1. Session: Workshop on EEB KPIs

1.1. Key Performance Indicators (KPIs) for Continuous Commissioning

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Abstract

The use of ICT devices, building automatic control system and technical building management, with an appropriate building operation management, can decrease energy consumption up to 25%-30%. Only rarely building performance are continuously evaluated in order to verify that the design performance are maintained both in term of energy efficiency and indoor environmental quality (IEQ) or to improve the system operation and set up. As a result, often the real building performance are quite different from how the building was intended to behave. Therefore, the Continuous Commissioning plays a relevant role in the energy assessment to solve operation problems, improve comfort, optimize energy use and identify retrofit strategies for existing buildings and plant facilities. In the current paper, we present a methodological approach of KPI-based continuous commissioning with example application on two case studies (one apartment building and office building). Through the application of this methodology was possible to identify the importance of resident behaviour for the apartment building and of the system regulations for the office case study.

1 Introduction

The recurring and persistent request for the reduction of building energy consumption requires an increasingly detailed analysis of the building-plant system performances. Indeed, a detailed continuous monitoring and data post-processing procedure can guarantee that the actual building behaviour respect the design as well as that the realization and operation was successful. Additionally, it can also identify anomalous management of the building systems and habits of the people who occupy the building as well as other possible problems of the plants or façade. The required monitoring system is composed of a series of sensors, meters and other instruments that must be applied for at least one year to acquired data useful to characterize the building energy performances during both heating and cooling. Specifically, the first year of operation of a building is often used as training for both the occupants to adapt to the new conditions and the building manager to familiarize with the controls and features of the building. Therefore, often the consumption of the second year is reduced compared to the first one if appropriate monitoring-based commissioning is implemented.

The Continuous Commissioning (i.e., the continuous evaluation of measured performance indicators via ICT devices) is based on the development of a standard analysis process which examines the building from its early phase (design) through its realization, to the consequent real usage of the people who occupy it. It is necessary to define the main parameters influencing the energy consumption that be part of a monitoring plan (based on ICT devices) that also include energy drivers. The data collected through ICT devices can be processed to develop graphs and metrics characterizing building performance. These Key Performance Indicators (KPI) represent a critical point in the commissioning process. With the generation and interpretation of these KPI it is possible to effectively inform both the energy manager and the building owner or inhabitant. A correct comparison between the consumption profiles in different seasons and between different buildings with the same usage purposes and executive typology can be made thank to interpretation tools. With this information, improvements can be suggested after a deep study of the interactions among variables and the identification of the affected systems. Therefore, data post-processing procedures and tools must be developed or adapted to assist with the data interpretation and to understand the connection among the variables as well as to visualize possible plant malfunction.

Considering the need for standardized procedures to post-process and analyse data regarding existing building performance, we developed standard KPI (figures and metrics) and applied them to two case studies, one office and one residential building.

2 Methods

In order to develop the standard post-processing procedure, we first evaluate the possible metrics and visualization tools typically used for building performance characterization. The figures and KPI selected should have the characteristics listed in Table 1. **Main characteristics to be considered during data post-processing and the protocol development**

Table 1. Main characteristics to be considered during data post-processing and the protocol development

Characteristic	Description
Relevance	Check whether the available information shed light on the issues of greatest importance for the users
Accuracy	The degree of correspondence between the estimates obtained by the analysis and the true value.
Accessibility	It refers to the simplicity for the user to find, acquire and understand the information available in relation to its objectives.
Comparability	It is the ability to compare the statistics on the phenomenon of interest in time and in space. process information.
Coherency	It corresponds to the possibility of combining the simple inferences in inductions more complex.
Completeness	It is a cross-characteristic between processes and it is the ability to integrate this information to provide a satisfactory framework of the domain of interest.
Regularity	It indicates the frequency with which the analysis is repeated and the data are made available.
Clarity	It is the availability of appropriate documentation in respect to the characteristics and phases of analysis, with the possibility of obtaining assistance in the use and interpretation of data

Secondly, since the structure and the tools used in the post-processing procedure should be common to the different buildings investigated, a sets of possible visualization types was identified (e.g., figures, diagrams). Table 2 presents the visualization tools used in the current methodologies with advantages and advantages. The performance evaluation would have similar structure and specifically include: electricity (e.g., plug loads, lights), thermal & mechanical plants (HVAC, DHW), IEQ (e.g., hygrothermal comfort, CO_2), user behaviour (window opening), RES (e.g., PV).

