ENERGY EFFICIENCY IN A LARGE UNIVERSITY: THE UNITO EXPERIENCE

Dario Cottafava[1], Paolo Gambino[2], Marcello Baricco[3], Andrea Tartaglino[4]

[1] Lagrange Applied Research Fellow, Physics Dept., University of Turin, dario.cottafava@unito.it

[2] Physics Dept., University of Turin, paolo.gambino@unito.it

[3] NIS Centre of Excellence and Chemistry Dept., University of Turin, Marcello.baricco@unito.it

[4] Energy Manager, University of Turin, andrea.tartaglino@unito.it

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Abstract

The University of Turin (Unito) counts over one hundred buildings in and around the city of Turin. Unito's stock includes buildings with different architectural features and functions: from historical XVIII century buildings to the splendid new Campus Luigi Einaudi.

In 2015 a thorough review of Unito energy consumption was started, The review has exposed several issues: the inhomogeneity of data sets, the lack of tools for data visualization and analysis, the lack, for historical sites, of modern equipment for an efficient management and, finally, the inadequate user awareness about sustainability issues. In the absence of centralized tools for building automation, the first steps to improve energy efficiency require a detailed work in collaboration with the users. For this purpose an interactive web application has been developed. Starting from historical consumption data, several cases of energy waste have been identified: reactive energy, off-hours lighting, sub-optimal heating and air-conditioning schedules etc.

Online Open Data tools and real-time monitoring can also improve users' awareness and their engagement in sustainability, and support the energy management of large building stocks. Due to the heterogeneity of its building's stock, the experience at Unito might be representative and is susceptible of generalizations at the district level.

1 Introduction

In the last decade the European Union (EU) has started the long path to reduce the Green-House-Gas (GHG) emissions, adopting various environmental measures in the context of the celebrated 20-20-20 policy. There are of course various ways to reduce the consumption of fossil fuels and to better manage our resources. One is to expand the use of renewable energy sources, another is to increase the energy efficiency, through structural changes on existing buildings, improvements in the way energy is managed, and by rethinking our lifestyle. Indeed, residential and service buildings are responsible for a large part of primary energy consumption: in the EU this is about 40%, more or less half of which is spent for indoor climate conditioning. (Poel et al, 2007) (Balaras et al). In the following we describe the general approach we have followed to identify and reduce energy wastes, together wih a few preliminary results obtained in our approach to energy auditing in a large buildings stock.

1.1 University of Turin Building Stock

The University of Turin (Unito) manages 120 different buildings in the city of Turin and in the surroundings, for a total of almost 550000 m^2. It has more than 67000 students (62% women, 38% men), about 2000 professors and lecturers and almost 2000 administrative and technical staff. The annual expenditure for energy amounts to almost 10 million €, corresponding to 23.5 GWh of electrical power, 2.08 TOE of gas and a minor quota of other fuels.

Unito's stock is intrinsically heterogeneous. This causes various problems to the energy and logistics management, mainly because of the different architectural features, the disparate functions of the buildings, and the varying technical equipment.

First, for what concerns the different functions, Unito includes libraries, administrative offices, educational and research centers, museums, hospitals, convention centers, stables, a botanical garden and so on, with intrinsic differences in management. For instance, hospitals never close, while administrative offices, libraries and museums follow standard day-time opening schedules; the timetable of the Departments depends on the field: for ex., humanities Departments have classical working schedules, while the science Departments hosting laboratories sometimes have to be kept open, at least partially, day and night.

Second, the buildings in Unito's stock were built in different historical period, and have completely distinct architectural features. For instance, buildings in the city centre go back to the XVIth and the XVIIIth century. This is case of the Rettorato (1713), the Maths Department at Palazzo Campana (1675), the administrative offices at Palazzo degli Stemmi (1683), Buildings in the Science cluster, close to the Valentino Park, were generally built at the end of the XIXth century, though many of them were renovated after the World War II, due to bombings. There are also newer buildings, from Palazzo Nuovo (1966), which hosts the Humanities Departments, to the buildings in Grugliasco (1999), up to the newest Campus Luigi Einaudi built in 2012.

This dishomogeneity affects any type of normalization and possible comparison among consumptions for different buildings. The first effort has therefore been to collect all the available data, to test a few general methodologies and to develop online web tools for fast analyses.

2 Data Mining

In next subsections, we report a few case studies, methodologies and results. All datasets derive from a data mining process. They have been obtained in different ways: reactive energy and time-of-day consumption data have been taken directly from the electrical bills, suboptimal HVAC schedules and off-hours lightings data have been obtained from the Control Room of the Campus Luigi Einaudi, which has a Siemens Building Energy Monitoring System (BEMS) named Desigo Insight and, finally, electric loads have been measured directly using electric current monitors.

