# Building EQ: tools and methods for linking EPBD to continuous commissioning

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## ABSTRACT

While the building sector accounts for more than 40% of EU energy consumption, the energy saving's potential - especially in existing buildings – achievable through operation parameter's optimization is in the range of about 5-30%. This is especially true for non-residential buildings. Today, usually there is no continuous evaluation of the building performance in order to reach or maintain an energy-efficient operation. As a result the buildings performance, even in cases where an accurate envelope and plants design is often poor and does not represent the optimum in energy and economic terms, regardless an optimal envelope and service system design. **A continuous commissioning process is seen as a prerequisite for the persistence of high energy performance of buildings**. Its practical implementation is constrained by a lack of data and cost. The **project Building EQ** (formally EPBD-cx) has the scope to **develop methodologies and tools that can be used for continuous commissioning and optimization of non-domestic buildings** using gathered data from the certification process according to the EPBD. The emphasis will be on feasibility and cost-effectiveness related to building-practice. The project started at the beginning of 2007 and its duration is 36 months. In this paper the phases and the first Building EQ steps are shown; the participant's contribution, the set of non-residential demonstration buildings selected for the monitoring activities, the modelling techniques, will be described. An analysis of the EPBD application in participant countries will be carried out. Overall a description of strategies and commissioning procedure for the building considered will be summarized.

## 1. INTRODUCTION

Building commissioning is rapidly becoming an important issue, especially for the reduction of the energy consumption related to the HVAC systems and the comfort of the buildings users. More and more architecture and engineering firms are including commissioning services as a core business component. Building commissioning is often a term associated with new construction projects as a process of ensuring that new buildings and their systems perform as designed. Commissioning is integrated into the construction process to ensure that owners and investors get good buildings for their investments (Haasl, Sharp, 1999).

Unfortunately, most buildings have never gone through any type of commissioning or quality assurance process and are therefore performing well below their potential. It can be estimated that especially existing buildings can reach an energy savings of about 5-30% by optimizing operational parameters or making small maintenance intervention. Commissioning of existing buildings is also known as retro-commissioning (Haasl, Sharp, 1999).

**The project Building EQ aims to develop methodologies and tools that can be used for continuous commissioning and optimization of existing non-domestic buildings using gathered data from the certification process according to the EPBD** (i.e., Directive 2002/91/EC on the energy performance of buildings)**.**

Continuous Commissioning (CC) can be defined as an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify needed retrofits for existing commercial and institutional buildings and central plant facilities. CC has produced typical savings of 20% with payback under three years (often 1-2 years) in more than 130 large buildings (Claridge et al., 2002). The CC process focuses on improving overall system control and operations for the building as it is currently used and meeting existing facility needs. **Continuous commissioning goes beyond an operations and maintenance program, including a comprehensive engineering evaluation that develops operational parameters and schedules to meet occupant needs**. An integrated approach is used to implement these optimal schedules to ensure local and global systems optimization. A key goal is to ensure that building systems remain optimized continuously. To achieve this, continuous commissioning requires benchmarking, pre and post-energy use via metering equipment that is permanently installed. Data are then continuously gathered and compared against the post-commissioning benchmarks to ensure that the building systems function optimally throughout their life. Steps of continuous commissioning are shown in figure 1.

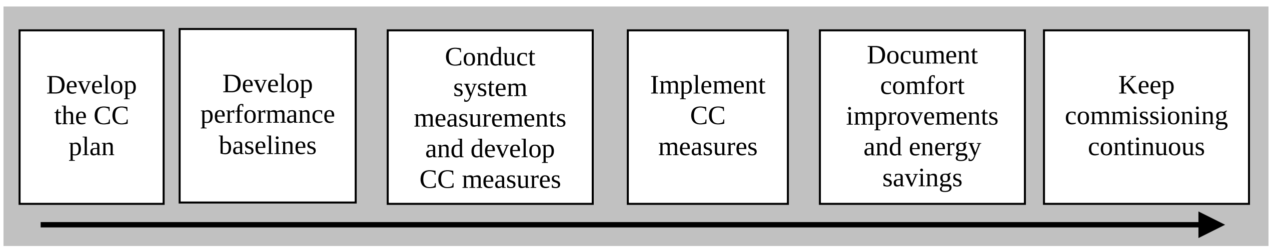



Figure 1 – Phases of continuous commissioning (CC) (Claridge et.al., 2002)

## 2. THE PROJECT: BUILDING EQ

Building EQ started on the first of January 2007 and it will end at the end of 2009. The work can be separated in three major phases:

- Evaluation of existing modelling and assessment techniques for the building performance;
- Development of new methods and tools on the basis of the results of the first working phase;
- Implementation and Monitoring in demonstration buildings over a period of at least 20 months;

In the third phase the developed tools will be evaluated in the demonstration buildings with the aim to reduce the energy consumption by about 20%.