Table 2. Visualization tools used in the Smart Build standard reporting protocol

Type of visualization	Description	Advantages	Disadvantages
Time series plots	Classical diagram of a measured value over time (on the x-axis).	Rapid creation; clear visualization of trend over time, peak values; clear comparison of before-after scenario.	Lack of information regarding the correlation between variables; no summary information about the distribution; depending on data resolution, significant information could be hidden.
Scatter plots	Figure showing a variable as a function of another variable(s).	Clear visualization of the relationship between variables; easier to understand the possible mathematical relationship between variables.	Unless different colours are used, hard to understand the time-dependency and the influence of other aspects; critical to identify the correct variables to compare and for sophisticated analysis the relationship among them.
Box plots	This graph depicts information regarding the distribution (median, lower & higher percentile, outliers) for different grouping strategies.	Useful to visualize the statistical distribution of a variable; when coupling with grouping useful to quickly compare distribution for different conditions; the shape of the boxes also helps in identifying the variance and the frequency of outliers.	Lack information regarding the specific values, especially regarding time-dependent phenomena and relationship between variables.
Carpet plots	They illustrates the values of a certain variable on a colour scale versus time. Usually they show the hours of a day on the y-axis and the days of a year on the x-axis. Each coloured pixel of the graph indicates a high frequency data point.	Effective to clearly visualize long-time series; effective to show recurring patterns or operation schedule	Lack the information regarding dependency among variables; lack summary indicators, although the frequency of colours can be used as surrogated metric; they may require advance data processing tools.
Tables and visualization bars	They include summary indicators as values possibly supported with colours (visualization bar).	They can provide quick summary information regarding overall and specific behaviours, typically average value; the visualization bar could be easy to quickly grasp.	Provide limited detail information regarding the reason for a certain behaviour and the correlation among variables; challenging to compare the values and define the correct meaning of the colour scale.

To facilitate the analysis and understanding of the data two important tools exist: filtering and grouping. Filtering consist on the selection of a subset of data that satisfies a certain condition, while with grouping all data are considered but grouped according to a specific logic. Important for the data analysis is also the resolution and duration of the data series. Different information can be convened depending on the data resolution (minute, hourly, daily, weekly, etc.). To assist with this process we relied on a commercially available software.

3 Case study application

The developed methodology of KPI based continuous commissioning was applied in two recent ongoing projects: SEE-Miniambiente (2009-2013); ICT PSP Smart Build (2012-2015).

SEE-Miniambiente "CasaNova" apartments

The first project concerns the study of an innovative "CasaNova" neighbourhood in Bolzano, Italy which was built in 2007 according to high energy efficiency standards. The district is composed of 31 buildings, with different shapes and sizes, which are grouped in 8 residential nucleus named "Castle_EA" (i.e., cluster of buildings). Figure 1. **Overview of the "Casanova" neighbourhood.**shows an aerial view of the neighbourhood.

Figure 1. Overview of the "Casanova" neighbourhood.

The project was realized to fulfil 3 main objectives illustrated below.

1St Objective – Reduction heating consumption

The first objective of the development was to have a low heating consumption. The limits of heating demand were set by Italian Standards in 2003, when the project was approved, was 90 kWh/m^2/year. For the CasaNova district, the municipality of Bolzano decided to apply more stringent thermal energy limits, based on the size of each building:

- buildings smaller than 5,000 m^3 the limit was 50 kWh/m^2/year.
- buildings larger than 20,000 m^3 the limit was 30 kWh/m^2/year.
- For buildings with volume between 5,000 m^3 and 20,000 m^3 the limit vary according to special classifications, presented in Figure 2.

This strategy attempted to not penalize smaller buildings to the detriment of the bigger ones, which have a lower surface area to volume ratio.

