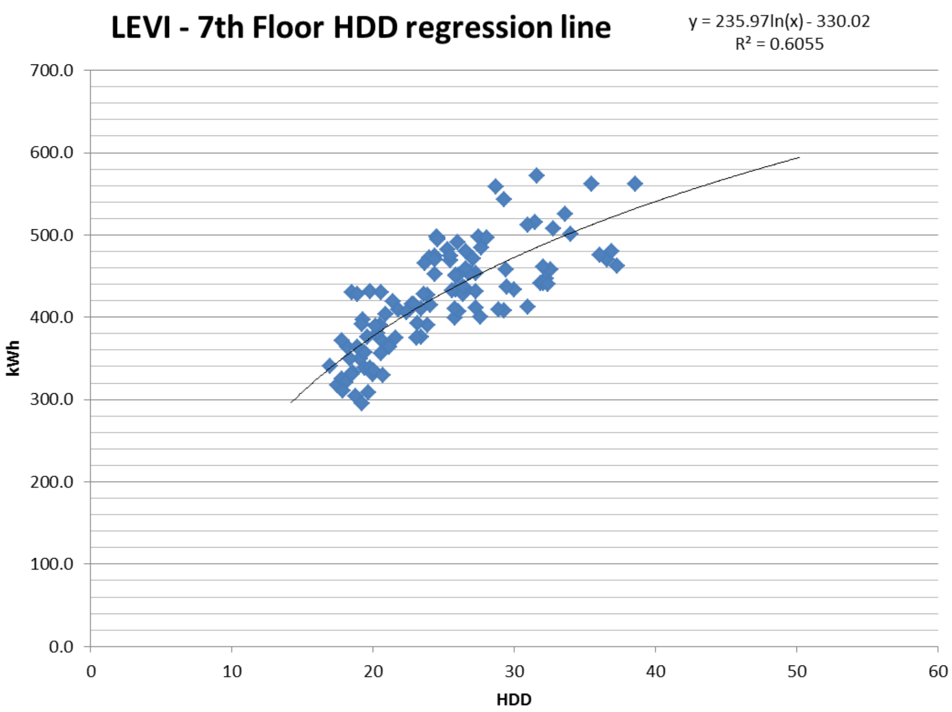

Figure 26. Levi 7th floor regression line.

And the comparison between the adjusted baseline and the thermal consumption measured is shown in the next image:

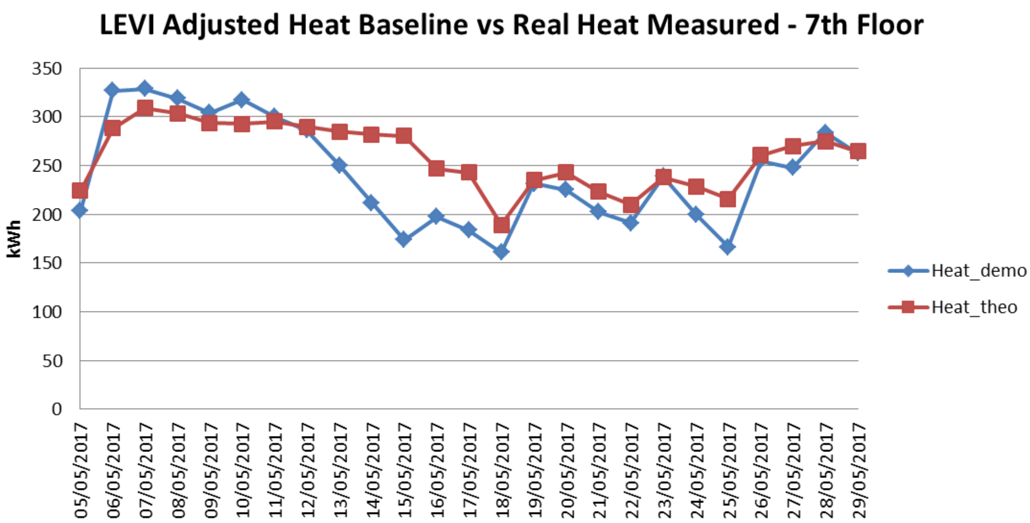

Figure 27. Levi savings.

Below, the numerical numbers of the energy savings achieved each day:

	Heat (kWh)	Savings (kWh)		Heat (kWh)	Savings (kWh)
05/05/2017	203.4	21.0	**18/05/2017**	161.0	27.9
06/05/2017	326.7	-38.4	**19/05/2017**	231.5	3.4
07/05/2017	328.7	-19.8	**20/05/2017**	225.2	17.9
08/05/2017	318.9	-15.1	**21/05/2017**	202.6	20.6
09/05/2017	304.2	-10.7	**22/05/2017**	191.2	18.8
10/05/2017	317.3	-24.7	**23/05/2017**	239.0	-1.0
11/05/2017	300.3	-5.1	**24/05/2017**	199.7	28.9
12/05/2017	286.5	3.5	**25/05/2017**	166.3	49.4
13/05/2017	250.3	34.4	**26/05/2017**	254.6	6.1
14/05/2017	211.8	70.1	**27/05/2017**	247.9	22.3
15/05/2017	173.7	106.5	**28/05/2017**	284.1	-9.4
16/05/2017	197.6	49.4	**29/05/2017**	262.6	1.9
17/05/2017	183.9	59.2			

Table 8. Levi 7th daily energy savings

In this case, although the savings achieved during the demonstration phase are not very high (6%) it can be seen that the possibility of energy optimization is possible without the interaction of the clients. There are some days where was not possible to improve the thermal consumption; however it corresponds mainly to the first days of the demonstration period (it could be because the maintenance people in the hotel did not perform all the recommendations that the OPG sent).

Levi – Projection study

Since it has been concluded that the rooms' zone is not a proper scenario for evaluating the potential of the OPG system, in this case, only the common areas have been analyzed (estimating 20% of the hotel corresponding the common areas). It is shown the District Heating consumption in 2016 for the whole building and the estimated for the 7th floor, the energy prices and the average energy savings obtained for the different season periods.

Table 9. Levi 7th floor heating savings.

Month	District Heating consumption 2016 (kWh)	7th floor	Winter period	Energy savings average	District heating €/MWh
Jan	368,650	31,308	Harsh	8%	63.76
Feb	305,610	25,954	Standard	12%	
Mar	275,500	23,397	Intermediate	12%	
Apr	173,520	14,736	Summer	20%	
May	70,650	6,000			
Jun	69,900	5,936			
Jul	46,780	3,973			
Aug	64,830	5,506			
Sep	85,280	7,242			
Oct	175,870	14,936			
Nov	272,880	23,175			
Dec	270,600	22,981			
Total	**2,180,070**	**185,144**			

The yearly savings in the whole building for DH consumption implementing the OPG only in the common areas would be 3% of the total energy consumption. This energy savings would mean around 3500 €/year.

In this case, the distribution of such energy savings in common areas would be the following:

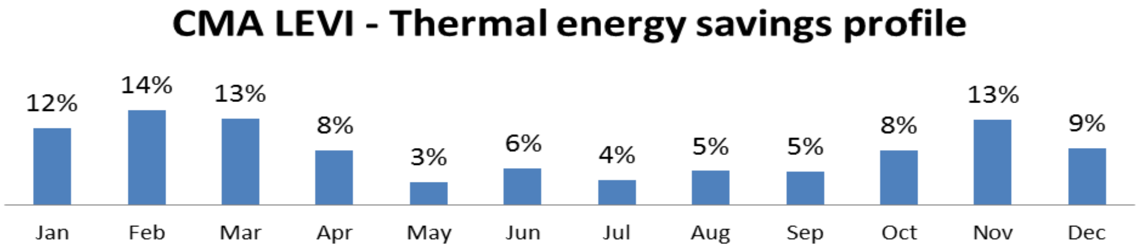

Figure 28. Levi thermal energy savings profile.

FARO Airport: The demonstration activity in Faro was carried out in the summer 2017. For the analysis of the results, August 2016 information has been used for developing the baseline and August 2017 measurements have been evaluated. One relevant point in this building is that cooling system is undersized for giving the maximum power that the cooling requirements need. This fact means that in the warmer period (such as August) the equipment is almost operating at its maximum power full time (at least, it was the typical situation all the summers in Faro). The OPG improves a little bit the energy consumption by reducing the number of operation hours some night when the flights were not so frequent and there was the possibility to optimize it. However, since the cooling requirements were so high, the energy savings in August do not represent the overall potential of the OPG system in Faro.

The lineal regression obtained in the baseline period analyzed (August 2016) represents the fact explained previously, where the cooling system is operating almost all the time:

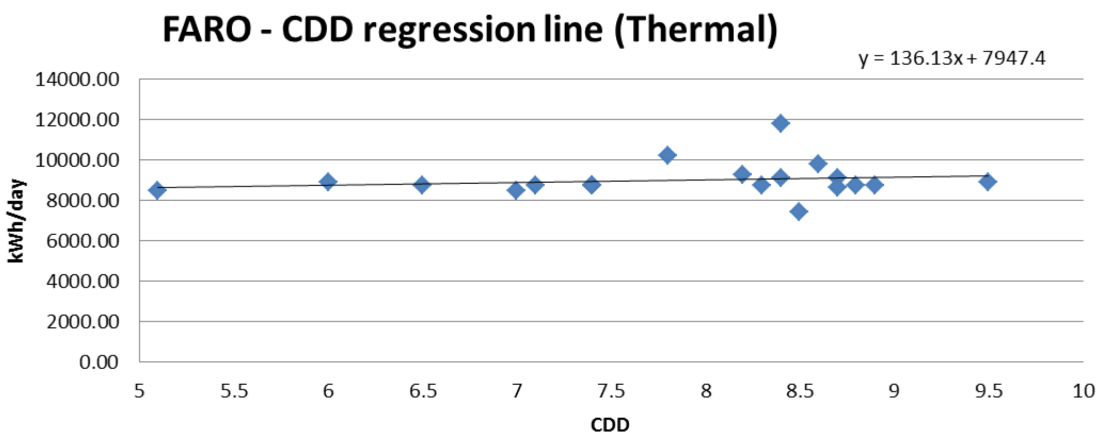

Figure 29. Faro regression line.

The comparison of the adjusted baseline with the weather conditions in the Summer 2017 (demonstration period) is shown in the next figure:

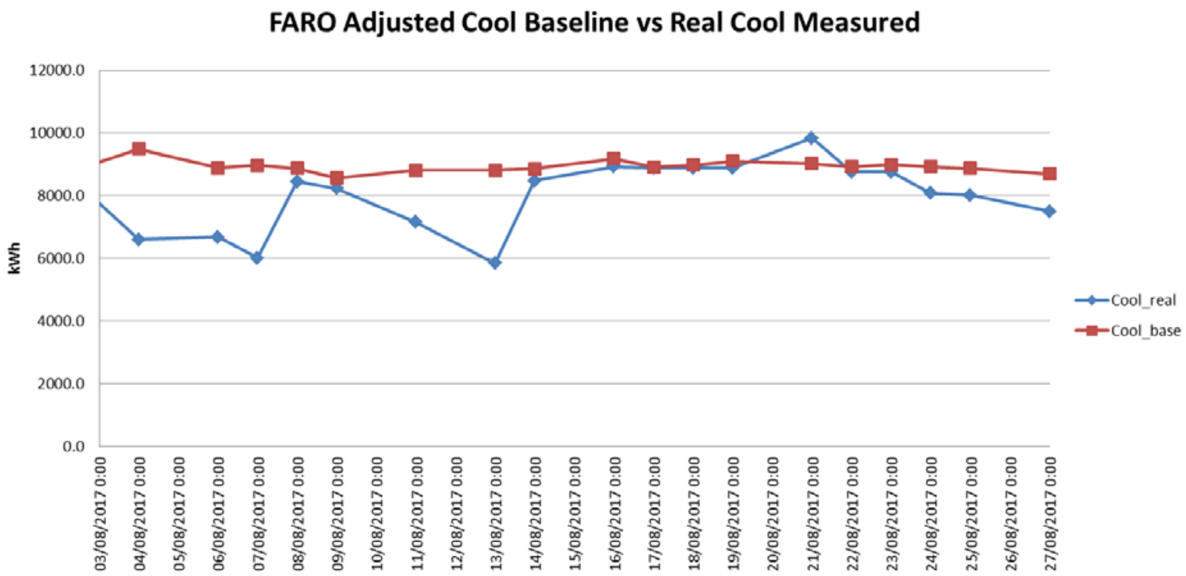

Figure 30. Faro baseline comparison.

Below, the numerical numbers of the energy savings achieved each day:

	Cool (kWh)	Savings (kWh)		Cool (kWh)	Savings (kWh)
02/08/2017	8917.4	-248.5	**16/08/2017**	8926.5	259.7
04/08/2017	6606.3	2879.4	**17/08/2017**	8889.1	24.8
06/08/2017	6683.1	2203.6	**18/08/2017**	8889.8	92.2
07/08/2017	6005.1	2963.3	**19/08/2017**	8891.1	213.4
08/08/2017	8445.6	427.5	**21/08/2017**	9842.5	-819.7
09/08/2017	8235.0	325.0	**22/08/2017**	8764.3	163.2
11/08/2017	7147.9	1657.1	**23/08/2017**	8755.2	240.4
13/08/2017	5844.9	2960.1	**24/08/2017**	8079.9	847.7
14/08/2017	8480.5	379.0	**25/08/2017**	8015.8	857.2
			27/08/2017	**7500.6**	**1195.5**

Table 10. Faro daily energy savings

As it has been observed, it has been possible to optimize the operation of the AHUs in the rooms selected for the pilot area. The energy savings obtained were 6% in thermal energy.