The project consortium includes six research teams, among research institutions and industrial players, from Italy, Germany, Sweden and Finland. In each country demonstration buildings are selected for the application of the methods and tools developed in the project. At least twelve demonstration buildings will be object of the research activities. Only existing non-residential buildings with a net floor area of above 3.000 m² are considered. The year of construction is not important. The buildings should have a minimum amount of HVAC equipment. Besides a heating system, at least a ventilation system and/or a cooling plant or an air-conditioning system should be installed. The buildings should be equipped with a buildings automation system (BAS).

In order to prepare an energy certificate for the building, the data of building envelope and the HVAC systems will be gathered in detail. On the basis of the certification first hints regarding the plants optimisation can be given.

The performance data of the building, preferably hourly data of energy consumption and further operational parameters, have to be recorded on a centralised data-server. The monitoring and the evaluation activities will be carried out for at least 20 months.

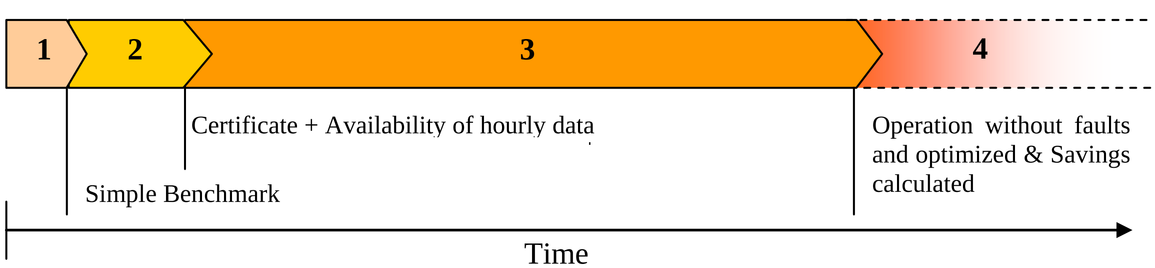



Figure 2 – The four step procedure elaborated by the project team (source: Fraunhofer-ISE)

The team has elaborated a four step procedure (figure 2) in order to perform the energy analysis and the benchmarking of the demonstration buildings. The four phases are listed below:

1. Simple Benchmark
2. Certification + data acquisition
3. Fault Detection and Diagnosis (FDD) + Optimisation
4. Continuous Commissioning

Based on the performance evaluation, energy saving measures have to be implemented in the building. The measures will mainly concern operational parameters and therefore can be implemented at no or minimal cost. The minimal data set that will be gathered for each building comprise:

- total consumption of fuels, district heating and cooling, electricity, water;
- outdoor air temperature and relative humidity, global solar irradiation;
- indoor air temperature and relative humidity of different zones;
- delivered/return temperatures of main fluid circuits (air and water).

Usually these measures will have a payback time of a few months up to 1-2 years. Typically, this will comprise changes in the control by changing or re-engineering the parameters or programs. In some cases minor changes in the installation can be reasonable, too (e.g. changes in the hydraulics).

## 3. EPBD APPLICATION IN THE PARTICIPANTS COUNTRIES

The second phase of the procedure, elaborated by the project team, foreseen to prepare the energy certificate of the building, following the EPBD (2002/91 CE Directive on Performance of the Buildings). This is seen as a baseline for further investigation of the building energy consumption and for the analysis of the building facilities operational parameters.

Project participants have compared the EPBD application in their countries: Italy, Germany, Sweden and Finland. The application of the EPBD results to be very different in participant countries, considering the calculation method (Asset Rating or Operational Rating) and the level of detail of the analysis of the building performance (e.g., in Italy up to now the energy consumption due to summer cooling is not taken into account).