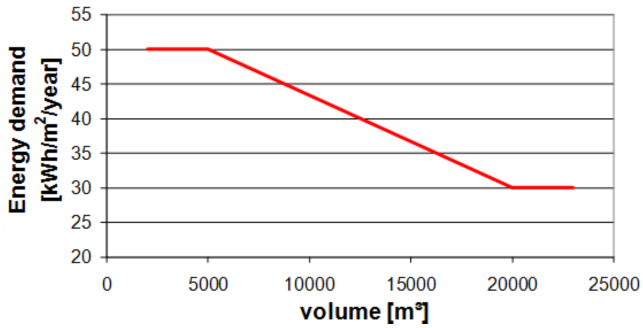

Figure 2. Correlation between energy consumption and Volume of the buildings

2th Objective – Rational and efficient utilization of traditional energy sources

A preliminary study was done to decrease the energy consumption from traditional energy source. First, different heating configurations were considered: independent boiler for each apartment, a centralized boiler for each building and the use of the district heating network. Subsequently, based on the detailed analysis of the overall average efficiencies of the three configurations, the district heating network was chosen. Additionally, a cooling district plan was implemented via absorption machines.

3th Objective – Use of renewable sources

Most of buildings in the neighbourhood have renewable energy systems like solar and geothermal. The solar energy is used to produce domestic hot water and electricity. The geothermal plant helps not only the heating and cooling system of the buildings with a water circuit, but also the ventilation system. The aim of these devices was to reduce the energy consumption and guarantee a high indoor comfort. The reduction in simulated consumption as results of these three objectives is illustrated in Figure 3.

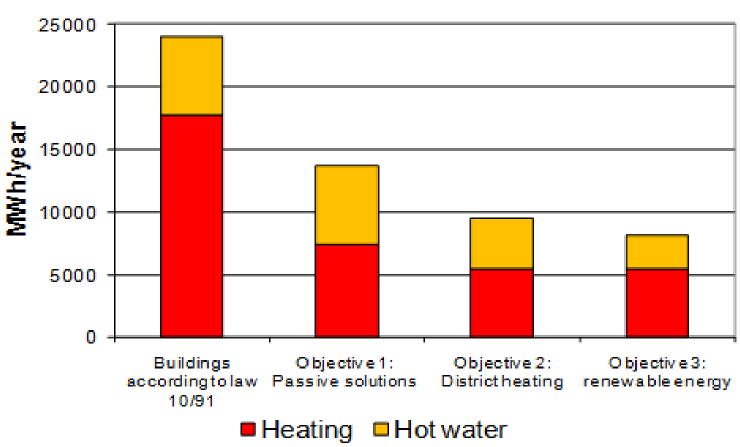

Figure 3. Consumption reduction for Heating and hot water via the application of Objectives

According to the province of Bolzano, a detailed monitoring system has been applied in some "castles" since 2009, for example "castle-EA2" (Figure 1) . This cluster is made of 4 buildings and each one has different height and sun exposure. The project of this residential nucleus aims at reducing the heating energy consumption with the following prescriptions:

- use of high thermal insulation thickness (from 10 to 15 cm of rock wool).
- glass walls with different size in function of the orientation
- thermal transmission coefficient of the glass equal to 1,1 W/m^2K and 1,4W/m^2K for the frame
- External wall in insulated brick with thickness of 30 cm.
- Ventilated façade.

The thermal energy is obtained via the district heating network. The solar collectors located on the roof and three tanks, one of which is connected to the heating system, ensure the production of domestic hot water. An area of 270 m^2 of photovoltaic panels provide part of electricity consumption.

The monitoring system was installed to assess the real energy consumption and verify the Indoor Environmental Quality (IEQ) in 4 apartments; two located on the ground floor and two on the last floor . The system is composed of:

- Energy counter for the district heating network
- Electricity analyser to evaluate the consumption of lights and appliances
- Sensors to measure in the four apartments indoor temperature, moisture, CO_2, opening/closing windows and temperature of external ventilated façade, in both sides.
- Weather station installed on the roof of the building to evaluate the temperature, moisture, global irradiation and wind speed

ICT PSP Smart Build office building

The second case study is part of a project focusing on the application of ICT to suggest improved control strategies in several public buildings (i.e., offices, hospital, schools) located in Italy, Greece and Slovenia to save energy, reduce peaks and improved comfort conditions. This can be achieved via an integrated monitoring and control system which can keep track of the energy flows in the building, find out possible faults and suggest system improvements.

One of the analysed cases is a building with some offices and a laboratory in Athens, Greece (CRES building). The building has been designed according to bioclimatic practices in 2001. The annual energy demand in degree days is 947 for the heating period and 5534 for the cooling period. The single-story 300 m^2 building has a low consumption thank to on one hand an electrical heat pump that generates the thermal energy for heating and cooling and, on the other hand, a photovoltaic area of 300 m^2 (24 kW) that largely guarantees the electrical energy demand.