2.1 Working-hours and off-time consumption

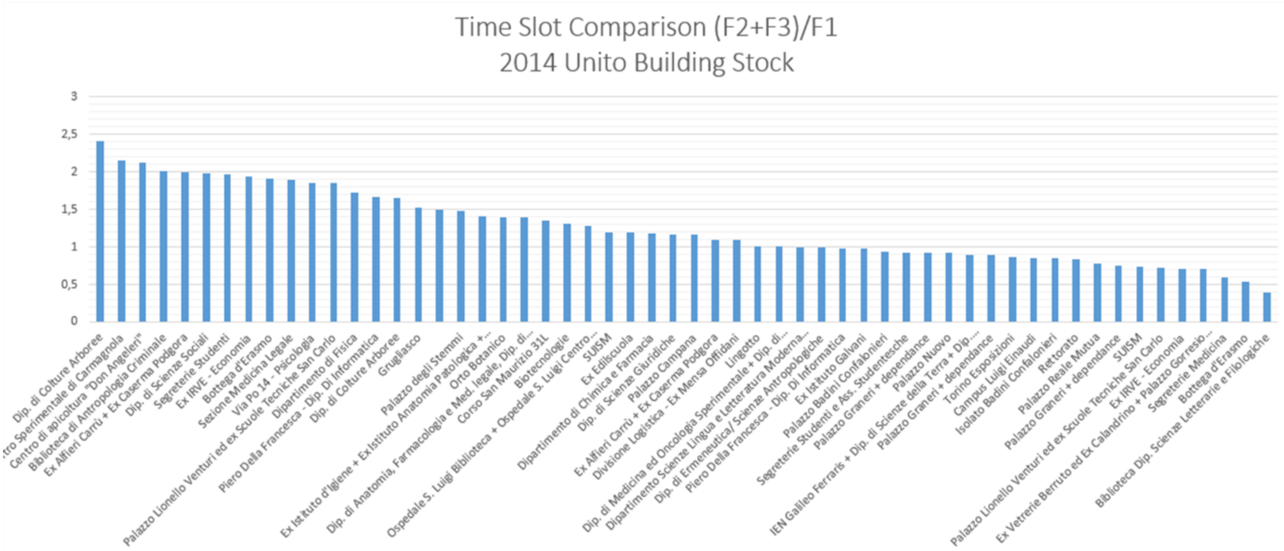

Figure 1: Daily Vs Nightly consumption for Unito's stock. (F2+F3)/F1 ratio represents how consumptions are distributed between working day, night and holiday.

A preliminary investigation has concerned the day and night electricity consumptions. The Italian law adopts time-of-day metering, dividing the day into three time slots, called F1, F2 and F3 and priced differently. F1 corresponds to 8:00-19:00, Monday to Friday, F2 corresponds to 7:00-8:00 and to 19:00-23:00, from Monday to Friday, and 7:00-23:00 on Saturday, while F3 corresponds to 23:00-7:00 from Monday to Saturday, and to the whole Sunday as well as holiday days. Due to the different rates, the electricity bill reports consumption for each time slot. Their comparison can quickly reveal inefficiencies in the lighting and heating schedules. A ratio (F2+F3)/F1 equal to 1 means that the average consumption during working hours is the same as the consumption during nights and Sundays/holidays. Figure 1 shows that there are some buildings which during nights and holidays use more than twice the power than during working days. Of course, one should keep in mind that the working hours (F1) represent annually only about a third of the total time. One should also consider the buildings' function: for some sites like Biotechnology, the Physics or Agrarian Department, the high (F2+F3)/F1 ratio is due to technical equipment that works 24h/24h every day. However, for the Administration building (ratio = 1.97), or the Anthropology library (ratio = 2.01) a ratio greater than 2 suggests some problems in the schedules of lighting or heating.

2.2 Reactive Power

Reactive power is defined for alternating current (AC) electrical systems; it is due to the change of phase in the electrical current caused by capacitors and inductances in the electrical loads. (Sauer, 2003)

The Italian law (art. 9.1 AEEGSI ARG/elt 199/11) defines the amount for the reactive energy penalty, based on the phase difference φ between current and voltage due to capacitive and inductive loads (Musciagna, 2011)

$$\cos\varphi = \frac{E_a}{\sqrt[2]{E_a^2 + E_r^2}}$$

where E_a is the active power, and E_r is the reactive one. The percentage of reactive over active power for $0.9 < \cos\varphi < 1$ is between 0 and 50%, if $0.8 < \cos\varphi < 0.9$ between 50% and 75%, if $\cos\varphi < 0{,}8$ is greater than 75%. According to italian regulations, for each kvarh (V*A) between 50% and 75% of the active power consumers must pay 3.23 cent/kWh (Low Voltage) or 1.53 cent/kWh (Medium Voltage), for reactive power beyond 75% of the active energy 4.21 cent/kWh (Low Voltage) or 1.89 cent/kWh (Medium Voltage).