A new study was done with the evaluation of the electricity consumed. The regression line in this case represents the information of data monitored in 2017 (before the demonstration phase).

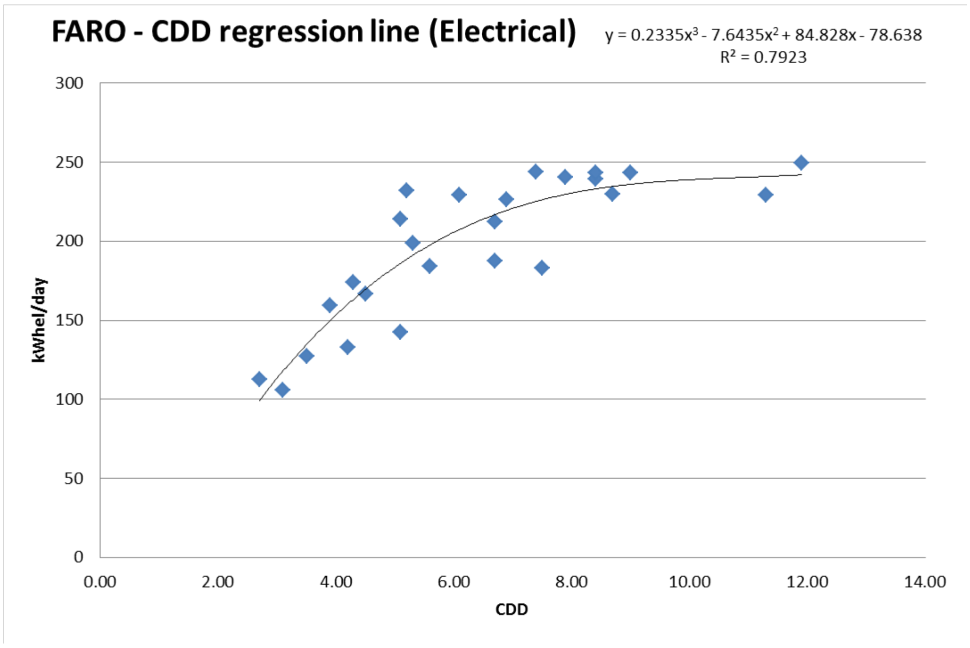

Figure 31. Faro electrical regression line.

The comparion between the adjusted baseline and the monitored data in the demonstration is shown:

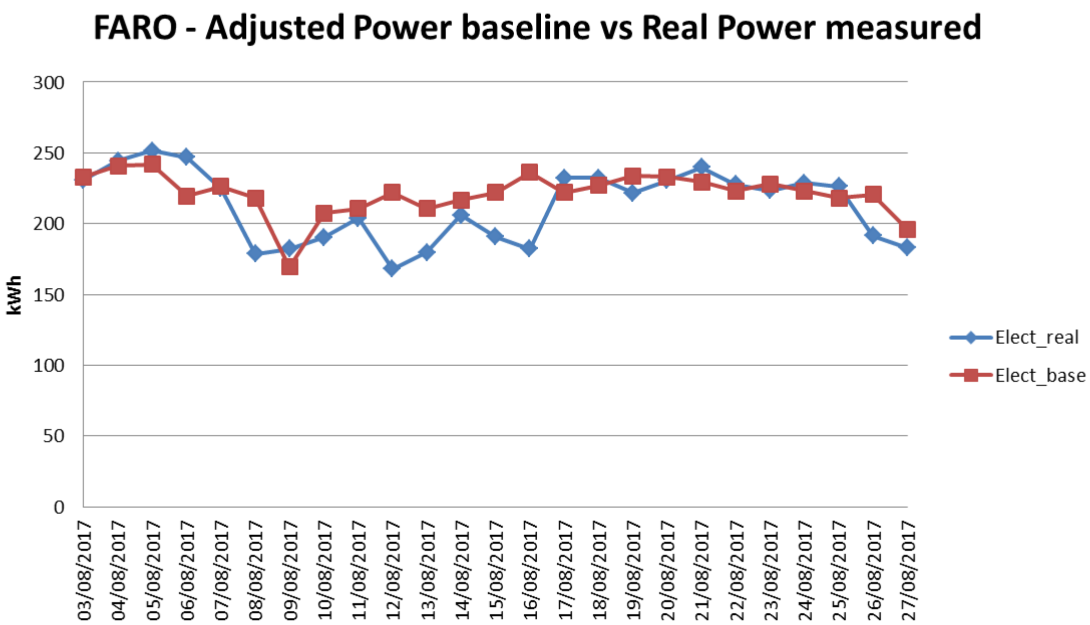

Figure 32. Faro baseline.

Below, the numerical numbers of the energy savings achieved each day:

	Cool (kWh)	Savings (kWh)		Cool (kWh)	Savings (kWh)
02/08/2017	209.4	-18.4	**15/08/2017**	190.9	31.1
03/08/2017	231.0	2.0	**16/08/2017**	182.1	54.2
04/08/2017	244.5	-3.6	**17/08/2017**	232.3	-10.4
05/08/2017	251.6	-9.7	**18/08/2017**	232.5	-5.4

06/08/2017	246.8	-27.3	**19/08/2017**	221.6	12.0
07/08/2017	224.8	1.4	**20/08/2017**	230.4	2.6
08/08/2017	178.8	39.4	**21/08/2017**	239.6	-10.0
09/08/2017	182.3	-12.7	**22/08/2017**	227.7	-4.6
10/08/2017	190.3	17.1	**23/08/2017**	223.3	4.7
11/08/2017	203.7	7.1	**24/08/2017**	228.8	-5.8
12/08/2017	167.9	54.0	**25/08/2017**	226.4	-8.2
13/08/2017	179.6	31.2	**26/08/2017**	191.4	29.3
14/08/2017	206.1	10.8	**27/08/2017**	182.9	12.6

Table 11. Faro daily savings

In this case, the optimization of the AHUs operation served for the electricity reduction of 3% during the demonstration period studied.

Faro – Projection study

It is shown the electricity consumption in 2016 divided in different uses (the same proportion has been used for the estimation of the energy consumption in the pilot area), the energy prices and the average energy savings obtained for the different season periods.

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Month	Electricity consumption breakdown (kWh) in 2016				
	Heating	Cooling	Other HVAC Equipment	Lighting	Others
Jan 2016	138,357	13,714	34,894	109,385	25,243
Feb 2016	194,938	11,265	48,399	109,479	25,264
Mar 2016	129,983	13,763	35,417	116,131	26,799
Apr 2016	8,083	35,889	21,295	110,045	25,395
May 2016	0	75,356	40,287	133,373	30,778
Jun 2016	0	241,800	109,855	133,770	30,870
Jul 2016	0	372,672	163,895	251,142	57,956
Aug 2016	0	489,739	214,593	255,398	58,938
Sep 2016	0	270,952	147,798	207,307	47,840
Oct 2016	0	158,465	105,856	154,903	35,747
Nov 2016	44,745	24,396	58,944	109,281	25,219
Dec 2016	191,135	5,252	68,984	127,275	29,371
Total	**707,241**	**1,713,263**	**1,050,217**	**1,817,489**	**419,420**

Month	Electricity consumption breakdown (kWh) in 2016 demo estimated				
	Heating	Cooling	Other HVAC Equipment	Lighting	Others
Jan 2016	10000	991	2,522	18,055	27,346
Feb 2016	16582	958	4,117	15,486	25,028
Mar 2016	10779	1141	2,937	17,342	26,755
Apr 2016	564	2506	1,487	16,718	26,208
May 2016	0	8340	4,459	19,415	27,266

Jun 2016	0	33305	15,131	21,151	26,727
Jul 2016	0	62447	27,463	24,516	27,965
Aug 2016	0	65597	28,743	26,406	27,528
Sep 2016	0	34969	19,075	25,552	26,441
Oct 2016	0	13241	8,845	26,223	27,066
Nov 2016	2434	1327	3,206	23,137	24,210
Dec 2016	12762	351	4,606	22,360	24,502
Total	**53121**	**225173**	**122591**	**256361**	**317042**

Table 12. Electricity consumption breakdown

Season	Energy savings average	Electricity concept		Costs
Harsh Summer	6%	Energy costs [€/kWh]	Empty Hours	0.0538
Standard Summer	15%		Super Empty Hours	0.0538
Intermediate	20%		Rush Hours	0.0538
Winter	20%		Flood Hours	0.0538
		Grid costs [€/kWh]	Empty Hours	0.0225
			Super Empty Hours	0.0218
			Rush Hours	0.0472
			Flood Hours	0.0408
		Power costs [€/kW/day]	Contracted Power	0.032
			Rush Hours Power	0.2263

Table 13. Faro savings.

The yearly savings in the whole building for electricity consumption implementing the OPG would be 13%. This energy savings would mean around 36000 €/year.

The distribution of the electricity savings hypothetically achieved in 2016 thanks to the OPG installation for optimizing the consumption in the whole building is shown in the next figure:

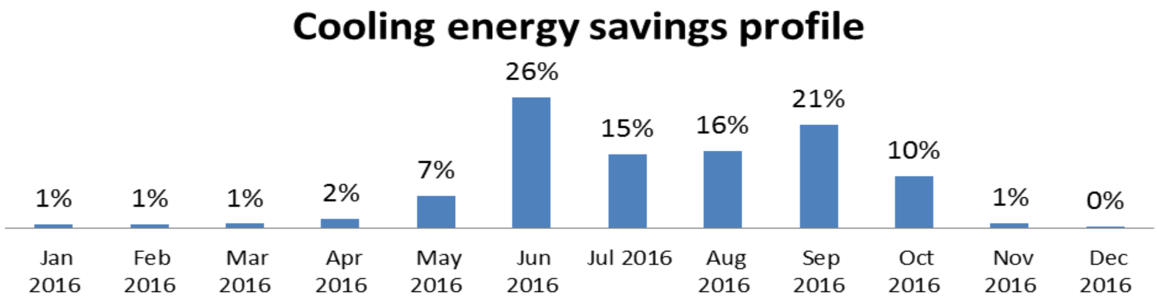


Figure 33. Cooling energy savings profile.

It has been observed that the warmest months in summer (July and August) do not represent the most energy savings but the lighter summer months (June and September). This is a consequence of the size of the installation because it does not offer many possibilities to propose different operational plans. In warmer period, the installation is working as it maximum power a lot of hours in the day, therefore, the optimization potential is not as high as in less warm periods.

Model On Demand Control

Model On Demand Control (MODC) uses approximated, low-complexity models (e.g. actual heating/cooling demand of a building) obtained *on-demand* by means of learning procedure able to capture the actual system behavior around current operating conditions. Finally MODC coordinates in real time the relevant equipment set-points by seeking the HVAC optimal behavior based on the learned model. The overall goal is to minimize HVAC energy consumption while maintaining user preferred comfort conditions.

MODC has the following features:

- Secure equipment operations;
- User comfort guaranteed;
- Higher building HVAC energy performance.

MODC was successfully demonstrated at Sanomatalo and Montluel buildings, where the satisfaction of the users' comfort constraints was met together with the achievement of substantial energy savings. In doing this, MODC showed the effectiveness of its adaptive strategy and the on-demand computation of low-complexity models, irrespectively of the HVAC architecture within the buildings.

MODC is a replicable control module that based on the thermal demand can rebalance efficiently the generation of heating/cooling capacity in the system. The controller is able to adapt set-points irrespectively of the system and its configuration and operate efficiently the heating system in different boundary conditions (occupancy, thermal loads, and weather conditions), with the aim of scalability/replicability across different buildings.

MONTLUEL Office Building: MODC was implemented in Montluel as a control module in the System Manager of the Aquasmart system. Carrier Aquasmart integrated solution is a hydronic system composed of four type of equipment monitored and efficiently controlled by a System Manager. The water side of the system is balanced by a Heat Pump (HP) and a Variable Water Flow Pump (VWFP): they are responsible to increase or decrease the heating/cooling capacity transported in form of water. The water-air side of the system is managed by Fan Coil Units (FCUs) and Air Handling Units (AHUs) which are finally responsible to transfer the heating/cooling capacity to the zones in the building: in particular FCUs are responsible for regulating zone temperatures and AHU is responsible for regulating ventilation in the building. Aquasmart is installed in one of the office buildings of Carrier facility at Montluel, France. This building has a floor area of 1052 m2, is occupied in average by 121 Carrier employees, and includes 77 FCUs, 1 AHU, 1 HP and 1 VWFP (see schematic below). MODC controller aims at adapting Entering Water Temperature (EWT) of the HP and the Water Pressure (DP) of the VWFP based on the thermal demand estimated from the air side of the system.

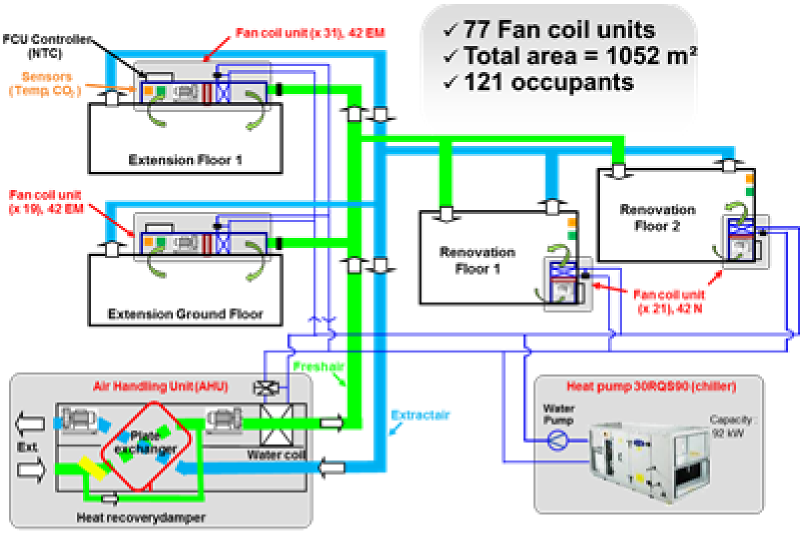


Figure 34: HVAC schematic at Montluel building.