The monitoring system at CRES focuses on building comfort and the energy demand as follows:

- Temperature, Humidity, CO2, presence and luminous intensity in 3 areas (2 offices and 1 laboratory)
- Energy and power of whole building and of the heat pump
- Temperature, humidity, wind speed and wind direction in a weather station

4 Results and discussion

SEE-Miniambiente “CasaNova” apartments

In the ‘CasaNova’ project, we analysed the data from October 2011 to April 2013. The results concerning the heating and domestic hot water (DHW) consumptions of the “Castle EA2”are shown in Figure 4 and Figure 5.

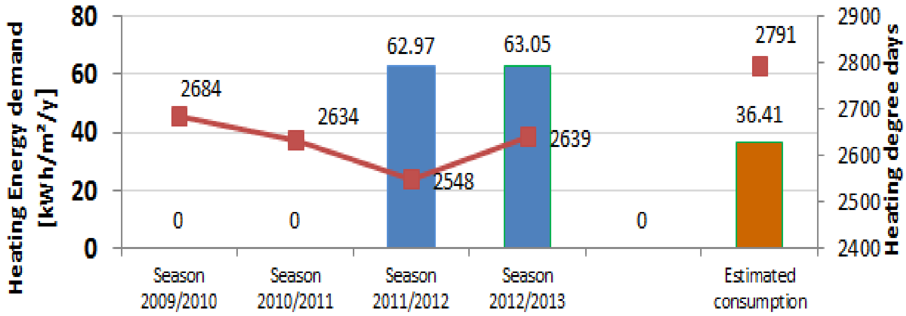

Figure 4. Castle EA2 – Heating consumption during season 2011/2012 and 2012/2013.

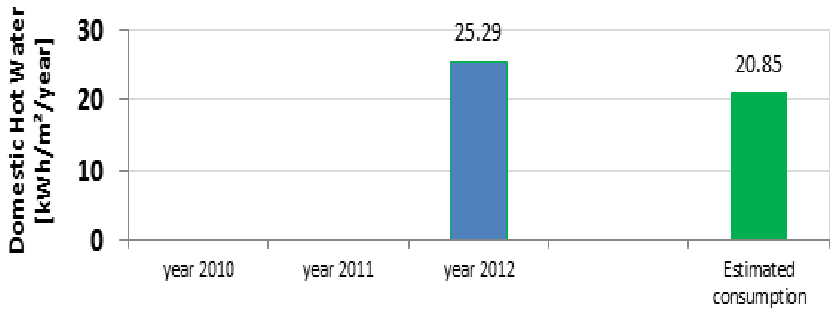

Figure 5. Castle EA2 - DHW consumption during year 2012

The graphs compare the estimated and the measured consumptions of the building. It can be seem that while the DHW consumption is very close to the real consumption, the heating consumption in the last two seasons is almost twice the calculated design consumption. The causes of this discrepancy is still under review but one of them could be found in the behaviour of tenants. The residents have an elevated influence on the heating consumption since they control the indoor temperature setting. Increased indoor temperatures were observed as shown in Figure 6.

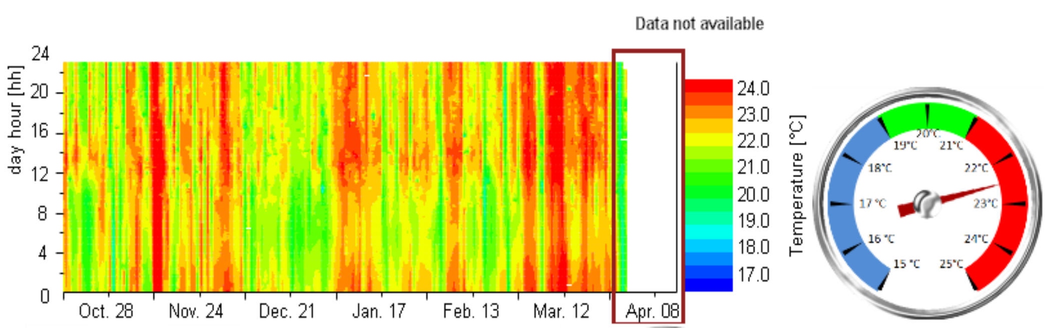

Figure 6. Temperature profile and (meter indicator)average seasonal temperature of the apartment on the top floor during the heating season

This figure depicts how the indoor temperature in the apartment is greater than the design temperature (19-21°C) for the most of time; sometimes it can reach values near 25-26°C. Additionally, the tenants also tend to open the windows while the heating system is operating as can be observed in Figure 7.