The computation of possible penalties due to reactive energy can be easily implemented and, in the case of the University of Turin, the total penalty during the year 2014 (for 9 months) has been 8282€ as shown in Table 1. Reactive power exceeding the limits can be cheaply reduced by installing a reactive compensation near the load.

Major Reactive Energy Fine - Cost (€)		
Building Name	**TOTALE 50%Ea<Er<75%Ea**	**TOTALE Er>75%Ea**
Lingotto, Via Nizza 262	**3207,30**	**256,99**
Ex Edilscuola, Via Quarello 11	**1475,56**	0,00
Ex Alfieri Carrù/Caserma Podgora, Via Giolitti 23	**1162,69**	**371,63**
Ospedale Molinette, Via Santena 9	**461,91**	0,00
Ex IRVE - Economia, Via San Marino 10	**446,36**	**0,00**
Total Major Penalty	6753,8223	628,614
Rest of Unito	780,5039	119,9016
Total of Unito	7534,3262	748,5156

Table 1: Main penalties due to reactive energy at Unito

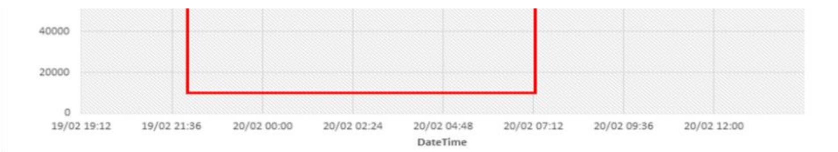

Figure 2: Total electrical consumption for two buildings of Campus Luigi Einaudi. The difference between night and day consumption is less than 14%.

2.3 A case study: Campus Luigi Einaudi

In this subsection, we describe the preliminary investigations regarding the new Campus Luigi Einaudi (CLE). They involved several aspects, from overall electrical consumption, to more detailed studies computers, coffee vending machines and lighting. First of all, Figure 2 shows the total electrical consumption related to one of the four transformers serving CLE, which supplies the D3 and D4 building inside the Campus. In particular, a very small difference between night and day consumptions is observed. In fact, the difference in the average power absorbed at night and during the day is less than 20kW, which corresponds to a reduction of 14% during the night. This possible sign of inefficiency has prompted an electrical audit on building D3 and D4.

2.3.1 Suboptimal heating and air-conditioning schedules

Thanks to the Desigo Insight BEMS we have monitored the heating and ventilation systems for over a week between 18 and 24/02/2015, i.e. in winter.

Figure 3 shows the example of a staff office in the CPS Department in the northern side of CLE (thus without solar irradiance). The main y-axis corresponds to how much the valve serving that office is opened (0-100%) while the secondary y-axis corresponds to the temperatures measured (in the office, outside the building and the HVAC set point of 22C). At a first glance, this figure shows that the heating system works constantly during day and night; indeed, it works harder at night than during the day, because of the high peak in the external temperature (notice that 21-22/02 were a weekend).