A list of 133 indicators has been provided to each participant country in order to assess the common baseline. Without considering Finland, that foreseen to implement EPBD on next season only 21 parameters seem to be comparable. This is due principally to the fact that Sweden limits the EPBD application to an Operational Rating approach, avoiding to perform a common calculation based on parameter of the facilities and building envelope characteristics. Common parameters are therefore limited to general building data (area, volume, etc.) and to the identification of the main characteristics of the facilities of the building (e.g., heat generation and distribution, etc.). Values of consumption certified are referred to gross volume.

Germany shows to have implemented the EPBD in the deeper level among the analysed countries: it consider all the energy consumptions listed in the directive, permitting to perform an Asset Rating based on calculation for new buildings and asset or operational rating for existing buildings.

Instead Italy have limited the approach to the Asset Rating for both the new and existing buildings, and the application of the directive is limited to the calculation of the consumption due to heating, ventilation and domestic hot water preparation. Although Italy represents the major market for air-conditioning in Europe, the consumption due to these appliances is not considered up to know. The energy consumption for lighting or other equipment is only partially considered. Values of consumption certified are referred to useful area or volume.

Finland up to now has not implemented the EPBD, but it is foreseen for the next season. Calculation of energy performances will be permitted following both the Asset rating and the Operational Rating approach. Among the particularities of this country there is the request to divide the electricity consumption in categories.

Regardless of all the above mentioned differences the consortium will perform a calculation of the energy performance of the buildings as similar as possible, in order to allow result’s comparisons among the implemented measures on each demonstration buildings. In Table 1 the differences between the EPBD implementations in each country are summarised.

Table 1: Energy Performance metrics for the certification in Building EQ participants countries (May 2007)

| Germany | Italy | Sweden | Finland |
|---|---|---|---|
| *Asset rating*<br>Total primary energy for the whole building (for Heating, DHW, Cooling, Ventilation, Air-conditioning. Lighting) compared to a reference building with same characteristics [kWh/m$^2$a]<br><br>Global heat transfer coefficient of the building envelope [W/m$^2$K]<br><br>End-Energy consumption for the subsystems: heating, domestic hot water, lighting, ventilation, cooling [kWh/m$^2$a] and separated for the different energy sources (gas, oil, electricity)<br><br>*Operational rating*<br>-Total heating energy consumption [kWh/m$^2$a]<br>-Total electricity consumption [kWh/m$^2$a] | *Asset rating*<br>Total primary energy consumption [kWh/m$^3$a] (kWh/m$^2$a) for the whole building (for Heating, DHW, Ventilation)<br><br>Rating:<br>from A (very good) to G (very bad) for the winter heating consumption (at regional level)<br><br>Heating system performance: $\eta_g$<br>as ratio between Building Heat Requirement and Total primary energy consumption | Operational rating<br>Measured annual energy [kWh/m$^2$a]<br><br>Energy:<br>Measured total annual energy use for heating of the building and electricity driven appliances controlled by the building owner.<br><br>Energy used for cooling is assumed to be measured and then added to the benchmark.<br><br>An upper and a lower benchmark<br>for each building category<br><br>No Primary energy factor (weight =1) | (National implementation of the EPBD is under preparation as well as the certification procedure)<br><br>No detailed information is available.<br><br>Heating energy [kWh/a]<br>Cooling energy [kWh/a]<br>Electricity [kWh/a]<br>Total energy consumption [kWh/a] |

## 4. DEMONSTRATION BUILDINGS

The demonstration buildings chosen for the project must have a conditioned surface above 3000 m$^2$ and beside the heating system, a ventilation or an air-conditioning system. Building must be non-residential, therefore the selected buildings can have the following final use: commercial, educational, office, shopping center, etc. The minimum amount of building analyzed in the project framework is twelve.

In this section two of the chosen buildings will be presented in details. Further information regarding all the demonstrations buildings will be shown on the project website (www.buildingeq.eu). At the end of the project for each building the energy certificate and the amount of savings achieved will be published.

The first building is located in Essen (DE). This is an office building erected in 1985, with a useful area of 19.500 m$^2$ . The building have a central part and four wings at each cardinal point. The building is connected to the district heating network and it is heated by radiators. Part of the building is ventilated by mechanical ventilation, whereas a lot of offices are ventilated naturally. Mechanical ventilation and air-conditioning is provided by six different air handling unit (AHU) of 6.000-8.000 m$^3$/h each (visible on the building's roof in figure 3). The building structure consists of a double leaf wall, with the insulation in between. Some multi-split air-conditioners are installed too. For further details see figure 3.