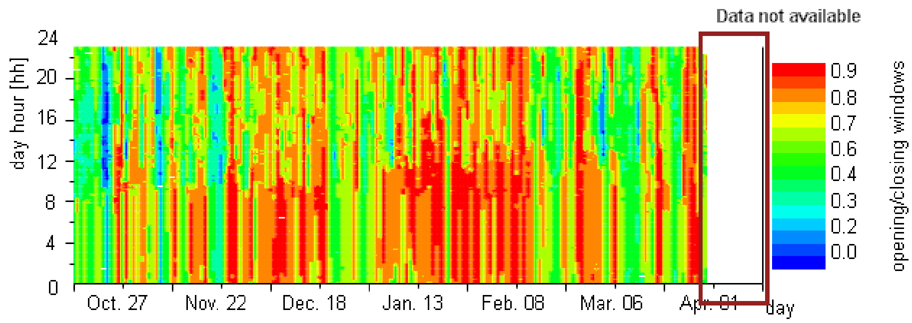

Figure 7. (Carpet Plot) Opening/Closing windows in the apartment on the top floor during heating season. (1 closed – 0 Opened)

The same incorrect behaviour has been observed during the cooling season(Figure 9) The temperature of the flat exceeds the design temperature (26°C) for more than 50% of the analysed hours (Figure 8)

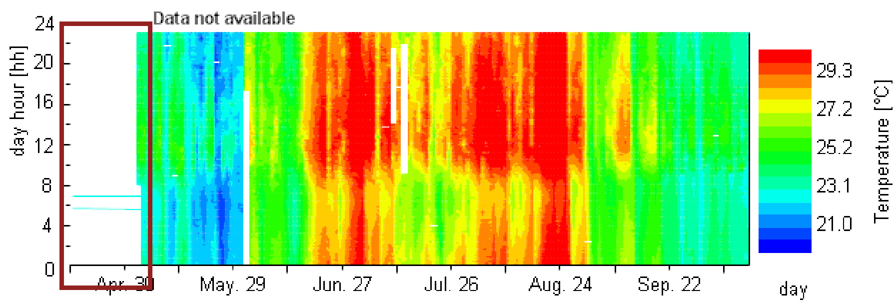

Figure 8.(Carpet Plot) Temperature profile of apartment on the top floor during the cooling season

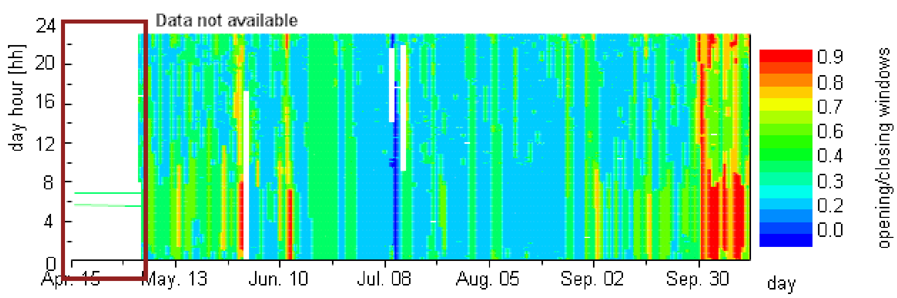

Figure 9. (Carpet Plot) Opening/Closing windows in the apartment on the top floor during not heating season.(1 closed – 0 Opened)

Despite the elevated energy consumption, the hygrothermal comfort falls into the ASHRAE comfort zones for the most of hours. However, it would be beneficial to achieve this result without the substantial waste of energy as mentioned before. Another fundamental aspect that has been analysed is the CO2 concentration. As can be seen in Figure 10 for the apartment 1 in the ground floor, the concentration of CO2 is higher than in the others, sometimes reaching peaks of 3400 ppm. After a brief survey, the problem has been located in the apartment's occupation and tenant's behaviour. The apartment covers an area of 80 m^2 and it is inhabited by 14 people, which are used to keep the windows closed for most of the time and some of them generally smoke inside. All that produces an exhausted air that could generate health problems, especially for children.