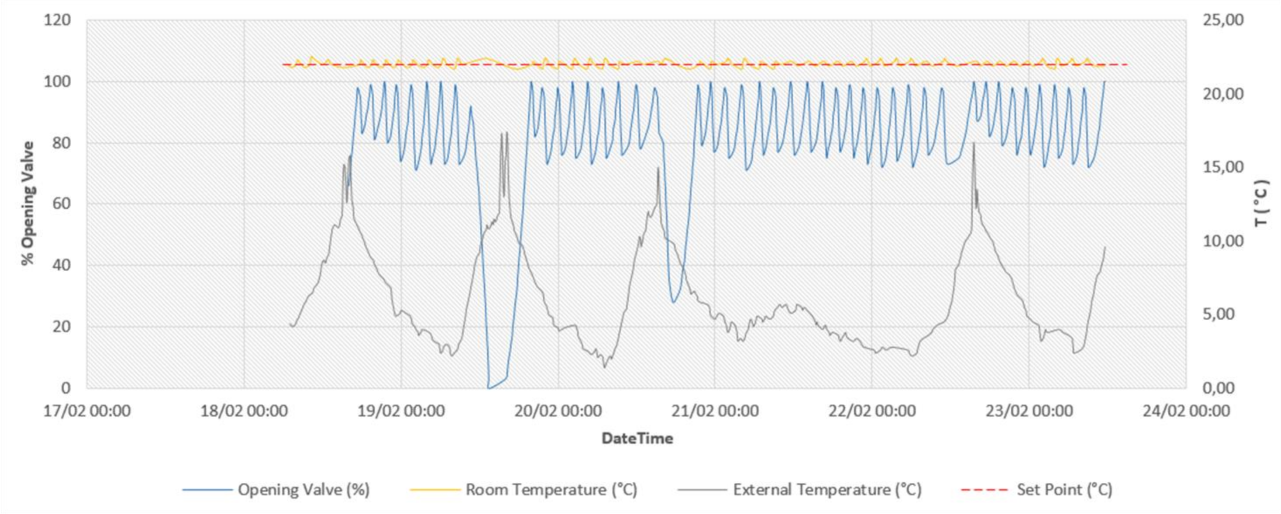

Figure 3: HVAC system at Campus Luigi Einaudi: staff office monitoring in winter. The plot shows the set point (red line) of 22C, the opening of the heating valve (blue line), the temperature in the office (yellow line) and outdoors (gray line).

The ratio of the total area below the blue line (the % opening valve) during nights and weekend and the area for the whole week is 0.73, which gives an indication of how little the system is optimized. Of course, one needs to keep heating during off-hours but the temperature in the office is stable at 22C during all nights and the weekend.

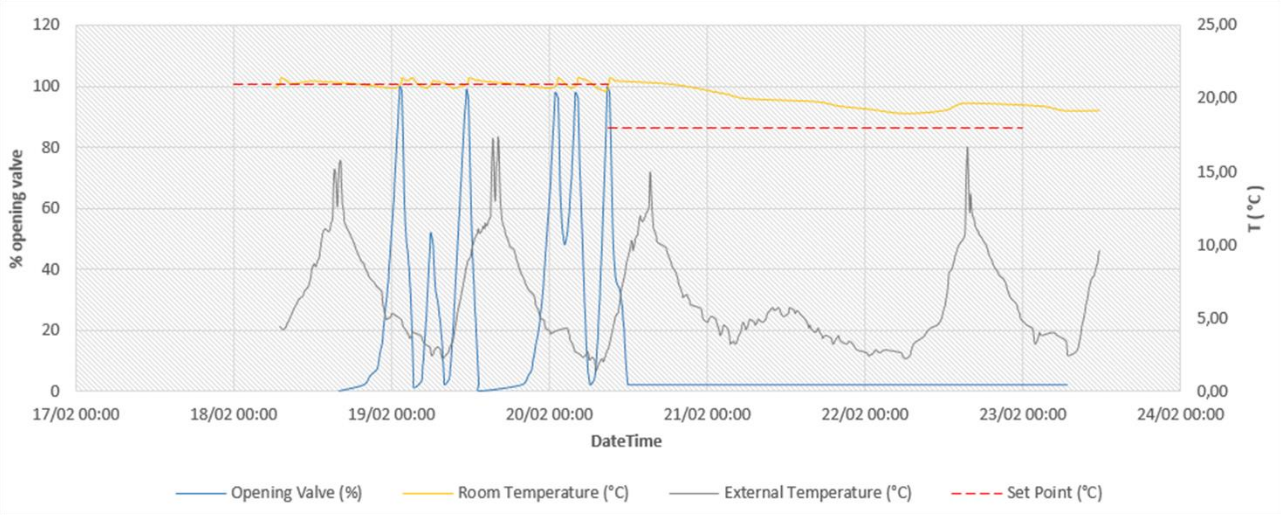

Figure 4: HVAC system monitoring (computer classroom). Changing the set point and exploiting weather conditions a remarkable energy saving can be obtained.

Second, Figure 4 shows the result for a Computer Classroom, on the ground floor, again in the northern side of the Campus. In this case, the heating set point has been changed on 20/02. In the left side of Fig.6 there are several peaks, all at night. After the target temperature has been lowered to 18°C the valves no longer open. This simple experiment proves that by changing the heating settings, or even better using a simple predictive model based on weather forecasting, one can considerably reduce the consumption, especially during holidays and weekend.

2.3.2 Off-Hours Lightings

In this subsection, we consider another example of wrong scheduling, concerning off-hours lightings. Figure 5, on the left, shows the schedule for the garage lightings, while on the right side it shows the external lights, which remained on the whole night, shining on a ping-pong table, even if the entire Campus was closed. In fact, all the external lights were constantly on, from 17:00 until 8:00AM, as well as the garage lights and the security ones, on all floors for the whole night.

It is easy to compute the possible annual saving one can get from a more careful use of external, garage and internal security illumination: respectively 31600kWh, 26100kWh and 80000kWh, which is equivalent to a total saving of 25000 € and a CO_2 emission reduction of 54.5 tCO_2.