In Germany will also be analyzed other 4 buildings: Kreiskrankenhaus Hagenow, Hagenow (hospital, 1995); Wirtschafts-ministerium NRW, Düsseldorf (offices); Kreiskrankenhaus Emmendingen, Emmendingen (hospital, 1970); Verfügungs-gebäude, Universität Stuttgart (office, hospital, lab, 1995).

**Kreuzgebäude, Essen, DE**
(ThyssenKrupp Real Estate GmbH)

| | |
|---|---|
| Year of erection | 1985 |
| Use | Office building |
| Net floor area | 19.500 m² |
| Electricity consumption | 1.000.000 kWh/a (2006)<br>51 kWh/(m²a) |
| Heat consumption | 1.500.000 kWh/a (2006)<br>77 kWh/(m²a) |
| HVAC equipment | heating, ventilation,<br>air conditioning,<br>(building automation system) |
| Energy source | district heating, electricity |

Figure 3 – One of the demonstration buildings chosen in Germany

The second building is located in Milan and it belongs to "Politecnico di Milano". The authors will carry out the research on 3 to 5 buildings of the Leonardo da Vinci Campus, chosen among office and educational buildings. The building showed in figure 4 is among the newest at the campus. It is used for lectures, offices and it has two computer rooms. The building is air conditioned by a primary air diffusion (2 AHU x 18.000 $m^3/h$) and a four pipes fan-coils network. Heating is provided by two 244 kW boilers and cooling is provided by a 474 kW air condensed chiller. Other buildings are the construction department (offices, 1960), the building "NAVE" (offices, laboratories and lectures rooms, 1960), the electronic department (offices, laboratories and lecture rooms, 1970) and the new general secretariat (offices, 2007).

**Lectures halls D, building 22**
(Politecnico di Milano, Milan)

| | |
|---|---|
| Year of erection | 1999 |
| Use | Office, lectures, computer room |
| Net floor area | 3.200 m², 14.000 $m^3$ |
| Electricity consumption | 512.000 kWh/a (2006)<br>160 kWh/(m²a) |
| Heat consumption | 320.000 kWh/a (2006)<br>100 kWh/(m²a) |
| HVAC equipment | heating, ventilation,<br>air conditioning, |
| Energy source | gas, electricity |

Figure 4 – One of the demonstration buildings chosen in Italy

Details and documents on the other demonstration buildings will be available on the project website. The total amount of demonstration buildings will be likely larger than the expected 12 buildings, covering most of the non-residential final use.

All the buildings will be provided with metering devices that will gather the minimum amount of described in section 2. Data will be collected hourly and provided to a central recording server, in order to construct the data set for the energy performance analysis of the buildings and for the benchmarking on the action that will be taken to reduce the consumption.

## 5. MODELLING TECHNIQUES

The research focus is on the continuous building energy analysis. Tools and methods for the continuous commissioning are being collected, evaluated and developed for this purpose. The procedure and tools under development are expected to produce savings from 5 to30%, whereas the target is 20%.

All these will be based on the collected data, the forecasted energy consumption and the comparison with the benchmark values. Tools and methods will be based on a minimum set of gathered data (see table 2, next page); the objective is contain costs and have a payback period of 1-2 years of the investment on measure devices.

Tools and methods that are analyzed are finalized to two different task. The first one is to quickly analyze the collected data and the actual energy consumption, showing these in different "compact" ways, in order to give a fast advice on possible systems bad operation. At this category belong statistical analysis, linear regression of data, energy signatures, etc. The second purpose is to try to foresee the future consumption, in order to have feedback of the intervention on operational parameters or to identify system bad functioning, via comparison with benchmarked energy data.