In order to have comparable boundary conditions (occupancy, thermal loads, and weather conditions), MODC was demonstrated at alternate days with the Baseline. The comfort results are shown in Figure 34: Baseline and MODC are totally comparable and they both guarantee comfort within the comfort band of 21.5C - 23.5C. Since comfort is met for both Baseline and MODC in a similar way, one can correctly compare energy savings: MODC can daily save 10-15% of energy consumption compared to the Baseline, as shown in Figure 35.

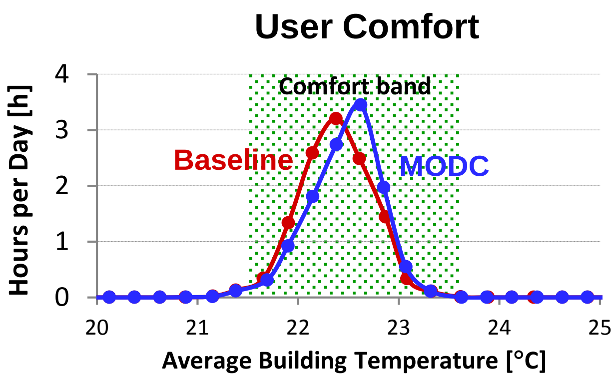


Figure 35: User comfort obtained during demonstration period at Montluel building.

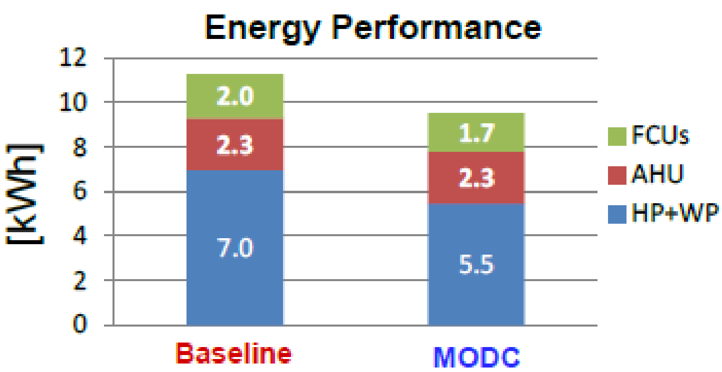


Figure 36: Energy reduction obtained during demonstration period at Montluel building.

SANOMATALO Office Building: In Sanomatalo test-bed, all the building heat demand is provided with a district heating system from Helsinki city, whose water network is connected to the building by means of four Heat Exchangers (HEX): one to supply AHUs hence provides ventilation in the building, one to supply radiator network and two to supply domestic hot water networks.

MODC demonstration focuses only on the two radiator networks N_11 and N_12 served by Heat Exchanger HEX 101LS01 (see Figure 36). These two networks comprise 54 zones inside the building in different locations and cover the major part of the building. The Supply Water Temperature (SWT) set-points SWT_11 and SWT_12 for the water coming from the district and entering the building radiator networks represent the control inputs of the MODC. The Room Air Temperatures (RATs) of building zones interested in the demonstration represents the measurements acquired by MODC from the building. By collecting temperature measurements from all the zones, the MODC is able to guarantee comfort conditions in whole the building. As such MODC does not focus on a selected area in the building, but supervises the temperature regulation at the building level.

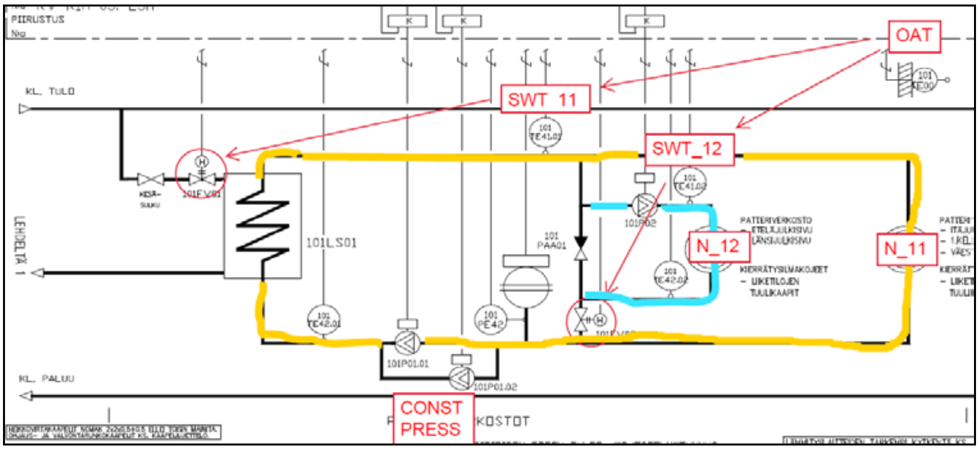


Figure 37. Mechanical schematics of Heat Exchanger 101LS01.

The main control objective is the minimization of energy consumption while maintaining the indoor environment within user preferred comfort conditions. This objective can be expressed as the realization of a number of partial objectives: (i) keeping SWTs in safe operating values, (ii) ensuring the RATs measurement to be in a given comfort band and, finally, (iii) minimizing the energy consumption related to the actuation of control inputs SWTs.

In order to compute the optimal set-points that bring the building behavior to optimal operating conditions with respect to the economic criterion, MODC continuously adapts the building model derived from the system measurements. This iterative and adaptive behavior is implemented following the subsequent steps: (i) data from the system are acquired and analyzed in order to detect different operating conditions of the system, (ii) an on-demand low-complexity model of the controlled system is generated and (iii) used for re-tuning the parameters of the controller, which at the end (iv) selects the actual values of the SWT set-points. These steps are repeated continuously in a closed-loop fashion so as to guarantee robustness with respect to the wide class of external disturbances and system/building uncertainties.

A long demonstration session from March 1st to April 29th was performed, during which MODC operated in different hours of the day, with a different heat demand and different outside conditions. During this time span, MODC has been alternated with the Baseline controller in order to obtain a fair comparison of the two control strategies.

Figure 37 shows that comfort requirements are equally met both by MODC and the Baseline. The distributions of the RAT measurements acquired during the demonstration period are almost identical either when the building zones temperatures are controlled by the Baseline (dashed red line) or by the MODC (continuous blue line). The fact that the Baseline and the MODC are comparable, from the point of view of the zones temperatures and achieved comfort, allows us to fairly compare the energy savings obtained by the MODC with respect to the Baseline.

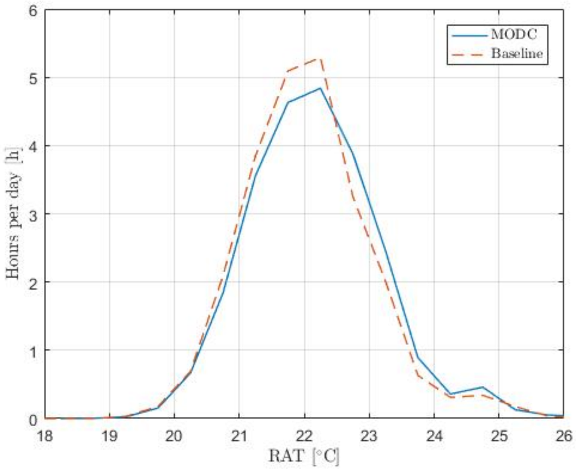


Figure 38. RAT distribution. Comparison between MODC and Baseline during the whole demonstration period.

For a detailed analysis of the energy consumption, it was selected two different periods characterized by high and low heating demand from the building and with very close weather conditions. As shown in Figure 38, MODC achieved different energy savings during the demonstration period, which are higher (24 %) in high demand periods and lower in low demand periods (1.6 %). On average, energy savings achieved by MODC during the demonstration period are substantial and amount on average to 17% with respect to the Baseline consumption.

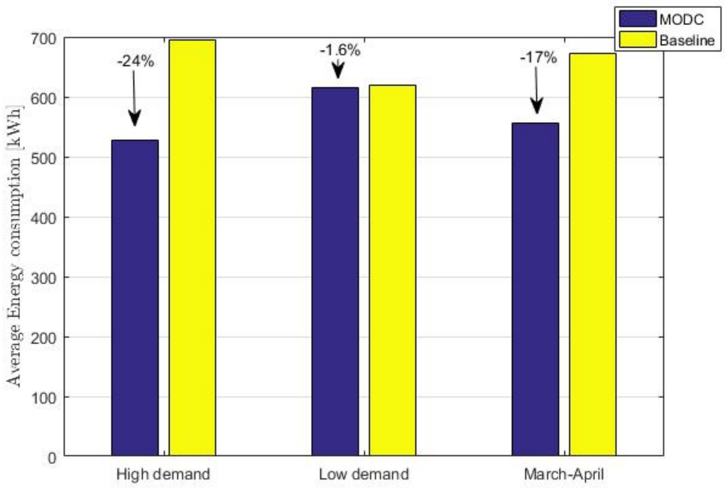


Figure 39. Average energy savings during high demand, low demand and the whole demonstration period.

Conclusions of the results achieved after the demonstration period

Carrying out the analysis of the outputs obtained in each demo building, some conclusions have been reached regarding the operation of the Energy IN TIME system. In general terms, in an automatic scenario, the Energy IN TIME system reduces the energy consumption, optimizing the functioning of the equipment and maintaining comfort levels (which have been always a limiting condition for deciding between plans or others). However, if the plans generated are used as decision support tool, the potential of optimization depends on the user responsible of following the plan suggested by the OPG.

After the study, a less potential scenario for the OPG application has been detected, that one in which the comfort observation depends directly on the clients and they are able to interact with the equipment. When there are extra manipulators involved in the operation of the system (such as the clients in a hotel), the potential of the OPG decreases since the plans generated are based on a particular comfort condition (usually limited by the regulations).

On the other side, since the accuracy of the generated plans depends mainly on the weather conditions, a reliable weather forecast should be used. Within the project a study was done varying the external temperature in order to evaluate when the plan generated could not be suitable. The study revealed than for winter/summer around 4ºC would be a high deviation and in intermediate seasons, more than around 2ºC would be enough for changing the plan generated by the OPG. Furthermore, the OPG potential is higher with intermediate weathers, when there are more possibilities of optimization, therefore again, a confident weather forecast is crucial. Apart from the weather forecast system, it is a must to work with a precise calibrated simulation model.

During the demonstration phase, the savings achieved with the application of Energy IN TIME systems varied from 2% until 26%, being 2% the worst scenario (“Rooms” package in the hotel) and 26% an scenario with 2 modules (OPG + MODC). Therefore, Energy IN TIME prototypes have been demonstrated in different operational environment (4 buildings), obtaining always positive values.

In order to have a more representative period, a projection study has been done extending the results to yearly period and for the entire demo buildings. The results obtained after such extension study have been:

- **ICPE** → Annual savings for DH consumption (OPG): 16% → ~ 5000 €/year
- **SANOMATALO** → Annual savings for DH consumption (OPG + MODC): 30% → ~ 40000 €/year
- **LEVI** → Annual savings for DH consumption (OPG): 3%* → ~ 3500 €/year
- **FARO** → Annual savings for HVAC systems (OPG): 13% → ~ 36000 €/year

The differences among the different buildings are explained taking into account each scenario. Icpe and Sanomatalo used the OPG for optimizing the distribution/terminal units operation (obtaining savings of around 15%), while Sanomatalo works in both the generation and the distribution systems, achieving around 30% of savings. The particular case of Levi Hotel studied only one minor part of the building (the common areas) since it has been concluded that the rooms zone is not able to be optimized by an external energy manager due to the interaction of the clients. Therefore the savings achieved for the common areas represents a small value in comparison with the whole energy consumption of this building (3%).

Environmental aspects

For the environmental analysis, CO_2 savings have been evaluated after the implementation of the energy efficiency measures in the project. The equation used has been the following:

Energy saving potential (MWh) * CO_2-factor ($kgCO_2$/MWh) = CO_2 savings ($kgCO_2$)

Next table summarizes the results in each demo building:

Building	CO2-factor (kgCO2/MWh)	CO2 savings in the demonstration phase (kgCO2)	CO2 savings per day (kgCO2 average)
ICPE Office	496 (DH*)	17.7	1.9
SANOMATALO Office	217 (DH*)	362.4	8.2
LEVI Hotel	217 (DH*)	Rooms: 274 7th Floor: 90.5	Rooms: 10.9 7th Floor: 3.6
FARO Airport	369 (Elect)	1147.02	60.4
TOTAL DURING THE PROJECT	**-**	**1891.6**	**85.1**

Table 14. Environmental savings.

*DH = District Heating

Thus, during the demonstration period within the Energy IN TIME project we have saved 1.89 Tons CO_2.

Fault Adaptive control (FAC)

Fault Adaptive Control (FAC) brings further the robustness of the control strategy, by using diagnostics information and implementing control adjustments that will minimize the impact of faults on the KPIs (i.e. comfort and energy usage).

The FAC module acts as a proxy between the Control & Monitoring Block and the Maintenance Block and coordinates with the MODC to reconfigure the control policy when faults implying noticeable performance degradation appear, in a similar way as it is done in the presence of significant deviations.