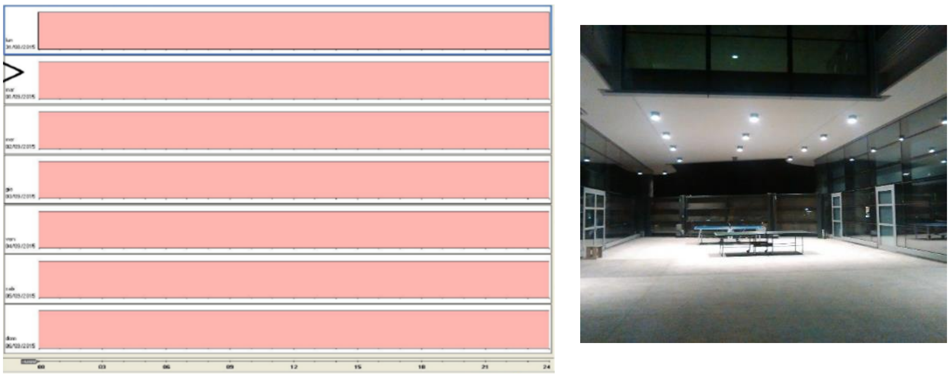

Figure 5: on the left: wrong lighting schedule for garage lighting. On the right: photo from a night inspection.

2.3.3 Generic Electric Loads

Two different targeted electrical audits have been performed during a one week period. The data have been taken with the CT sensor Efergy 2.0 Classics. Figure 6, on the left, points out the power absorption of two PCs in a computer room of building D4. Each PC uses about 20W in standby and 30W when it is working. The waste during nights and weekends is evident. They have been used for only 4-5 hours, for a total consumption of 0.233 kWh, over the 195 hours of the test. In other words, for 191 hours they remained in standby: during only one week the two PC wasted about 8 kWh, which corresponds to the 97% of the total consumption during the monitoring. In general, considering the closing time of the Campus, the 8 hours during the night, the weekend and the holidays during a whole year, about 40 MWh could be saved, for the 369 PCs of the

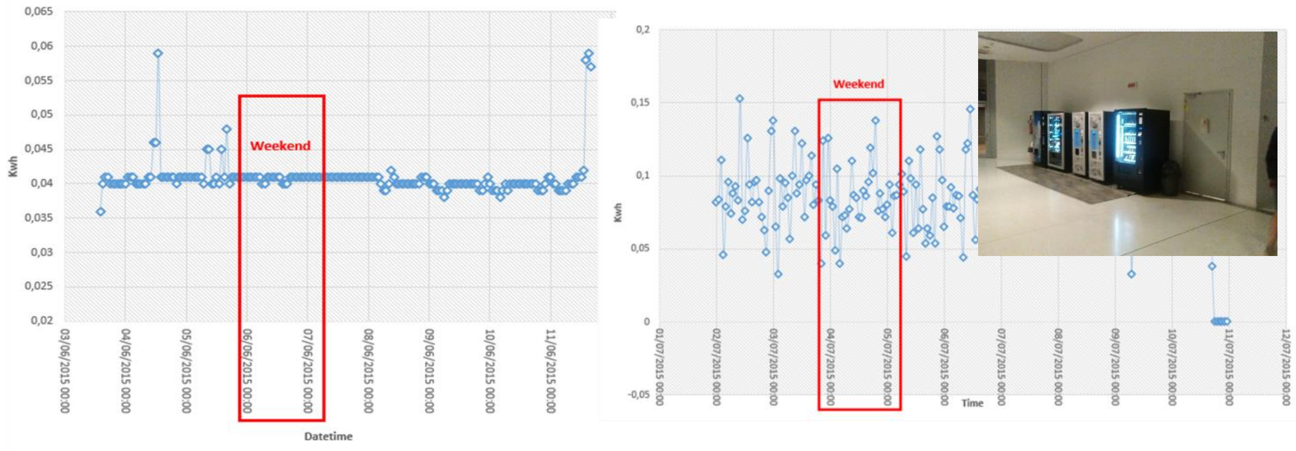

Figure 6: on the left: power monitoring for 2 pc within a computer room during an entire week. On the right: a photo from a night inspection and power monitoring for a vending machine during an entire week.

classrooms, which corresponds to a cost saving of 7500€ and a CO_2 emission saving of 15 tCO_2. In addition, there are PCs and various electronic appliances in the staff and administration offices.

A vending coffee machine has been similarly monitored. Figure 6, on the right, points out the energy waste during the nights and the weekends. The average power absorbed by a single vending machine corresponds to about 90W. Considering the 26 vending machines in the Campus, during the whole year, 12400 kWh can be saved, which corresponds to 2300 € and 4,9 tCO2 of avoided emissions.