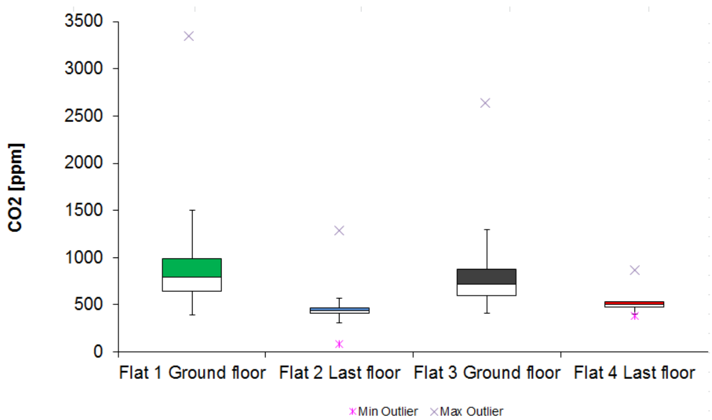

Figure 10 .(Box Plot) CO2 concentration in the apartments monitored

ICT PSP Smart Build office building

In the second case study considered, part of the Smart Build project, the analysis focused on the optimization of the heat pump system and the achievement of a better indoor environmental quality. The main aspects investigated are the electricity consumption of the heat pump, lights, appliances, the electricity production of the photovoltaic system, the user behaviour and internal comfort (Figure 11) presents the breakdown of the overall electricity consumption for March 2013.

System	Month Average [kWh\m2]
Heating Pump	0.07
Light+appliances	0.08
UPS	0.02
Photovoltaic Plant	0.19

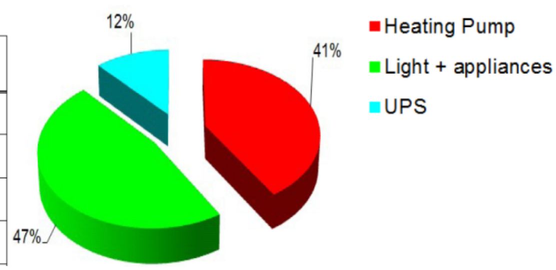

Figure 11. Electricity consumption of the building in March 2013. The UPS or battery/flywheel backup, is an electrical apparatus that provides emergency power to a load when the input power source, typically mains power, fails.

According to the diagram, the electricity consumption is due to the heat pump for almost 40%, and the remaining 60% is due to lights, appliances and UPS system all together. A deeper investigation is still in progress, but the first results and the graph below show that there is no correlation between the consumption of the electrical heat pump and the outdoor temperature. We even observed heating consumption even for outdoor mean temperature of 23°C (see Figure 12) Additionally, sometime the consumption is higher when the external temperature reaches 22-23°C than when there are 17°C. Moreover, it starts during the night only for brief periods (see Figure 13) This behaviour denotes a typical problem of the regulation system, which influences the electrical consumption and the thermal comfort as well. As can be seen in Figure 14, there are often cold conditions observed in the monitored offices (approximately 60% of the working days, considering only the working hours)

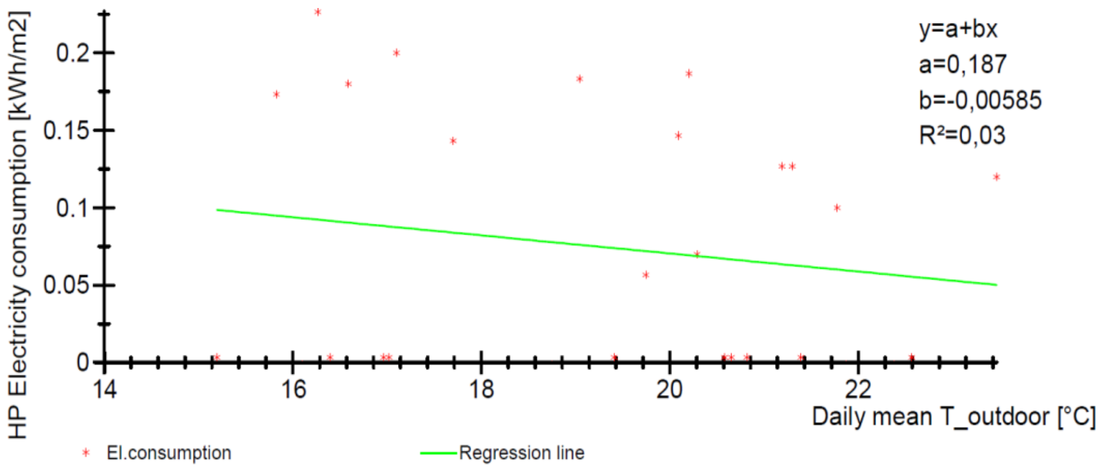

Figure 12. Energy signature of the building in March 2013.