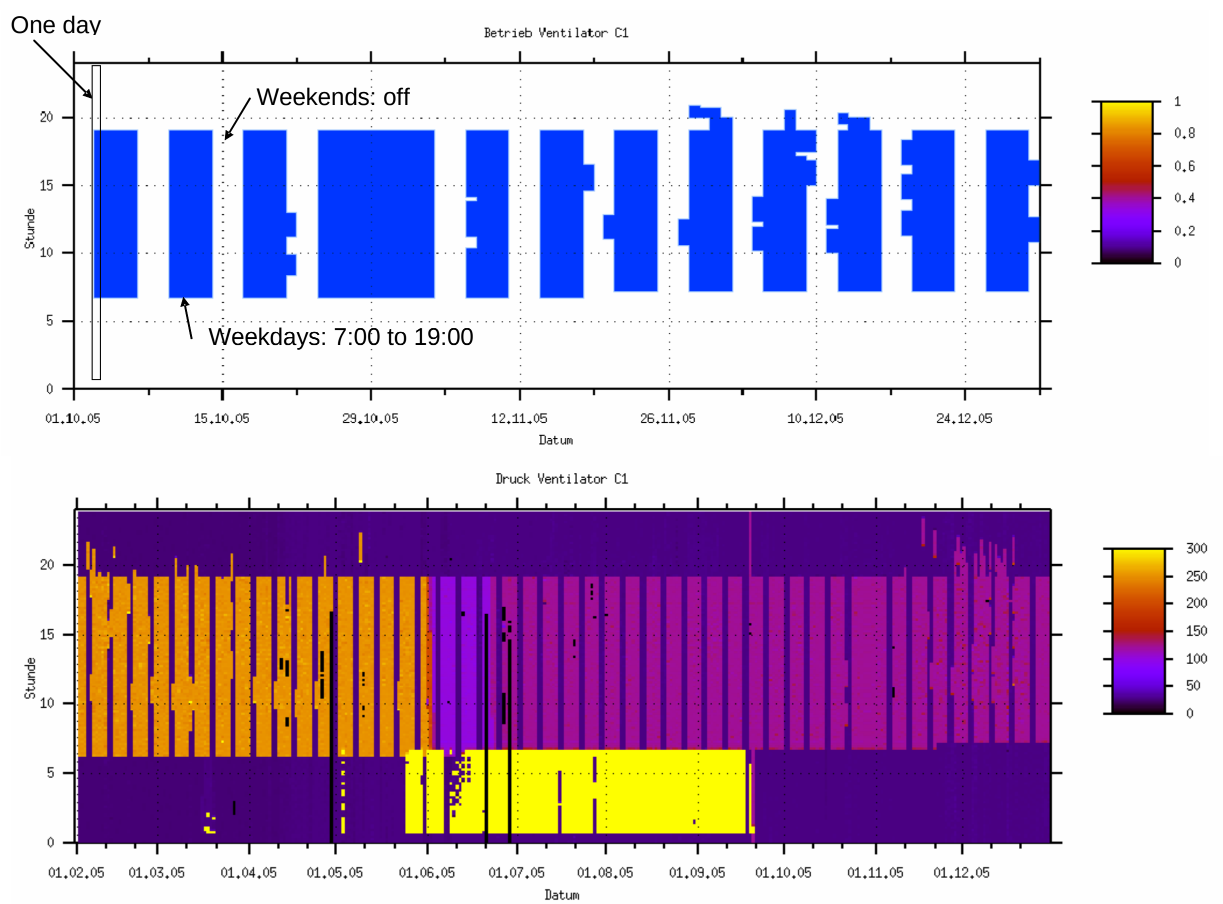



Figure 5 - (Above) carpet plot of control signal (0/1) of an rooftop exhaust fan (SIC Freiburg). X-axis: days, Y-axis: hour at day. Thus the data of each day is a line running from the bottom of the graph to the top. If – like in this example- a fan is only in operation on weekdays between 7:00 and 19:00 o'clock, "week-blocks" are displayed that are vertically divided by the weekends. On the 29.10. the fan was obviously operated at the weekend. (image have an enhanced contrast for e more readable, set-point is always 1 in colored areas)

(Bottom) carpet plot of the set point for the control of the same fan. The plot shows almost one year of data. Obviously the set point was changed three times in this year (In June it was reduced and in July again slightly increased). The bright area represents full load operation for the night ventilation during the summer period (passive cooling).