3 Large Scale Web Application

We have also started developing tools for real time monitoring, in order to support the energy and the logistics management of Unito's large building stocks. In the last year we have worked on an open-source online web tool prototype for smart data visualization and preliminary analysis. An Open Source library, HighCharts, has been used as starting point. Other open source tools can also be used, such as D3.js (Bostock et al, 2011), GoogleCharts, bokeh, Julia. (Bezanson et al, 2014). These web tools can be used together to PHP, MySQL and HTML to create interactive smart data visualization for any type of dataset with direct query to database, or from a real time stream of data.

For the moment, only the consumption data for the period 2010-2014 have been analysed for all buildings in Unito and used as a starting database. In the next subsections, we will describe some of the tools we have developed and discuss their role in supporting future energy efficiency decisions.

3.1 Online Tools

3.1.1 Buildings/Years Comparison

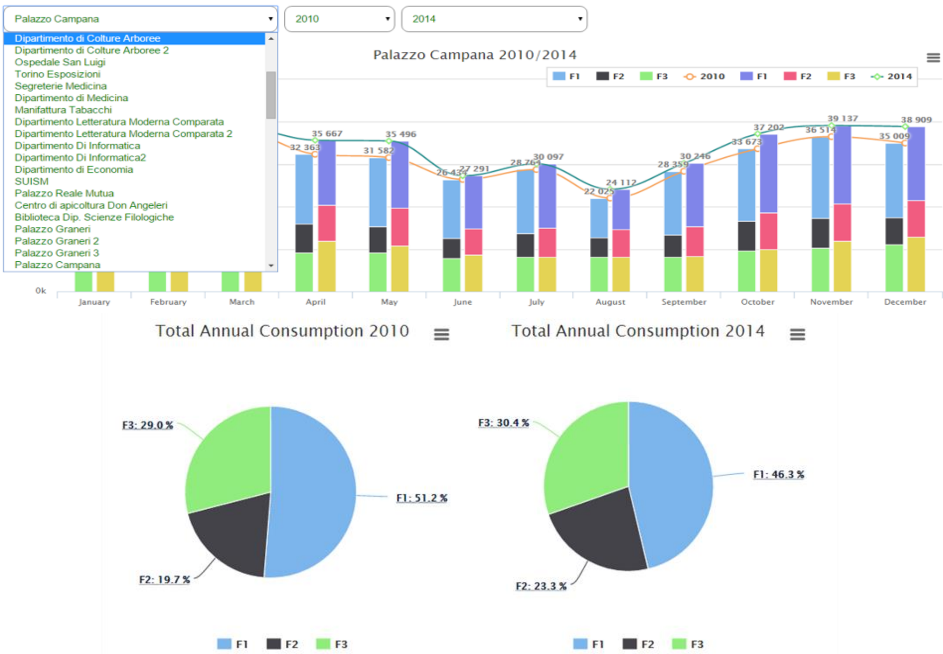

Figure 7: Script for smart data visualization. The tool allows the user to choose different buildings and/or years and to compare their monthly and annual consumptions.

Figure 7 shows the visualization capabilities of the online analysis tool. The user can quickly visualize the data, comparing the consumptions of a building in different years or the consumption of different buildings, and print the electrical consumptions for any building in stock. Figure 7 displays the electrical consumption in 2010-2014 of Palazzo Campana (Maths Department). In particular, the graph shows increasing consumption at nights and weekends (F2 and F3) with respect to daily consumption (F1) and a total consumption higher in 2014 than in 2010.

3.1.2 Scatter Method

The Scatter Method is a preliminary analysis method to identify the top priorities for energy auditing in a large building stock (Ariaudo et al, 2011). In Figure 8 the x-axis represents a rough indicator of the efficiency of a building, namely the normalized electric annual consumption per squared meter (kWh/m^2), while the y-axis represents the total consumption during the year. The graph is split into four different quadrants; any quadrant has a different priority. The top right quadrant represents “very high priority” because of high absolute *and* normalized power consumption; thus, maintenance or efficiency renovation could reduce significantly the total consumption of the total stock. The top-left quadrant represents “high priority”: high total but low normalized electrical consumption. In this case efficiency actions are more unlikely to bring a significant improvement; still, even a small improvement would have an impact at the aggregate level. The bottom-left quadrant corresponds to “low priority”, because of the low absolute *and* normalized electrical consumption. Finally, the bottom-right quadrant corresponds to “medium priority” because of the low absolute and high normalized electrical consumption: efficiency actions, even if necessary, are unlikely to affect the total building stock consumption.