FAC was demonstrated following the Model-In-the-Loop (MiL) approach, which allows validating equipment level faults and evaluating the impact of the FAC strategies by using complex models of the thermodynamics of the equipment. In particular, the valve stuck fault is proposed as typical example of faults at FCU level and it is validated in MiL simulation. Figure 39 shows the results of simulating a stuck valve fault on a typical cold day, where the outside ambient temperature changes from 0C to a peak of 4C at midday. The fan speed in the FCU is considered fixed at constant speed (here 50%) in the nominal operation: this control action allows enough recirculation of the air inside the room. At time 9:45 a fault occurs and the valve is stuck. As regards comfort one can note that the fault leads the hot air recirculate into the room hence causing persistent overheating. Therefore, without adaptation, comfort can be never met. Clearly to reject the fault an adaptation is required: the only possible adaptation is at the fan speed. Indeed due to the fault the fixed value of the fan speed is no longer valid and hence it should be adapted. In Figure 39 we can note that by adapting the fan speed the overheating in the zone is avoided and comfort can be met.

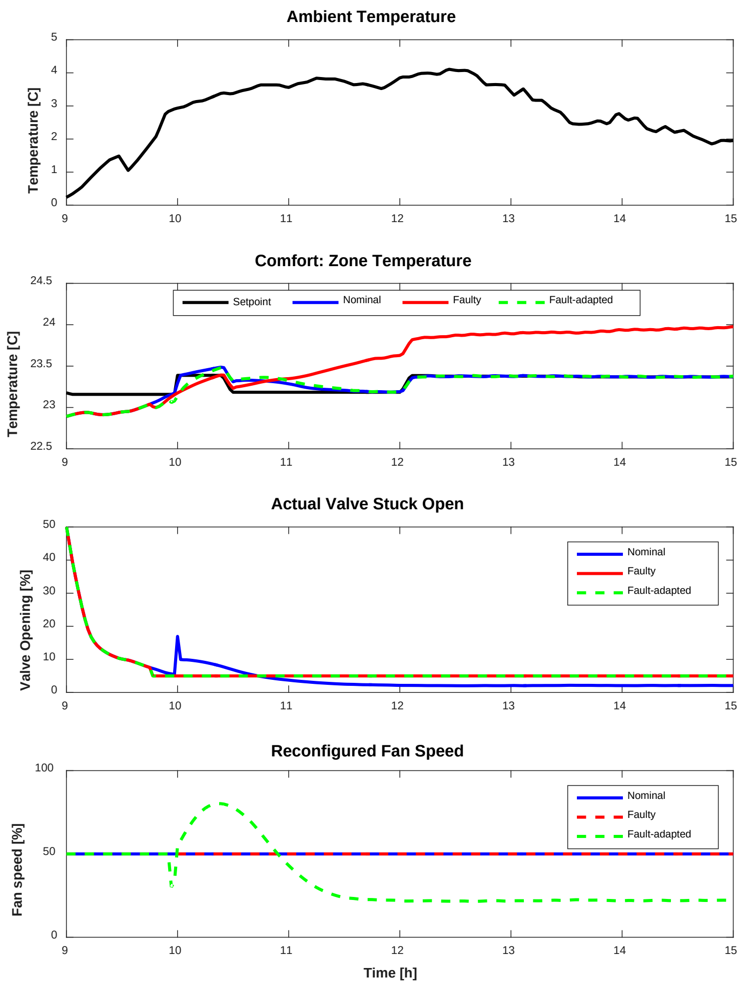


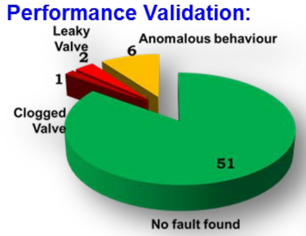
Figure 40. MiL simulation of the stuck valve fault.

Fault Detection and Diagnosis

Poorly maintained, degraded and inefficiently controlled equipment waste an estimated 15-30% of the energy consumed in a commercial building. Consequently reducing the amount of energy wasted by building Heating, Ventilation and Air Conditioning (HVAC) systems can achieve much of the aforementioned energy saving objectives. Furthermore, the FDD would facilitate a significant value addition to the end-user in terms of efficient energy management and optimal equipment maintenance. Finally, the FDD module can provide information regarding existing faults to fault adaptive control modules to prevent further degradation of equipment and KPIs.

The developed technologies mainly comprise of two paradigms: (a) Real Time FDD for continuous monitoring and (b) On demand Building Health Analysis and HVAC Commissioning for one-time diagnostics. A hybrid data and Physics based modelling approach was developed for the Real Time FDD, whose scope was detection of issues in Fan Coil Units (FCUs). In addition to the real time monitoring technology of the building HVAC system, a customized on-demand building health analysis framework was developed for FCUs which can be used: (a) during the commissioning of an HVAC system or (b) for building health analysis on demand without installing the aforementioned full-scale real-time FDD system.

The developed FDD methodologies were demonstrated in the Montluel. A detailed analysis of the detected faults using this real-time monitoring methodology was performed with 60 FCUs (due to availability of data not all FCUs were used), the detailed results are shown below in Figure 40. The results were physically verified for assessment of performance.



Fault (NTC key)	Physical Verification of Diagnostics
Leaky valve (NTC 53, 54)	Leaky valve confirmed.
Clogged valve (NTC 45)	Sensor had been displaced while modifications on the unit were tested.
Anomalous behaviour (NTC 43, 46, 48, 50, 55)	These units are incorporated with faulty / incorrect valve bodies.

Figure 41. Detected Faults and Corresponding Physical Verification.

On demand building health analysis demonstration results are shown in Figure 41. Note that the "on demand building health analysis" method could detect all the faults which were detected by the real time diagnostics method, which further validates the performances of the methods.

NTC	Condition	Possible Cause
33	Fault	40% less cooling
43	Fault	Leaky Valve
45	Fault	(Valve opens to 100% with 10% command)
46	Fault	(Valve opens to 100% with 10% command)
48	Fault	(Valve opens to 100% with 10% command)
50	Fault	(Valve opens to 100% with 10% command)
53	Fault	(Valve opens to 100% with 10% command)
54	Fault	Leaky Valve
55	Fault	(Valve opens to 100% with 10% command)
59	Fault	40% less cooling
76	Fault	40% less cooling

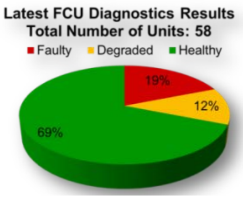


Figure 42. On Demand Building Health Analysis Results. The NTC in the table denotes the number of the FCU.

<u>Maintenance Techniques and Continuous Commissioning</u>

<u>Predictive maintenance</u>

Predictive Maintenance (PM) module implementation is demonstrated in Levi site according to the availability of degradation and failure data. The Predictive Maintenance module monitors the physical condition of the equipment in order to carry out the appropriate maintenance works to maximize the life cycle of HVAC system without increasing the risk of failure, guaranteeing comfort and reduce energy consumption. Predictive Maintenance is working closely with Fault Detection Diagnostic, which provides measured indicators of degradation and the list of faulty and degraded components by detecting slow or abrupt jumps in these indicators. Predictive maintenance provides a schedule of future maintenance activities, and gives information to the Decision Support Tool.

PM consists in 2 processes: prognostic and maintenance decision making (see Figure 39)

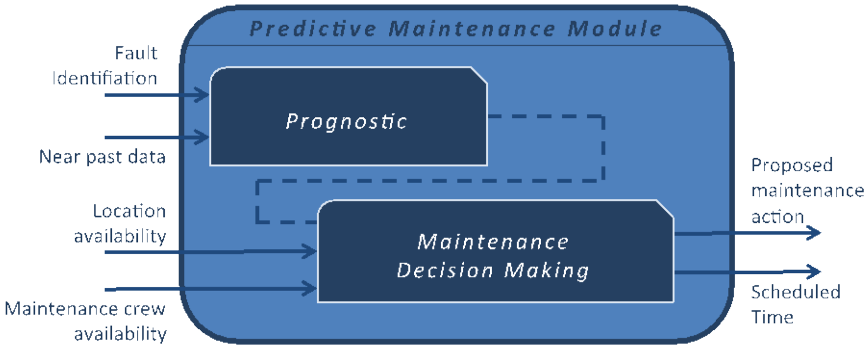


Figure 43: MO11 Architecture

The prognostic process embeds a degradation model of the equipment. This degradation model is mainly constructed based on historical data. When using it, it is updated depending on stress, age and degradation current measure. Degradation model is projected over future in order to predict remaining useful life of the item in consideration.

Maintenance decision consists in planning maintenance actions at the right time in a dynamic way, i.e. which can be adapted according to new maintenance date opportunity. This module provides an optimal maintenance date to maintenance manager. Optimality refers to reliability if the equipment, in relation to the prognostic, availability of the maintenance crew and HVAC system and maintenance action duration.

The methods proposed and validated to detect valve faults (valve blocked at different opening) could be also used to detect leakages in the valve. Actually the proposed approach relies on the estimation of the valve opening, using redundant information. The fault is detected when there is a deviation between the valve opening command and the valve opening estimation. A valve leakage will also induce a discrepancy between the valve model and the actual measurements, therefore making it possible to be detected.

Continuous commissioning

Basic idea of the continuous commissioning is to have continuous monitoring for some building equipment or HVAC system and detect indicators for high energy use, unexplainable increase in energy consumption, constant failure of building equipment or system and continuous occupant complaints about indoor temperature, air flow and indoor air quality. With the continuous commissioning, the target is to see errors in advance and find the reason why systems are not working as designed. With continuous commissioning it is expected to have savings for energy consumption and maintenance actions and also increase the quality of the indoor air.

In the Energy IN TIME project the Continuous commissioning was implemented on Sanomatalo's AHU331 which serves the meeting rooms in the 9th floor. In Sanomatalo there has been problems with the VAV-dampers; they often are stuck in one position and that is noticed only when there comes complaints or the energy consumption has been increasing. On the building management side the complaints are usually signs from the unhappy tenants, and they try to avoid them as much as possible. Rise of the energy consumption is often detected late, which depends on the activity of the building maintenance crew. There might even be situations that the consumption has been raising and that has not been detected. In the building like Sanomatalo, one stuck VAV unit cannot be seen from the energy readings. That's why there has to be developed new ways to monitor the functionality of the HVAC systems.

Idea for the continuous commissioning in Sanomatalo’s AHU 331 is to detect malfunctions of the VAV operation. Usually in VAV-systems, there are two typical faults that occur; mechanical jamming of the VAV-damper and a measurement error in the pressure difference sensor in the VAV-damper.

After the implementation, the BAS can monitor air flows in the VAV-dampers and compare them to the designed air flows, and detect malfunctioning dampers. Also the total measured air flow in the space can be compared to the indicated air flow of the air handling unit. This will indicate if there are faults with the air flow measurements.

Sanomatalo’s BAS now has an alarm system, so any faults detected in the VAV-system will be notified to the maintenance staff. In addition, the system runs a testing procedure once a week to ensure all dampers work as intended and have no mechanical problems. As a result of applying the continuous commissioning methodology, indoor climate in the targeted area is more controlled and unnecessary use of energy is minimized.

Since operating, the system has been alarmed total 11 times. Most of these (10 alarms) are from the supply sides upper limit. That means that during the time alarm occurred, there was going too much air than designed in to the spaces. Those would indicate that the damper had some jamming or slowness when the damper should be closing. One alarm was from the exhaust side’s lower limit alarm, which means that there was not enough air take off from the spaces.

The alarm log does not show when was the alarms happened, only when was the latest alarm and how many alarms in certain data point. But interviewing Sanomatalo’s maintenance personnel, none of these alarms was recurring alarms. That would mean that every time there was an alarm, the system has “repaired” itself by doing the weekly testing program. Also the comments from the maintenance people were that these VAV units did not cause any maintenance at all. Without the continuous commissioning alarm system, and more precisely without the weekly testing procedure, all of those alarms could have caused extra maintenance. Compared to the others VAV units, this AHU’s VAV units were practically maintenance free during this time period. History shows that in Sanomatalo the VAV units are key part of the maintenance costs.

Main advantages and probably the key function was the weekly testing procedure which ensures the VAV unit’s full operating range at least once a week. Normally it is possible that the VAV unit is in the same position quite a long time which causes jamming in the long run. With the testing, VAV unit goes in each it’s possible position every week. Also important advantage of this system is that the system will inform from the possible failure, not the user in the spaces. In that way the user satisfaction stays high. Same thing relates also to the energy efficient use of the VAV units and the pressure ratio of the AHU.

Decision support tool for building design and retrofitting

The prototype of decision support tool has been developed to help facility managers in designing and assessing mid-long term building energy renovation scenario for the Faro airport pilot site. The methodology used in the tool includes: a) a dynamic energy simulation model (COMETh), b) a Life-Cycle Analysis method which reads Energy Product Declaration of construction products, and c) a Life-Cycle Costing algorithm, and d) a module dedicated to scenario ranking. These 4 models and methods exploit inputs extracted from a BIM file (quantities and metrics). This decision support tool has been tested to the terminal building of the FARO airport.