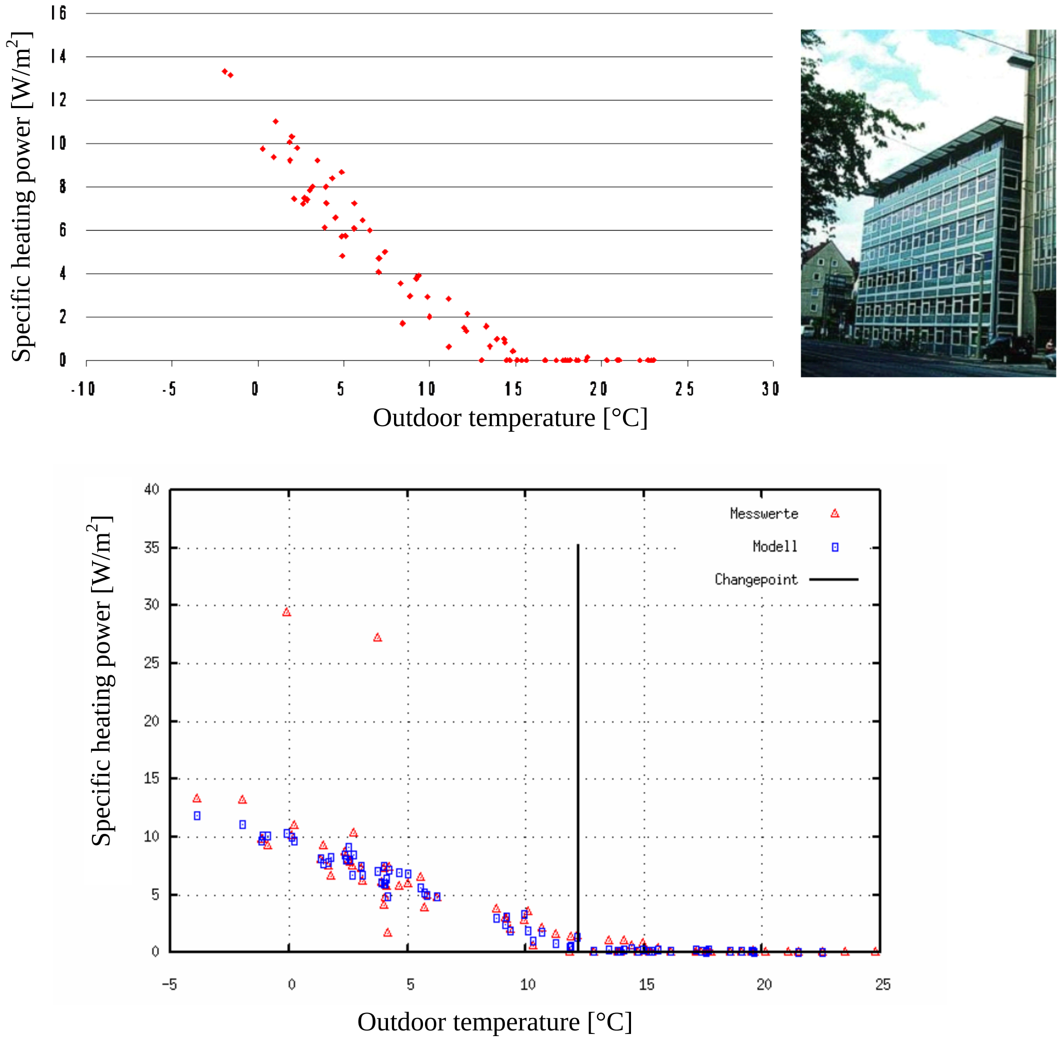



Figure 6 - energy signatures of TU Braunschweig - IT Centre (Above) and Automatic identification of energy signature of the same building (down). Red: measured consumption, blue: model. The two outliers are detected automatically and have minor influence on the model.

In order to achieve this second goal, a simplified building/system model has to developed, being able to fast on-line estimation of energy consumption.

In figure 5 (previous page) and figure 6 it possible to see some example of energy signature. The first one is a way to represent the operating hours of facilities. With this visualizations is possible to see abnormal functioning of the facilities. The second one show how is possible to have automatically the energy signature of a building by gathered data.