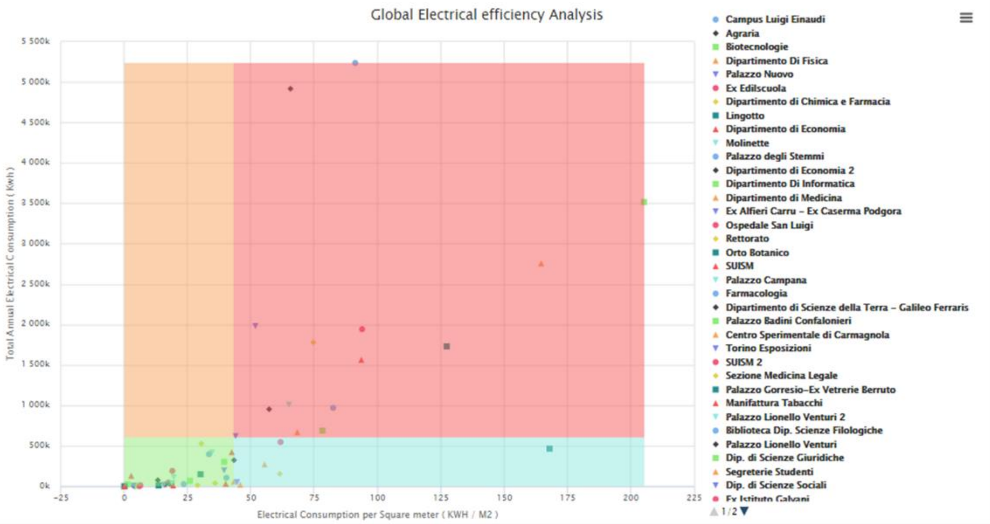

Figure 8: the scatter method allows to quickly identify priorities in efficiency actions. The y-axis represents the total annual electric consumption, while the x-axis represents annual power consumption per squared meter. Each quadrant defines a different action priority for energy efficiency.

3.1.3 Visualization on Interactive Map

A third smart data visualization tool is shown in Figure 9. Thanks to this interactive map prototype it is possible to visualize various types of data collected in the context of the Comfortsense project. This was a living-lab project in the field of the Internet of Thing, focussing on the relation between comfort perception and building management. In this case, the user can choose among objective data, like temperature, humidity, CO_2 concentration, room occupancy, collected by fixed sensors in the building, or some subjective data related to personal feedback on Comfort, thermal comfort, air quality and so on; after choosing a reference interval period, the average during the chosen period is shown directly on an interactive map, with the opportunity to zoom in and out from the entire building to the single classroom. Figure 9 shows an example at CLE. In this case, an overview on people Comfort Feedback is shown. In the Comfortsense project, users could express their global satisfaction within a range from 1 to 5 (1 very uncomfortable, 5 very comfortable). For example 1.75

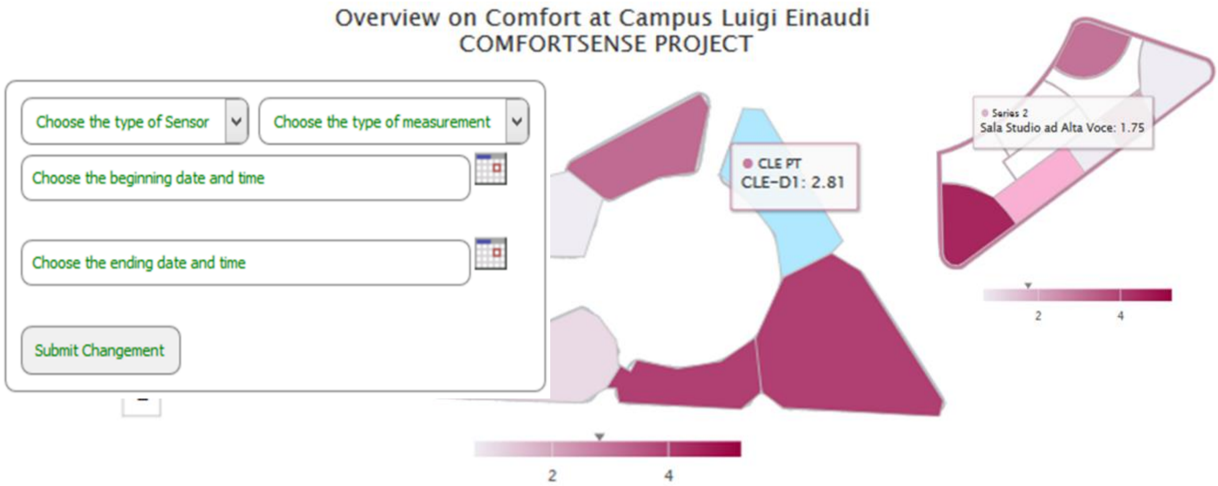

Figure 9: Script for Interactive map. The tool allows to visualize any data collected inside the building and to zoom in and out from the entire building until the single classrooms and offices.

corresponds to mostly uncomfortable people in the particular classroom shown in the Figure. This kind of visualization allows for a quick analysis of the Comforsense data, and illustrates the importance that the users' feedback can have in the energy management of large buildings.