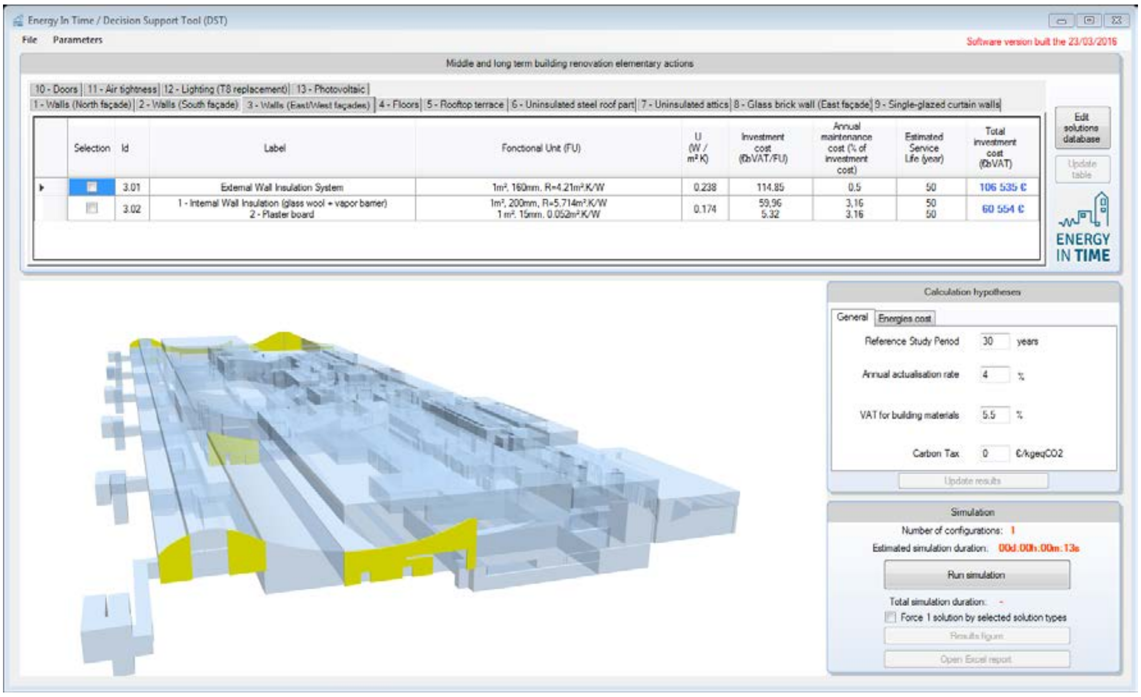


Figure 44: DST User Interface

<u>Centralised Remote Control</u>

The Centralised Remote Control (CRC) tool has been conceived and implemented as a remote tool in the form of a web application with the purpose of providing the building manager or any other stakeholder with the ability to monitor and manage the Energy IN TIME system from different places and not on-site. This allows not only for a remote management but for the possibility to manage many different facilities from a unique location, what goes in favor of scalability, for example from the point of view of an energy service provider as stakeholder for Energy IN TIME solution. This feature makes possible to deal with a large number of buildings at the same time and operate the solution implemented in them with a common management.

The web application implemented for the CRC provides a common interface to all the modules. A user-friendly interface makes easier the interaction with the modules because it avoids the complexity of using many different interfaces implemented by different designers and with different technologies. The CRC unifies appearance through a unique accessible technology.

The interface provided by the web application is mainly devoted to monitoring activities. Main activity is not only to monitor the equipment or facilities in general, what is a task typically implemented by local utilities and SCADA software associated to the BMS of the building. CRC is focused on Energy IN TIME features gathered around a central tool with unified format for interfaces. Energy equipment performance and related KPIs are an important part here but also other Energy IN TIME internal tools and modules outputs are monitored.

Energy IN TIME solution has been designed from a modular approach where the different tools or components (organised in modules) complement each other and collaborate with the purpose of achieving a common objective directed towards the energy efficiency, an improved performance and cost effectiveness. All these modules are present in the CRC web tool through their implementation for the different 4 demonstration buildings (not all technologies are present in all buildings) and the pilot scale laboratory that were selected for the project.

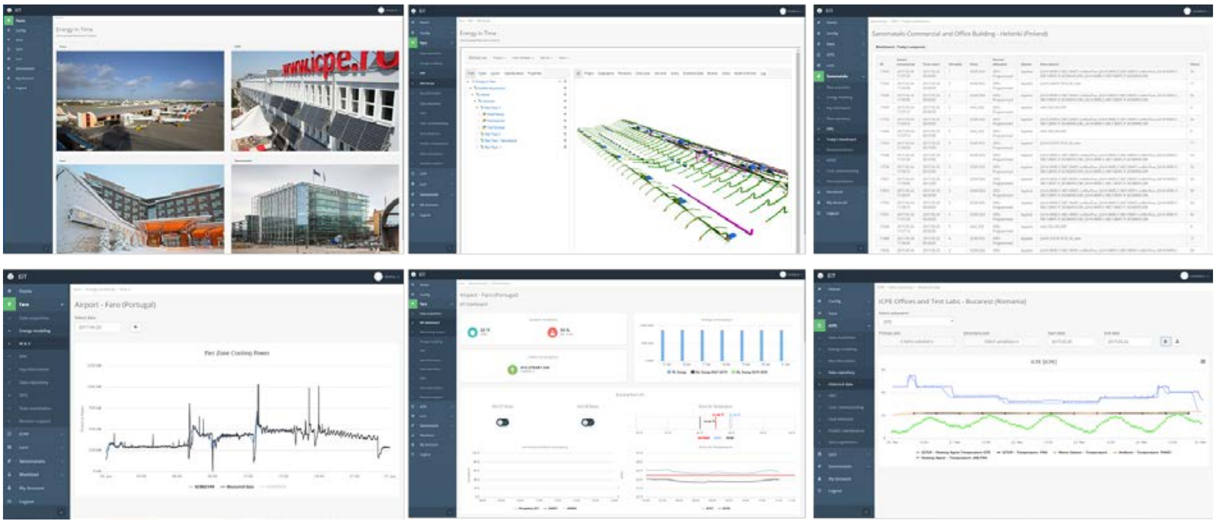


Figure 45: CRC web tool

Two possible approaches for the application of the supervisory control in the buildings arise from Energy INTIME. High level operation of the control set points can be deployed automatically or under the supervision of the building managers. In the scope of the Centralised Remote Control these approaches have been implemented as a non-graphical automated application that will be used only for fully automatic control and a graphical interface for the visualisation of the operation plans that allows for supervision and tracking for manual implementation of the control actions.

The Set-point Provider Tool, based on the same connectivity and interactive features used by the web tool, complements its functionalities with remote abilities for control set-points managing in time and other advanced monitoring features.

Building owner conclusions:

Energy IN TIME modules demonstration revealed expected benefits like energy savings but also provided new ways to monitor HVAC functioning from the point of view of energy performance. The demonstration of the control tools showed real results and also increased awareness of the building users. The maintenance block generated useful information how to detect possible faults in the systems and the development continues after the project.

Each demo site responsible answered questions after the Energy IN TIME project. Questions concerned about the Energy IN TIME tool and how it affected on building behavior.

Faro Airport

Faro Airport has several different systems that monitor and control all the electrical, mechanical and electromechanical equipment.

Having a Centralized Remote Control tool that can interact with all these systems, analyze all the outputs produced and, without human interference, implement all the necessary changes to improve the air quality conditions and, at the same time, increase energy savings is a great advantage to any company that deals with lots of different systems and variables.

Implementing the CRC tool was a time savior measure for Faro Airport, because the 24/7 technicians now have the time to execute other tasks without having to worry about the monitoring of all the systems that act over the HVAC system. The Energy IN TIME solution also managed to increase the comfort level for arriving and departing passengers and simultaneously being able to reduce the HVAC energy consumption.

Energy IN TIME project is an added value feature for Faro Airport maintenance team, as they now spend less time monitoring and acting over the equipment, which improved their efficiency in other tasks.

However, Energy IN TIME installation was not easy, as Faro Airport terminal is a very complex building and, mainly, because in October of 2015 a contract started to extend and refurbish nearly all the terminal. As Energy IN TIME started 2 years before with the objective of being implemented in all the building, Faro Airport had to reduce the scope area of the project to an area that would not be changed by the refurbishment works. This was only an area reduction and not a design feature reduction.

The implemented solution provided some improvements in the HVAC operation, as a 6% thermal savings and a 3% electrical savings were measured, without manpower.

Faro Airport team is very interested in keeping and improving this solution in their building and they will certainly try to expand it to the rest of the building and add some more features – the lighting, for example.

ICPE

With the implementation of the Operational Plan Generator module in ICPE demo BEMS, the heating system is automatically controlled via remote Energy IN TIME server based on the optimal generated plan and forecast for the next day. This provides the ICPE team with an additional level of intelligent control over the BEMS based on real monitored data in the building. Since the system was implemented the comfort level increased for all occupants of the building and energy savings were achieved during the testing period.

The Energy IN TIME solution further improved and simplified the heating control for the ICPE Office Building compared with the situation without Energy IN TIME. Without Energy IN TIME the control was done in a semi-automatic way based on the energy manager of the building, thus meaning that the system was not very efficient. Now with the implementation of Energy IN TIME solution – the OPG module – the control is done an automatic close loop that has different feedback from the building to adapt and react to changes during the day.

The implementation of the Energy IN TIME solution was a bit problematic for ICPE demo, because the building was old and needed more upgrades in order to fully comply with the project scope. This is why further implementation into other non-building will be done more easily into new buildings then old ones, but it is possible for old buildings also.

The feedback received during the 2nd user comfort questionnaires phase was positive and based on the results the majority of the building users sad that the comfort has improved in the ICPE Office Building and in the pilot areas.

For our experience in ICPE demo the Energy IN TIME solution implemented provided a series of improvements in the heating system operation with can be translated into greater comfort for all building users and improved energy efficiency.

ICPE is very interested in keeping this solution in our building and maybe try to expand it in to other building owned by ICPE.

Sanomatalo and Levi

All of the modules that has been demonstrated (continuous commissioning, predictive maintenance, model on demand control, optimal operation plan generator) has given valuable information of the new possible ways to improve HVAC operation. There has been clear energy savings for demo buildings and new ways to perform maintenance actions and detect maintenance need. All of the modules have given new business model opportunities for Caverion.

Main advantages per module:

Model on demand control:

- More precise control than existing one
- Larger possibilities to have certain target temperatures in certain times
- Energy savings, also improved indoor quality

Optimal operation plan generation:

- More precise control than existing one
- Possibility to have new set points for the air flows based on the simulations (compared to existing one: two set points; on and off use)
- Energy savings, also improved indoor quality

Predictive maintenance:

- New way to detect faults in the HVAC systems by using BAS data. No need to program the actual BAS.
- Potential to have automatic alarm system for e.g. filter leaking = energy savings
- Possibility to organize maintenance actions based on the values in the BAS

Continuous commissioning:

- Continuous monitor for VAVs
- Alarm function to know possible faults
- No necessary maintenance actions and decreased number of user complaints

In Levi OPG was created for using manual control. The existing heating curve is automatic. So in that case, the Energy IN TIME tool was more work full than the existing control. To get the most optimal set points, manual work must to be done. The Predictive maintenance was more helpful and in the future would give more data to realize potential faults in the HVAC systems. The maintenance actions would be known in advance and unnecessary actions would be avoided.

In Sanomatalo the control tools (MODC and OPG) worked automatically, like the existing system. So there was no increased work. Meanwhile it gives energy savings which will help on the energy management. Continuous commissioning gives main advantage because of the automatic monitor. Before there had to be done physical checks and now it can be done automatically by the Continuous commissioning. This improves maintenance efficiency by decreasing the unnecessary faults.

EiT gives added value for the buildings. Especially in Sanomatalo the control is now more precise and the continuous commissioning gives valuable information from the VAV units' function. Also in Levi the Predictive maintenance has shown potential to improve the current maintenance actions. As demonstration results have shown, there has been detected clear energy savings.

In Sanomatalo main barrier was the connection of the old BMS to the Energy IN TIME data transfer. Main problem trough out the project was the jamming of the BMS which created some difficulties. But it did not sabotage these results.

In Levi the non-automatic control already increased the potential to see energy savings. Also in Levi the geographical location was slightly challenging, which slowed down some development process.

Main added value for demo buildings have been the demonstration results and for Caverion the new business models. Also important part is that these new features can be done by just collecting the data from BAS and processing it somewhere else.

Sanomatalo has shown clear interest for the demonstrated modules. Especially the Continuous commissioning has interest them, and after showing the demonstrated results, also the control tools and their energy savings have started promising talks. So the interest for Energy IN TIME tools has been very high.

On the other hand in Levi the OPG and manual control was not very interesting for the building owners. But this will not exclude the possibility to have automatic control tools which would raise interest. Predictive maintenance is on development phase but the results have been promising. Especially for the site where the location is difficult, predictive maintenance practice for at least some of the HVAC components have been interesting idea. Idea to decrease sudden maintenance cost has been interested Levi.

Also there has been done some works that has not been shown in the results. In Levi there was created a new way to control floor level dampers. Unfortunately this was not able to demonstrate because it needed actions from Levi hotel personnel. First idea was to connect that to hotel reservation system and control dampers automatically. In Sanomatalo there was built an AHU air flow decreasing program which starts when the outside air temperature drops down. Both of these functions can be process to be part of continuous commissioning by constantly following needed values and control the systems based on them.

The potential impact

Energy IN TIME presents an innovative solution for building control and management. Taking full advantage of Simulation as well as Model Based Control techniques, the project aims at developing an integrated approach to building operation, maintenance and management. Non-residential buildings have 40% more average specific energy consumption (280kWh/m^2) than the equivalent value for residential, moreover the Energy Management System in non-residential buildings renovation is more important due to their high share of electricity use[4]

EiT uses calibrated simulation models coupled with data mining techniques to draw accurate predictions of how the building will perform or should be performing, **significantly narrowing the gap between the actual and the predicted assumptions**. This information is essential to design optimal operational plans and control strategies for the target buildings, taking into account their actual situation, reducing buildings' system inefficiencies and improving building's overall performance.