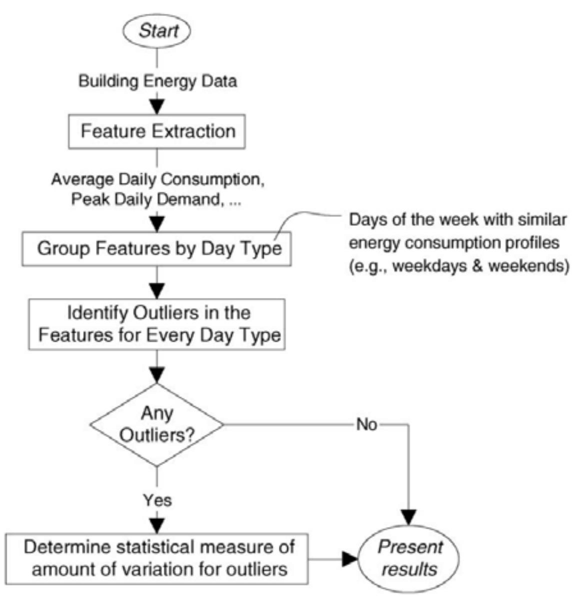
In the next page (figure 7) it is shown an example of statistical analysis. It permit to quantify how many times energy consumption is more than the expected value. (Seems, 2006)

With all this examples the authors want to show the first typology of analyzed and developed tools.

Table 2: Minimum set of gathered data chosen by Building EQ project team

| Measured value | Unit | Time resolution* | Remarks |
|---|---|---|---|
| total consumption of fuels | kWh | h | e.g. gas, oil, biomass |
| total consumption of district heat | kWh | h | |
| total consumption of district cold | kWh | h | |
| total consumption of electricity | kWh | h | |
| total consumption of water | m³ | h | |
| outdoor air temperature | °C | h | own weather station or from weather data provider |
| outdoor rel. humidity | % | h | own weather station or from weather data provider |
| global irradiation | W/m² | h | own weather station or from weather data provider |
| indoor temperature | °C | h | one or more reference zones for that measurement |
| indoor rel. humidity | % | h | one or more reference zones for that measurement |
| Delivered / return temperatures of main water circuits | °C | h | main heat/cold distribution |
| supply air temperature of main AHUs | °C | h | only if supply air is thermodynamically treated |
| delivered /return temperature of emitters | °C | h | If rational: temperature of secondary circuits might vary from primary circuit |

h = hourly



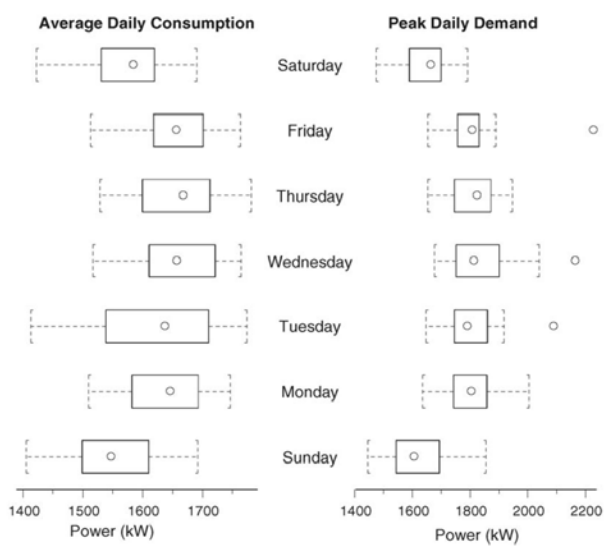




Figure 7 - Left: Block diagram of major steps to detect abnormal energy consumption; Right: box-plots of average daily consumption and peak demand. These data is the basis for the “Daytyping”. (Seem J. E., 2006)