4 Discussion

We have illustrated the first year of work on energy efficiency at Unito by way of a few examples. Some of problems observed are closely related to the reality of a large italian University and the way it has traditionally been managed, with minimal or intermittent attention to the responsible use of energy. While this aspect might be interesting in its own, because it is most likely shared by most italian University and public Organizations, we have tried to emphasize the methods we have employed, which may have wider relevance. We have identified a few general problems: inhomogeneity of datasets, absence of monitoring equipment in historical buildings, lack of tools for data visualization and analysis, and inadequate awareness for sustainability issues. Our approach and the tools we have presented may contribute to solve these problems; in fact a large organization, in order to undertake the path to sustainability and, at the same time, to transparency, can easily adopt some of the discussed approaches: online tools and energy audit, Internet of Things solutions, opensource web applications and opendata are the main strategies. In particular, three different fields of action can be identified:

1. **Data Visualization and Energy Saving**: the aim of systematically analysing energy data in a large building stock such as Unito is to create opportunities to increase the energy efficiency. As a first step, data visualization can help the energy manager to identify wastes and malfunctioning, such as excessive night consumption. Indeed, it is widely recognized that improvements in the building management are a very effective and cheap way to improve the energy efficiency (Holmes, 2007, Goodwin et al, 2013).
2. **User Awareness and Behavioural Change**: the easy availability of energy data enhances the final user's awareness, encourages behavioural change and stimulates final users to adopt a sustainable conduct, such as turning off lights, PCs or heating (Owen et al, 2010, Friedrich et al, 2010).
3. **Scalability of Open Source Software and Hardware**: an open source management system, including software analysis tools, web visualization applications, and a monitoring system can be very powerful and allows for great scalability. It can be generalized and adopted by Public Administrations, by other Universities or schools (Abiona et al, 2009, Lovelace et al, 2015).

5 References

Abiona O., T. Aladesanmi, C. Onime, A. Oluwaranti, A. Oluwatope, O. Adewara, and T. Anjali, and L. Kehinde, 2009, A Scalable Architecture for Network Traffic Monitoring and Analysis Using Free Open Source Software, Int. J. Communications, Network and System Science, 6, 528-539

Ariaudo F., Balsamelli L., Corgnati S.P., 2011, Il Catasto Energetico dei Consumi come strumento di analisi e programmazione degli interventi per il miglioramento dell'efficienza energetica di ampi patrimoni edilizi., 48° Convergno Internazionale AICARR, Baveno, 22-23 settembre. pp. 547-559

Balaras C., E. Dascalaki, A. Gaglia and K. Droutsa and S. Kontoyiannidis, Energy performance of European buildings, in: Proceedings of the Energy Sustainability Conference, Long beach, USA, pp. 387–396.

Bezanson J., A. Edelman, S. Karpinski and Viral B. Shah, 2014, Julia: A fresh approach to numerical computing., arXiv:1411.1607

Bostock M., V. Ogievetsky and J. Heer, 2011, D3: Data-Driven Documents, Computer Science Department of Stanford University

Friedrich K., J. Amann, S. Vaidyanathan and R. Neal Elliott, 2010, Visible and Concrete Savings: case studies of effective behavioral approaches to improving customer energy efficiency, ACEEE American Council for an Energy-Efficient Economy, Report Number E108

Goodwin S., J. Dykes, S. Jones, I. Dillingham, G. Dove, A. Duffy, A. Kachkaev, A. Slingsby, and J. Wood, 2013, Creative User-Centered Visualization Design for Energy Analysts and Modelers, I*EEE Transactions on Visualization and Computer Graphics*, 19(12), pp. 2516-2525

Holmes T., 2007, Eco-visualization: Combining art and technology to reduce energy consumption, C&C, Department of Art and Technology Studies School of the Art Institute of Chicago

Lovelace R., A. Goodman, R. Aldred, N. Berkoff, A. Abbas, and J. Woodcock, 2015, The Propensity to Cycle Tool: An open source online system for sustainable transport planning, University of Leeds, UCL Geospatial Science Seminar Series.

Musciagna A., 2011, Come migliorare la gestione ambientale della piccola e media impresa, Risparmiare energia, ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Owen T., A. Pape-Salmon and B. McMurchy,2010, Employee Engagement and Energy Information Software Supporting Carbon Neutrality, BC Ministry of Energy, Mines and Petroleum Resources, ACEEE American Council for an Energy-Efficient Economy, Summer Study on Energy Efficiency in Buildings 7-233

Poel B., G. van Cruchten and C.A. Balaras, 2007, Energy performance assessment of existing dwellings, Energy and Buildings 39 393–403.

Sauer P. W., 2003,What is Reactive Power? Power Systems Engineering Research Center, Background Paper and Department of Electrical Engineering University of Illinois at Urbana-Champaign Engineering talk.