Additionally, the number of simulations needed to meet the optimal system efficiency will decrease as they will be run on the actual representation of the building (calibrated simulation model), thus, reducing the uncertainties and **consequently, the assessment time**. Moreover, additional benefits are expected from up-to-date building simulation models and the continuous analysis, by means of data mining techniques, of the information collected for pattern extraction. The combination of both techniques **reduces the assessment time** needed and will support a more effective decision making when accomplishing a building retrofitting or renovation process, as most of the information needed for the project design (i.e. underperforming equipment, zones with heat losses) will be already in place when required.

Reduction of building operation energy costs

[4] Europe's building under microscope. October 2011. Building Performance Institute Europe (BPIE)

Reduction of building operation energy costs

Buildings energy consumption represented more than 40% of final energy consumption at EU level in 2010 (27% for residential buildings and 14% for non-residential buildings).[5]Non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector. Commercial buildings comprise the largest portion of the non-residential stock while office buildings are the second biggest category[6]. It is estimated that the average specific energy consumption in the non-residential sector is 280kWh/m2 (covering all end-uses).

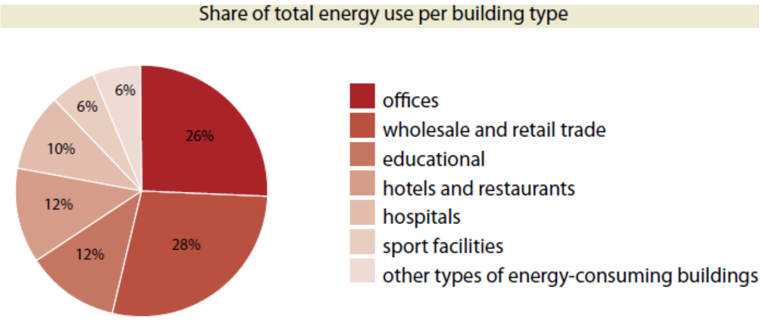


Figure 46: Share of total energy use per building type

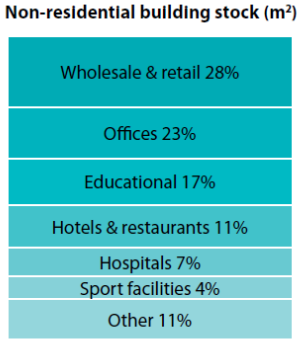


Figure 47: Non-residential building Stock

Energy can make up to 19 percent of total expenditures for the typical office building, representing the single largest controllable operating expense for office buildings, typically a third of variable expenses[7].Climate control alone accounts for up to 41% of an office building's total electrical energy consumption almost doubling that of any other building system[8]. For other large energy consumers such as hotels, energy consumption accounts for between 3% and 6% of the total operating costs [9]and represent one of few items that can be decreased and therefore contribute to the hotels higher profit[10]. In the Commercial sector, for instance, while in small commercial buildings, energy consumption can be about 180 kWh/m^2, in large commercial buildings the energy consumption can reach values of 333 kWh/m^2[11].

Recent experiences on building simulation-based-control including predictive strategies have demonstrated energy savings up to 20% compared to the conventional control strategies. Considering the case of a large office building with 6000 m^2, and an energy consumption of 300 kWh/m^2 year, the adoption of Energy IN TIME solution could lead to cost savings for the building operator of more than 35,000 € yearly[12].only due to energy consumption optimization.

Reduction of maintenance costs and needs

Poorly maintained, degraded and improperly controlled equipment wastes an estimated 15% to 30% of energy in commercial buildings[13].Effective maintenance can reduce HVAC energy costs by 5 to 40 per cent

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[5]Energy performance assesment of existing dwellings". Energy and Buildings (2007). Poel B., van Cruchten G., Balaras C. A..
[6] "Europe's buildings under the microscope" Buildings Performance Institute Europe (BPIE), October 2011
[7] "Building Owners and Managers Association (BOMA) International", http://www.boma.org/AboutBOMA/
[8] BOMA International, "BOMA-Kingsley Quarterly", Spring, 2006
[9] Energy Management in Hospitality: a Study of the Thessaloniki Hotels by Soultana Tania Kapiki, 2010
[10] "Possibilities for High Temperature Cooling in Tourism Accommodation Facilities" VlastaZanki, Ivan Galaso, University ofZagreb, Croatia
[11] Energetic audits guideline", Community of Madrid, 2010, www.madrid.org
[12] Considering: electricity price = 0'16 €/KWh (Spain) and gas price= 0,048 €/kWh
[13]Katipamula and Brambley (2005)

depending on the system or equipment involved[14]. Unless an adequate maintenance of HVAC components are not continuously perform energy performance degradation will occur. Regular scheduled maintenance of heating, ventilation and air conditioning (HVAC) systems can increase their efficiency.

Main dissemination activities

To raise awareness on the innovative solutions developed within the Energy IN TIME project and facilitate their introduction onto the market, project partners have participated in a wide number of dissemination activities. Early on in the project, graphical material has been produced for the Energy IN TIME project to ensure consistency and efficiency in communication activities. As part of this material, a visual and written identity has been developed for the project together with key messages on technology, energy and economic impact. In addition, a project leaflet has been created and updated to include the main project achievements. A poster, in three versions, and roll-up banners of different sizes have also been produced and used to promote the project at events, fairs and conferences.

This graphical material has been presented in a detailed Awareness and Dissemination Plan aiming to define the key messages, target audiences and main dissemination channels for the project. The Awareness and Dissemination Plan was used as guideline for all communication activities related to the Energy IN TIME project and has been updated according to the specified timelines at the beginning of the project itself. Each of the subsequent versions summarised the dissemination activities already carried out by project partners and presented an updated list of stakeholders that should be targeted within the project and the concrete plans and dissemination opportunities of the year ahead.

The first list of target audiences established at proposal stage has thus been enriched by partners throughout the whole project. The stakeholders mentioned in the following list have been identified as target audiences. This list gives examples of the specific stakeholders that have been targeted with dissemination activities, but it is nevertheless not exhaustive as project partners have been in contact with a wide range of audiences that was addressed through different communication channels, defined at the beginning of the project. The dissemination channels were selected to reach out to a wide variety of audiences and comprised:

- *A dedicated website presenting the objectives, partners and the activities of the project.*

The website has been online at the early stage of the project and has been updated with 79 posts qualified as useful contents on activities and developments within the project and related information. Besides that, the website contains frequently updated bands with direct links to the extend information about different activities undertaken within the project. Periodically generated newsletters generated under the project were also uploaded to the website to make them available for any visitor to the web of Energy IN TIME.

Automatic input from Social Networks as well as multimedia contents (a gallery with plenty of photos and 24 videos) were also added to provide a complete professional and dynamic aspect and utility to the website.

- *Social Media presence.*

The Energy IN TIME project had a social media presence throughout the entire duration of the project. Facebook, Twitter, LinkedIn and Google+ have been selected as main social media channels to communicate about the innovative solutions of the project. To disseminate the information about the project a great number of posts was created on all the social networks. The latest statistics are the following:

[14]Maximizing Chiller Efficiency.Maintenance Technology Magazine. www.efftec.com/resources/maximizing-chiller-efficiency.php

Facebook - 135 posts since creating the site, 194 followers;

Twitter - 248 posts since creating the site, 145 followers;

LinkedIn - 65 posts since creating the site, 62 followers;

Google+ 125 posts since creating the site.

Additionally, a Youtube channel was created to host all the **audiovisual material** to strengthen the awareness of the project. It included both videos and photos production. During the project there were different types of videos produced:

6 videos summarizing the periodical meetings among the consortium members (the final event included),

12 videos with full interviews with each consortium partner,

5 videos with Key Exploitation Results with insights of the various technological solutions developed under the project,

1 full video of the Energy IN TIME project.

- *Publications in scientific literature and dedicated journals and reviews.*

The target of publications in international academic journals to make the results available to the scientific community has been successfully achieved with 7 papers published in Elsevier, Atlantis Press, EC Joint Research Center and Electra Editura.

Articles were also submitted to conferences for presentation, including large, international industry conferences such as IFSA World Congress, Sustainable Places and International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities, among others.

In addition, partners have produced a number of non-scientific articles about the project, making 4 generic publications per partner.

- *Presentations and participation at congresses, workshops, symposia conferences, exhibition fairs.*

Throughout the project, partners have presented the Energy IN TIME project in over 20 international conferences or congresses such as Hanover Messe, Sustainable Places, SDEWES, AIEE Energy Symposium, just to name few. The project was also presented in more than 50 national events held in the countries of each partner.

At the end of the project, the Energy IN TIME was presented in the final public event held at the international airport of Faro, Portugal, which was one of the demo sites for the technological solutions. This enabled an effective presentation of the results of the project and face-to-face interaction with a wide conference audience from different industries, scientific community, policy makers and media. The Final Event was an ideal opportunity to explain the advantages and future potential of the Energy IN TIME project and discuss the possibilities for commercialisation or further development with a wide group of stakeholders.

In total, project partners took part in over 70 events to disseminate information about the Energy IN TIME project. Through these events, a wide range of audiences covering building industry representatives, researchers, entrepreneurs, students, investors and policy-makers were reached.

- *Project events*

To reach the dissemination objectives of Energy IN TIME, two workshops were organised with the aim to involve professional stakeholders to enhance their awareness about the project and the novel technologies which are being developed as a part of it, spread best practices, and foster networking opportunities.

The first workshop developed within the Sustainable Places Conference, entitled “How to save energy and costs” took place on 30 June 2016 in Anglet, France. The workshop brought together professional stakeholders from technological and construction sector mainly to discuss the current challenges related with management of non-residential buildings and present the results from the four demo sites deployed in different types of buildings located in different climatic zones of Europe. The event allowed for exchange of views on the proposed innovative technologies and facilitated networking opportunities and synergies with potential early adopters and users throughout Europe.

The second workshop of interactive format was organized within the European Research Conference on 1 March 2017 in Wels, Austria, under the title of "Energy costs savings solutions for building operation". The event presented results of the project advances in different software solutions designed and offered a networking reception for a broad audience: construction and energy sectors as well as regulators, researchers and policy-makers attended the event to learn about the technology developed and discuss how to bring the technological solutions closer to the market.

Additionally the Energy IN TIME Project took part in Sustainable Places 2017 by presenting a poster in its third version. Besides that, some of the project members attended the event to raise more awareness of the solutions developed for an efficient management of energy in non-residential buildings.

- *Networking activities*

Different types of networking activities were conducted, mainly focusing on establishing networks with existing networks or projects. Close collaborations were undertaken with 5 related R&D projects: Direction, BuildHeat, Tribute, EEBERS and Tribe. Besides that, links with other related platforms, such as EeB-CA2 online geoclustering platform, BUILDUP and EeB PPP, were established.

Exploitable results

Energy IN TIME has achieved **six different results** that should reach the market and the commercialization. These **six Technologies are integrated altogether** in the Energy IN TIME Platform and are presented below:

KER1	Virtual Auditing App (VAA)	A smart tool to gather data from the building on its systems, the equipment availability and condition, in a very easy and fast way.
KER2	Simulation Reference Model	Thermodynamic and energetic building simulation model that accurately reflects the building performance.
KER3	Predictive Maintenance Application	The innovative aspect of this application is the on-line character of system reconfiguration and/or maintenance scheduling.
KER4	Fault Diagnostics HVAC Systems	To improve the current state of service by making decision on replacement of parts. The interface will provide functionality to specify the manufacturers of components that have failed and furnish other details such as part numbers.
KER5	Medium and long-term building and equipment decision support system and data mining tool	A new tool for investment mid-term analysis. Improve trend analysis by data mining techniques implemented in a user-friendly tool.
KER6	Intelligent Operational Plan Generator	Generates operational strategies to be provided to the simulation engine.

Table 15 KERs overview

Six different Exploitation Plans of Energy IN TIME's KERs have been developed to allow the sustainability of the project beyond its life and are based on future exploitation, needed improvement for better market competitiveness and how to better exploit this project to create opportunities for the members of the consortium and the targeted markets.

KER 1: VIRTUAL AUDITING APP

The traditional process of gathering data from the buildings on its systems, the equipment availability and condition can be quite onerous, time-consuming and involve data being collected and tracked in a number of different documents or software tools. In addition to this, there is a typically large range of building components and parameters in commercial buildings, making it difficult to identify or prioritise the key parameter information to be audited. The VAA aims to overcome these issues through the development of a smart tool to gather data in a very easy and fast way. This is achieved through the design of a virtual app-based framework which minimises the effort and requirements in gathering data from buildings, and prioritises relevant information required, based on a per building basis to optimise the data collection process.

The principal unique and differentiating features of the VAA tool to the user are:

- Identification and prioritisation of energy parameters to be audited based on a number of building specific questions.
- Ability to pre-load building drawings (plans, elevations and schematics) to the VAA.
- To gather data from the building on its systems, the equipment availability and condition, in a very easy and fast way.
- Tagging of information to specific locations on the pre-loaded drawings with high level Drawing Tags as the user moves around the building.
- Ability to take pictures using the VAA which can be allocated as linked resources to the Drawing Tags.
- Resource Tags can be added for different Tag Types to record specific information on lighting, equipment, Heating Ventilation and Air Conditioning (HVAC) and renewables, as well as related schedules to create a linked hierarchy of information for a specific location.
- The VAA allows for full reportage of the data collected to be output in a clear and structured format.
- All information can be stored digitally in one place in a structured format.
- The same project/audit can be open in Desktop (for pre-loading Drawings and for detailed analysis) or Tablet (or portable collection of information while on-site).
- Information can be input/updated at any time (pre-audit, during audit, post audit).