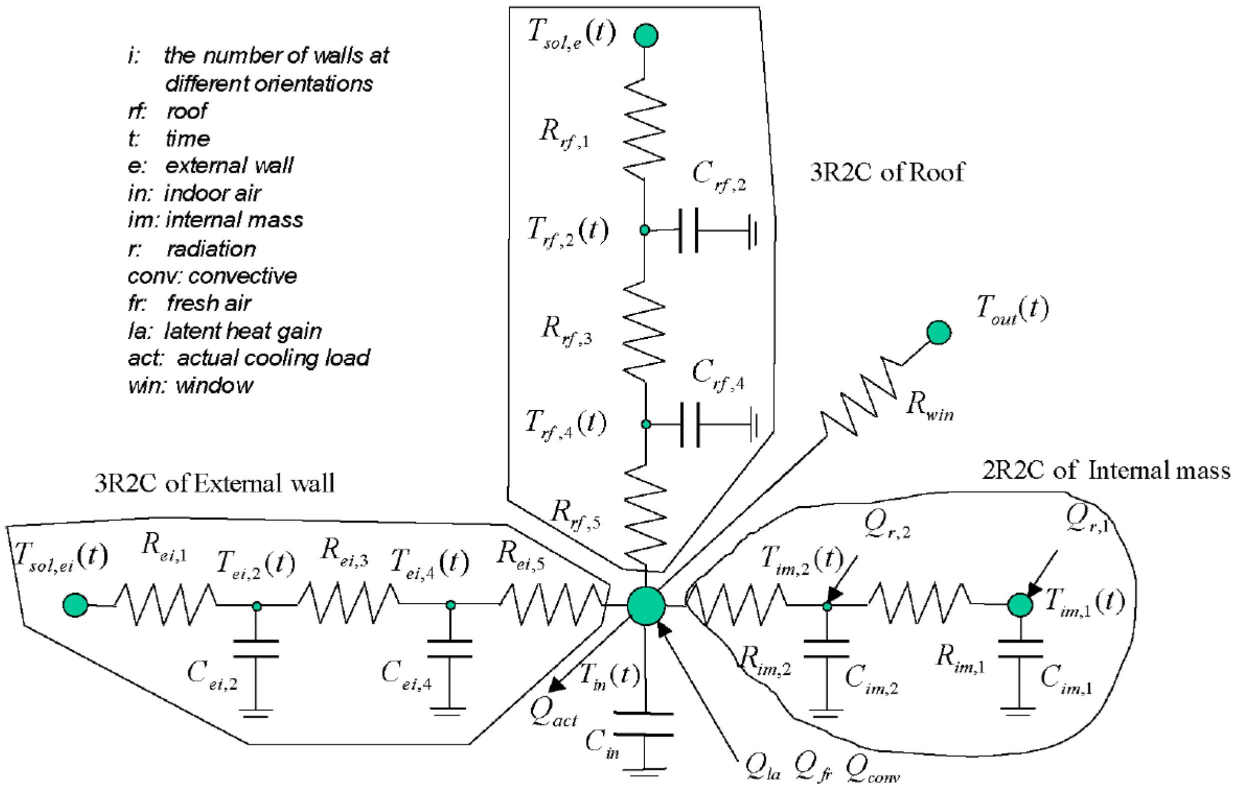



Figure 8 - Schematics of simplified building energy model (Shengwei Wang, Xinhua Xu, 2005)

$$\frac{T_{ei}}{T_{ci}}\left(1+\frac{1}{COP}\right)-1=\frac{T_{ei}}{Q_e}\Delta S_T+Q_{leak,eq}\frac{(T_{ci}-T_{ei})}{T_{ci}\times Q_e}+\frac{R\times Q_e}{T_{ci}}\left(1+\frac{1}{COP}\right)$$

The three performance parameters are:

a) total internal entropy production, $\Delta S_T$

b) total heat exchanger "thermal resistance" $R=\frac{1}{\varepsilon_c M_c C_{pw}}+\frac{1}{\varepsilon_e M_e C_{pw}}$

c) equivalent heat leak $Q_{leak,eqv}=Q_{leak,e}+\frac{Q_{leak,comp}\times T_{ei}}{T_{ci}-T_{ei}}$

Figure 9 - formulation of the Gordon-Ng chiller model (Sreedharan, 2001)

The second typology, used for benchmarking purpose, is presented in figure 8 and 9 in this pages. For further detail see (Shengwei Wang, Xinhua Xu, 2005) and (Sreedharan, 2001).

The proposed methodologies don't want to be comprehensive to the all possible models that can be used. Those are representative of the result of the first investigations of the research team.

But, basically, for the EPBD framework, the "ad hoc" developed CEN Standards will be used and adopted for such a goal.

## 6. CONCLUSIONS

A research work has been started aiming to provide simple tools for continuous commissioning of no- residential buildings. The first step, consisting in the demonstration building selection, is already over and the other phases of the project is already started. Further action will be the implementation of minimum set of measurements, equipments monitoring and models development.

Objective of the paper is to show the possibilities offered by the results of the project, which aim to identify the most interesting methods and tools, and implement it on a freeware software tools that will be distributed by the end of the project. Authors intend also compare the results of the EPBD application with the application of different methods of analysis of energy consumption.

## ACKNOWLEDGMENTS

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