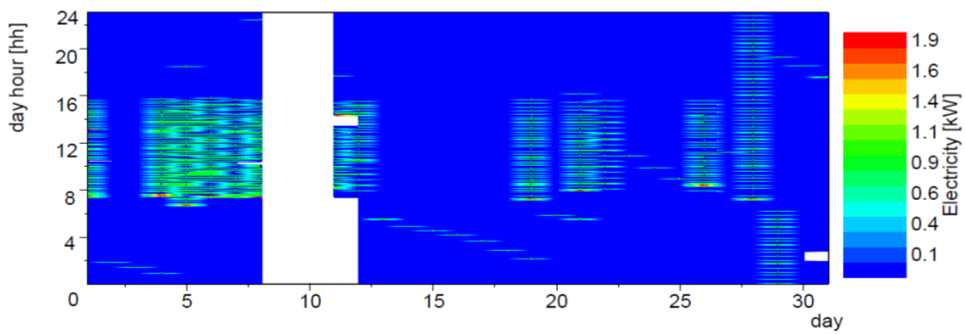

Figure 13. Electricity consumption of the heat pump during March 2013

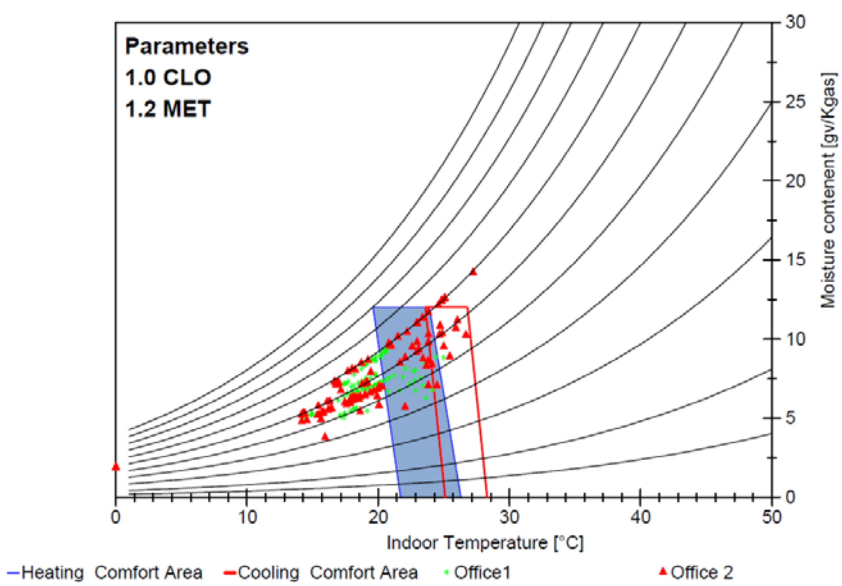

Figure 14. Daily ambient air temperature and humidity with ASHRAE comfort zones, considering only the working hours.

The next step of the project is the definition of improved control strategies to apply to this building in order to reduce energy consumption, shift peaks, optimize photovoltaic production and improve occupant comfort. The solutions include the introduction of an automatic control in the heat pump as a function of the building occupancy and of the outdoor temperature as well the control of the sky-light windows to regulate indoor temperature and take advantage of night cooling.

5 Conclusions

The continuous commissioning represents an excellent strategy to improve the energy behaviour and the overall performance of a building. It requires the identification of the energy flows and parameters to monitor. Once the data is acquired, it needs to be processed to identify faults, incorrect settings and potential for improvement. The processing of great amount of monitoring data is a complex process needed to be able to make visualize the performance. In the current paper we identify a procedure assisted by a series of visualization tool and specific KPI that allows us to first identify potential problems for each analysed cases and, subsequently, to figure out the possible refurbishment to apply in the buildings. In the case studies presented we were able to underline the importance of apartment user behaviours (e.g., temperature setting, window opening) and of the system control (heat pump regulation based on external temperature).

One of the main objective is to develop guidelines that could advice the tenants, the owners or the energy managers on the potential/possible actions to be implemented to solve the problems and improve the building/system performances.

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