Given the different building types involved in the project, and the potential building's that could utilise the Energy IN TIME system in future, the VAA framework was devised in such a way that it could be deployed for the majority of commercial building stock and that the resulting information can be used to develop an energetic model in any selected model simulation environment.

As an example of the novel functionality in the VAA, following figure (left) below shows how the user can answer high-level building questions in the app, and next figure (right) shows the updated estimated energy breakdown for the building with an associated priority list of data to be collected based on the user's answers. The energy breakdown is based on 1.000 seconds of pre-run simulations for a range of building types and locations, with the aim of ensuring that the user focuses on the areas that consume the most energy during the audit in order to minimise the amount of data that needs to be collected.

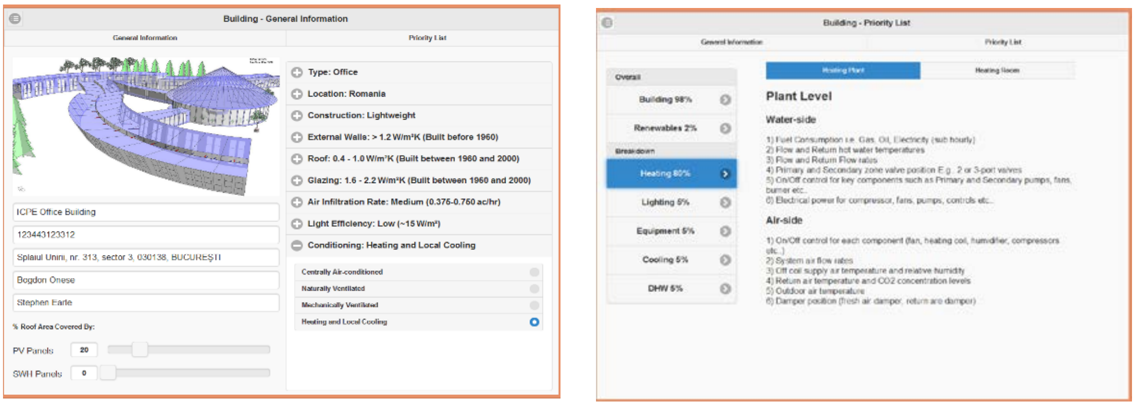

Figure 48 General Building Information (left) and Generated Priority List

In terms of the Energy IN TIME, the VAA (currently defined at TRL 7) is a key development in order to minimise the effort and requirements in gathering data from buildings with respect to relevant information on building components and systems required for developing energy models in a simulation environment. It was used in each of the Energy IN TIME demo buildings in the early stages of the model creation process to gather the key building audit information from the building, which was then updated in the building simulation models to ensure they further reflected the actual operational performance of a building (as opposed to models being based on the building *design* information only, which is often mismatched from the *actual* operation)[15]

Due to the complexity of the building and its operation, the VAA was used extensively in a three-day audit of the Faro building which greatly enhanced the speed, auditing capabilities and increased the amount of information that would have otherwise been collected on-site using traditional auditing approaches. This in-turn improved the accuracy of the SRMs, which are described in more detail in the next section.

KER2. SIMULATION REFERENCE MODEL

In optimising a buildings operational performance, determining the actual detailed performance breakdown, predicting performance and assessing the impact of any changes to a buildings operation is a complex undertaking. This difficulty is compounded even more so when attempting to continuously assess and optimise a building's performance due to dynamic nature of buildings, their use and the effect of user behaviour (which can be difficult to measure directly). The SRMs developed in the Energy IN TIME will contribute to overcome these issues through the incorporation of a thermodynamic and energetic building simulation model that accurately reflects all aspects of a building dynamic performance. The SRMs are developed in the IESVE software platform, which is a suite of building performance-modelling tools incorporated into a single integrated data model[16]. The SRMs are calibrated and verified to reflect buildings actual operation, and are updated with "live" Building Energy Management Systems (BEMSs) and building data to continuously adapt to the building as it evolves. The latter allows for accurate and dynamic forecasting incorporating actual and forecast weather data enabling advanced optimization and decision making to

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[15] Bell, H; Milagre, R; Sanchez, C, *Achieving the Green Dream: Predicted vs. Actual - Greenhouse Gas Performance in Green Star-certified office buildings in Green Building Council of Australia*, 2013

[16] *IESVE* [Accessed 15 Sep 2017]; Available from https://www.iesve.com/

improve the buildings operational performance. The software model is uploaded to the cloud, where it can be continuously updated with new data or accessed by 3rd party tools to simulate the model and download results. The SRM also allows accurate energy conversation measure and retrofit analysis. The key unique and differentiating factors of the developments include:

- Use of the IESVE which is a proven building simulation software product.
- Automated calibration process to create better calibrated models.
- Cloud based access through the IES SCAN platform to continually update and access the models
- More accurate building performance prediction using simulation models, which results in improved building control optimisation.

During the Energy IN TIME, four SRMs (currently at TRL 7) were developed for each of the demo sites which accurately reflected the actual buildings performance. The following Figure 3 shows an image of the SRM created for Sanomatalo's office building.

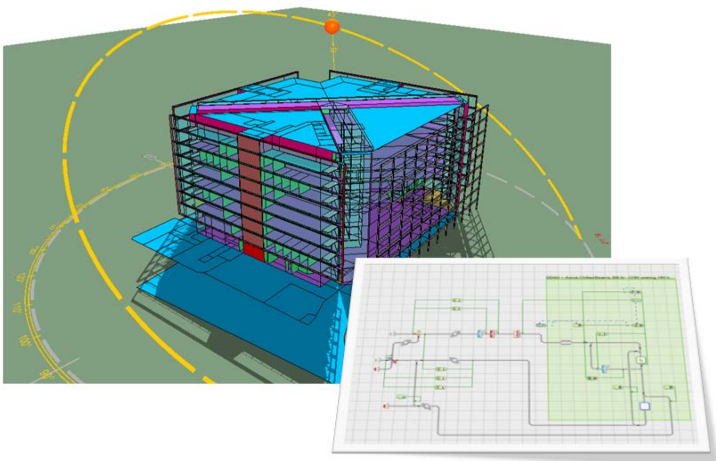

Figure 49 Sanomatalo's office building SRM

In order to create the final SRM for the project, each SRM was developed through the following stages:

1) Passive model which includes modelling all passive (or static) elements of the building such as building constructions, framework, façade, claddings, location, orientation, etc.
2) Active model which involves modelling all active (or dynamic) elements of the building such as its HVAC systems, occupancy, weather, infiltrations, etc. Information collected from site-audits carried out using the VAA (previous section) was also updated at this stage.
3) Operational model where steps were undertaken to automatically acquire operational data from the BEMS to further improve the accuracy of the models.
4) Model Calibration where a semi-automated procedure was developed to further fine-tune the final building model parameters to match the actual building performance to within ±5% accuracy (which was achieved for all four demo buildings).
5) Variant Model which enables other Energy IN TIME modules and tools (e.g. OPG and PMM) to connect to and use the SRMs for automated analysis and decision making.

The final SRMs were uploaded to the cloud and used by the OPG (discuss in further detail in a later section) to optimise the control plan of the buildings for the following day through the prediction of all aspects of the buildings performance (weather, occupancy, lighting, infiltration etc.) and test the impact of a range of scenarios under the Energy IN TIME system.

KER 3. PREDICTIVE MAINTENANCE APPLICATION

The maintenance costs represent a significant percentage of the expenses in most of facilities and in most of cases account for almost the same facility's operating budget as the energy expenses. Thus, they can be an important problem in the building management and is therefore worth optimizing. Usually, the maintenance budget is spent inefficiently with a reactive "wait till it breaks" approach (i.e. corrective maintenance, leading to system unavailability and unplanned resource management) or with a systematic maintenance (i.e. preventive maintenance) that leads to replace a facility even if its useful life remains. On the other hand, predictive maintenance promises beyond traditional approaches (corrective and preventive), to reduce downtime and maintenance costs as well as to enhance system performance efficiency, availability and sustainability. Furthermore, predictive maintenance is one of maintenance strategies that has been widely addressed in the literature by various authors since years 2000. It consists in three processes: Monitoring and diagnostic, Prognostic and Decision-making[17] In the Energy IN TIME, the first process was considered in the FDD and CC modules, while the other two has been considered during the development of the PM. The aim of Prognostic is to provide the remaining useful life of facilities while the Decision-making has to provide the scheduling proposition to the maintenance manager.

The PMM will be well fitted with building maintenance where a BEMS is available (in order to collect information from monitoring) and when the O&M crew is not always on site but performs inspection/maintenance tour (in order to maximize O&M personnel resources). In the Energy IN TIME the PMM was implemented to the Levi's Hotel demo site. Main aspect was to collect the actual HVAC data from the BEMS. Based on the data there was made analysis on how the components behave. Because the active life time and fouling of the HVAC components usually takes a long time, there were performed "simulated faults". With these simulations there were modelled the following faulty situations: fouled filter, leaking valve, false temperature readings.

Currently, results achieved are hard to present because a running of the module in the building for few years is needed. And even in that case, there is the possibility that system works perfectly. Nevertheless, by analysing the existing data from Levi's Hotel, there was made an observation that at least the filter replacement was made so frequently that there was not seen an increased pressure difference. This indicates that the replacement interval was too frequent in comparison with the optimal. On the other hand, concerning maintenance decision making, it was implemented to Levi's Hotel in accordance with the maintenance subcontractor which is in charge of two others buildings in the Levi's Hotel area. The decision algorithm was based on adapted for maintenance by Levrat[18],[19]. The main originality lies in the consideration of crew availability. It was noticed that predictive maintenance actions are integrated in systematic preventive maintenance actions and corrective maintenance actions, thanks to the concept of opportune decision which is a Decision Making approach that take profit of the corrective maintenance (needed as soon as possible for

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[17] Voisin, A., Levrat, E., Cocheteux, P., & Iung, B., *Generic prognosis model for proactive maintenance decision support: Application to pre-industrial e-maintenance test bed*. Journal of Intelligent Manufacturing, 2010. 21, p. 177–193
[18] Bruss, F.T., *Sum the odds to one and stop*, Annals of Probability, 2000. p. 1384–1391
[19] Levrat, E., E. Thomas and B. Iung., *'Odds'-based decision-making tool for opportunistic production–maintenance synchronisation*, International Journal of Production Research, 2018. p. 5263–5287

critical components) to plan a maintenance action for another component This approach can be considered well suitable in the context of building exploitation and concern critical components.

KER4. CONTINUOUS COMMISSIONING AND AUTOMATED FAULT DETECTION AND DIAGNOSTICS OF BUILDING HVAC SYSTEMS

The preventive or corrective strategies, as commented in the previous section, do not guarantee the optimal functioning and the cost effective maintenance of building facilities. In order to avoid facilities faults that will also worsen the indoor comfort conditions, is recommended to perform the building system maintenance, in particular those related to critical systems, using a predictive strategy. The latter was implemented during the Energy IN TIME adopting three approaches. Prognostic and Decision-making are part of the PMM (commented before) while the Monitoring and Diagnostic approach was implemented by CC and FDD modules that will be explained at following.

Continuous commissioning

The CC aims to have continuous monitoring for some building equipment or HVAC systems and to detect indicators for high energy use, unexplainable increase in energy consumption, constant failure of building equipment or systems and continuous occupant complaints about indoor temperature, air flow and indoor air quality. The target of CC is to see their errors in advance and find the reason why systems are not working as designed. With CC it is expected to have savings for energy consumption and maintenance actions and also increase the quality of the indoor air. CC was implemented in the Sanomatalo demo site where was followed the function of the Variable Air Volume (VAV) units. In this case, CC had three functions:

1) Comparing Air Handling Unit (AHU) air flows to the sum of the VAV air flows.
2) Comparing individual VAV air flow to the design air flow.
3) Weekly testing for whole range of motion for each VAVs.

The 1) was used to detect possible fault in the system. In case the difference was too much, it gave an alarm meaning that a fault was occurring in the AHU flow sensor or in some of the VAVs. With the 2), was possible to detect individual faults. The reason for these faults was usually in the jamming. Finally, the 3) drives the VAV plates in all of the positions once a week and was used to prevent the jamming. The CC operated two years and there was around ten alarms detected. None of these was recurring, indicating that the weekly testing program expelled the emerging faults. There were a lot of faults in Sanomatalo's VAV units in generally causing extra maintenance, even though some of the units were perfectly fine. By expanding the CC methodology to every VAV units, can be achieved a lot of savings both in energy and maintenance cost, and also in indoor comfort conditions.

Automated Fault Detection and Diagnostics of Building HVAC Systems

The building HVAC equipment, which is badly maintained, degraded and inefficiently controlled, can waste an estimated 15-30% of the energy consumed in a commercial building. In addition, a faulty HVAC system failing to maintain air quality and zone temperature to the prescribed level in a building can be critical for the occupants' health, cognitive abilities and productivity. For many common faults, HVAC energy efficiency decreases before there is a noticeable change in occupant comfort and the building operator does not perceive an issue with the HVAC system, since is applied a corrective and not a predictive maintenance strategy. A FDD can facilitate early detection of HVAC health issues in a building by preventing waste of energy while maintaining occupants' comfort level. A robust, efficient and scalable automated FDD technology was developed in a pilot building HVAC system with the following objectives: (a) Real-time (continuous) monitoring: relevant sensor data are continually fed into the models and the FDD generates alarms through a user-friendly graphical user interface, whenever a fault is detected. (b) On demand health analysis: a methodology to group equipment by failure modes to produce a report consisting of information, based on which corrective actions can be initiated.

Both methodologies were tested using the sensor data from a demonstration building containing 71 Fan Coil Units (FCUs) and 1 AHU. The on demand health analysis methodology was further validated using data from a test building containing 218 VAV units and 18 AHUs. The detected faults by both the methods were physically verified. Development of an optimal maintenance schedule and prioritization of the maintenance action depend on the criticality of the detected faults in terms of its impact. An analysis framework was developed to perform a detailed study of the impact of the commonly occurring faults in a building HVAC system. Injecting faults and analysing their impact in hardware set up is challenging mainly due to: safety issues, difficulty in the choice of magnitude of the faults, risk of permanent damage to the system etc. To mitigate these risks, a detailed simulation model was developed in the Dymola environment, for studying the impact of the faults in energy consumption of the system and the comfort level of the occupants.

The differentiating factor of the FDD is the fact that is envisioned to be an integrated part of the BEMS and will support and provide improved decision support in the context of building HVAC commissioning and maintenance.

KER5. MEDIUM AND LONG-TERM BUILDING AND EQUIPMENT DECISION SUPPORT SYSTEM AND DATA MINING TOOL

This component of the Energy IN TIME system relies on two different tools: a DSS that helps to decide which improvement package(s) to apply among a list of possible/available energy related actions/works. Complementary, the Data Mining Tool (DMT) implemented in the project does not need a priori knowledge about the options to implement. It is an explorative tool that discovers new insights about how the established energy system behaves by finding trends or anomalies. In the following, both tools are described in more detail.

Decision Support Systems

DSSs are software products that help users apply analytical and scientific methods to decision making. They work by using models and algorithms from disciplines such as decision analysis, mathematical programming and optimization, stochastic modelling, simulation, and logic modelling. DSS products can execute, interpret, visualize, and interactively analyse these models over multiple scenarios. In recent years, the growing popularity of online analytical processing, data warehousing, and supply chain management has led to an increased interest in the development of DSS. DSS tools could assist decision-makers in problems involving risk management, the allocation of scarce resources, and the need to balance conflicting objectives. When well implemented and used wisely, DSSs can significantly improve the quality of an organization’s decision making. Input of data process represents a real challenge today, as data are not easy to collect and represent a quite complex process. Reliability is also another question to be considered.

The DSS has been tested to the terminal building of the FARO airport pilot site. The prototype of DSS has been developed to help facility managers in designing and assessing mid-long term building energy renovation scenarios for the pilot site. The methodology used in the DSS includes: a) a dynamic energy simulation model (COMETh), b) a Life-Cycle Analysis method which reads Energy Product Declaration of construction products, c) a Life-Cycle Costing algorithm, and d) a module dedicated to scenarios ranking. These 4 models and methods exploit inputs extracted from a BIM file (quantities and metrics).

The DSS is developed in both C# and Python languages [26]. The first one targets facility managers with an easy-to-use Graphical User Interface (See Figure 5), the second targets R&D applications such as mono-objective optimization algorithms.

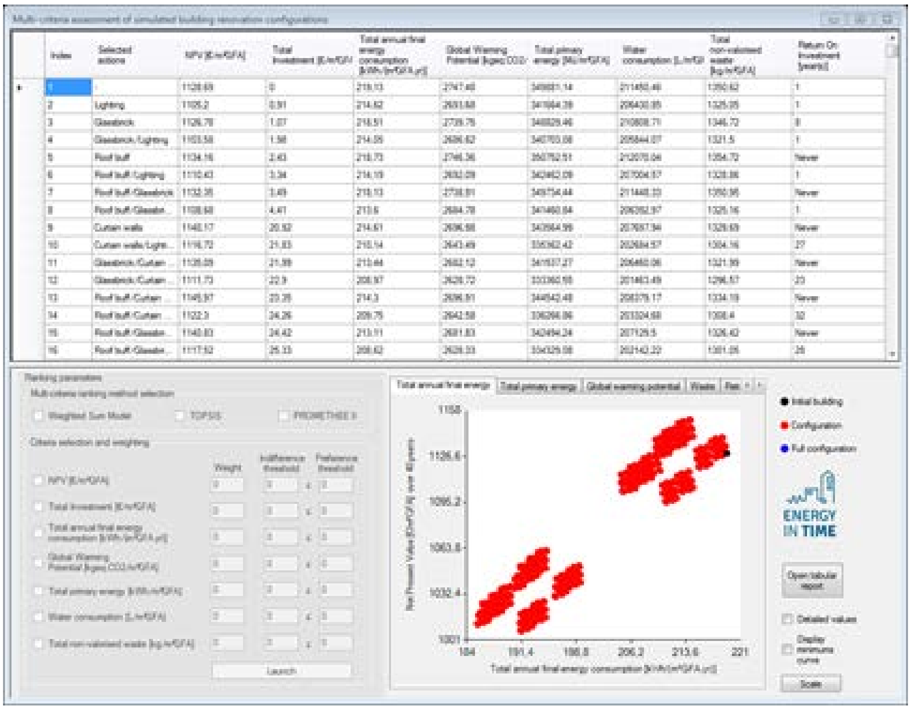

Figure 50. Graphical User Interface of the DSS tool

The DSS improve the current state of service by processing various input data to retrieve different options relevant to building retrofitting and aims to:

- Offer a new tool for investment mid-term analysis
- Introduce reliability instead of inaccuracy
- Perform extensive comparisons of renovation sub-sequences
- Gather experience and knowledge in appropriate databases
- Gather experience and knowledge in analysis/filtering techniques of energy-related big databases
- Introduce focus on lifetime, in addition with energy and cost
- Train people in asset management and energy performance

The level of development for this result (TRL) is 7 at the end of the project.

Data Mining Tool

Data mining aims to build systems and algorithms to discover knowledge, detect patterns, and generate useful insights and predictions from large-scale data[20],[21] It encompasses the whole data analysis process, which begins with data extraction and cleaning, and extends to data analysis, description, and summarization. The result is the new information gathered from data which may turn out in sets of classified data, behavioural trends or future predictions, which will be conveniently visualized. Thus, Data Mining involves mathematical

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[20] Tan, P.N., Steinbach, M., Kumar, V., *Introduction to Data Mining*, (First Edition). Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2005

[21] Wu, X., Kumar, V., Quinlan, J. R., Ghosh, J., Yang, Q., Motoda, H., McLachlan, G. J., Ng A., Liu B., Yu P. S., Zhou Z.-H., Steinbach M., Hand D.J., and Steinberg D., *Top 10 algorithms in data mining*, Knowledge and Information Systems, Vol. 14, 2008. p. 1-37

and statistical analysis, combined with information technology tools. However, deriving insights from data is not only achieved by using such techniques. The expert must also manage and interpret the data in order to obtain valuable knowledge. There are different aspects of Energy Efficiency and Management that Data Mining techniques can support and improve[22] :

- Predicting the energy demand required for the efficient operation of a building.
- Optimizing building operation.
- Verifying the operational status and failures of building equipment and networks.
- Analysing the economic and commercial impact of user energy consumption.
- Detecting and preventing energy fraud.

The DMT developed within Energy IN TIME includes different stages: it starts with the collection of streaming raw data which is stored in the information repository. After that, it is necessary to clean the data and to select the segment that might have interesting information for the analysis. For that purpose, the expert must apply filters to the data or formulate queries that will remove irrelevant information. Once data are prepared for use, an exploratory analysis (including visualization tools) can help to decide which methods or algorithms are the most effective to obtain the desired knowledge. Finally, the application of such tools will lead to a set of results that will guide decision-making.

The DMT has been developed in Python within a Big Data architecture framework that enables to process massive data, retrieved from multiple sensors during a time period[23] The final result consists on a set of trends and relations among the selected data that can be conveniently visualized using several graphical tools. The generated output produces valuable information that is important by itself and also can serve as input for the Decision Making process.

KER6. INTELLIGENT DAILY OPERATIONAL PLAN GENERATOR

Energy costs of daily operation are a problem that building managers face since are not easy to reduce. The OPG is an intelligent sub-system that automatically computes a plan including the actions (i.e. set points) that should be applied during the next day to optimize energy consumption while guaranteeing comfort in the building. To do so, the OPG evaluates the expected energy consumption of many possible equipment configurations by running simulations (thanks to the online connection with the SRM) that consider the forecasted state of the building (weather, occupancy, etc.), and selects the best of these configurations. The OPG system performs the following tasks:

1) Information collection: OPG retrieves weather forecasts, user occupancy, building status and other information about the expected building operation conditions from a specific-purpose database containing weather data, occupancy estimations, energy tariffs, etc.
2) Simulation execution: OPG runs simulations testing different operating actions on the simulation engine in order to reproduce the expected building behaviour (in terms of energy consumption and comfort). Accordingly, simulations use as input the building conditions (collected in the previous

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[22] Molina-Solana, M., Ros, M., Ruiz, M.D., Gómez-Romero, J., and Martin-Bautista, M.J. *Data Science for building energy management: A review.* Renewable and Sustainable Energy Reviews, 2017. p. 598–609
[23] Gómez-Romero, J., Ruiz, M.D., Fernández-Basso, C., Molina-Solana, M., Ros, M., and Martin-Bautista, M.J., *Advances in Data Science for Building Energy Management*. Proc. 9th International Conference Improving Energy Efficiency in Commercial Buildings and Smart Communities (IEECB&SC'16), 2016

step) and the operation actions (suggested by the OPG algorithm), and produce as output the values of energy consumption and temperature inside the buildings according to these conditions and actions.

3) Plan selection: OPG selects an appropriate plan (ideally, the optimal plan) from the large number of possible plans simulated in step 2) such that: (a) can be applied on the equipment; (b) are compliant to the comfort requirements; (c) minimize energy consumption.

4) Plan storage: The OPG stores the generated operational plan and the associated context (i.e., which external conditions led to the plan) to make it available for later justifications and data analysis procedures.

The process flow of OPG tool is represented at following in Figure 6.

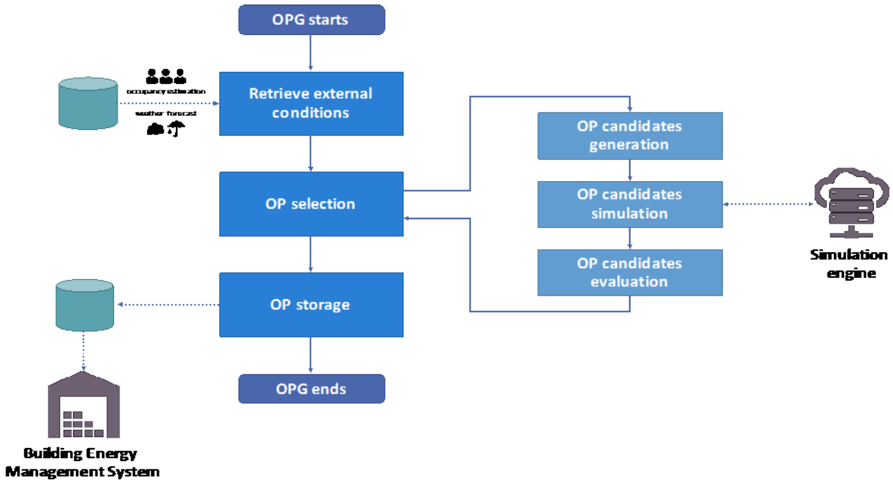

Figure 51: OPG process flow

The OPG tool provides unique features compared with typical planning solutions since it optimizes the operation for the whole day rather than performing minor real-time adaptation, which makes it possible to better address the inertial nature of HVAC systems. Furthermore, the use of Artificial Intelligence techniques and the capability to incorporate expert knowledge to the OPG allows reducing the time required to evaluate all the large amount possible equipment configurations. The OPG can be automatically applied to the BEMS by using a setpoint writing component, and/or presented to the building operator for further inspection and application. All data about successful plans, influencing conditions, etc. is stored in the system, and can be afterwards manually and automatically analysed. Besides, the OPG is agnostic of the underlying building equipment, and can be adapted to any scenario provided in a simulation model.

Demonstration in the project demo sites have shown significant energy savings, while keeping comfort (up to 15% in some cases). It is particularly effective in the mid-seasons, when it is not necessary to use the heating/cooling equipment at full and allows to automatically adjust the operation, adapting to daily weather forecasts, without the need of continuous supervision by the building operators. End of heating/cooling seasons can be anticipated, and at the same time, the software can react to particularly cold/warm days.

The level of development for the result (TRL) is 6 at the end of the project.

CONCLUSION

The Energy IN TIME system can be integrated with the BEMS of different type of non-residential buildings with multiple facilities and maintenance strategies for the reason that its modules can work separately from each other.

The implementation of the Energy IN TIME system in the four demo sites of the project has allowed energy savings between 2% and 26% that have been demonstrated thanks to the data collected from the monitoring systems installed in the pilots and in particular due to the adoption of the OPG tool. Furthermore, has been also demonstrated that important economic savings and improvements in indoor comfort conditions can be reached thanks to the optimization of the maintenance strategies and of the O&M personnel management as well as to the shortening of time required for a first building information analysis and collection.

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The address of the project public website and contact details

www.energyintime.eu

All project contacts, its logo, diagrams, reports and photographs on progress, as well as the official project video may found directly at the web page indicated above.

4.2 Use and dissemination of foreground

All the contents related to Section A and Section B may found at Participant Portal in sections related Dissemination and Exploitation, in division on:

A. Dissemination measures, including scientific relating to foreground
B. Exploitable foreground and plans for exploitation

In addition to part B1, No patents, trademarks or registered designs were applied for.

4.3 Report on societal implications

All contents related to the report on societal implications may be found at the Participant Portal in sections related to financial contribution

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

All the contents related to the report on the distribution of European Union financial contribution may be found at Participant Portal in sections related to financial contribution.