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Energy consumption data as a decision-making tool for energy efficient interventions in PA: the case-study of Turin

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Abstract

European Directive 2012/27 states that Public Administration (PA) of member states must retrofit at least 3% of the useful area per year until 2020 for reducing their energy consumptions. On the other hand, the need for retrofitting PA owned buildings crashes with budget constraints and the necessity to guarantee services at all the time. For these reasons, when considering large publicly owned building stocks it is fundamental to establish prioritizing methodologies that help decision makers to address investments properly and efficiently. The present work considers the City of Turin as a case study for establishing a methodology to analyze the energy consumption data of a large buildings stock in terms of space heating, DHW and electricity needs. The first part of the work analyzed the stock as a whole, providing useful reference values for specific energy consumptions for different building categories (offices and schools in particular) and providing a tool for investments prioritization. In the second part, five buildings have been analyzed in detail collecting full historical data about electricity and thermal energy consumption. The union between data analysis and focused on-site inspections has allowed individuating specific inefficiencies in the energy-related facilities of the buildings. A preliminary economic analysis has been also assessed to show the strong energy and cost-saving potentials of simple low-cost actions aimed at the reduction of energy consumptions in PA owned buildings.

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Keywords: real-time consumption; buildings; data analysis; public administration.

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1. Introduction

Energy retrofitting of existing real estate has become a crucial factor to meet the targets of reduction of consumption and cost of heating, cooling and illuminating buildings, as well as those of CO_2 emissions reductions.
Publicly owned real estate is an important element because of its elevated energy consumption - essentially caused by the obsolescence of buildings and engineering facilities – and because the many activities and services that take place in these buildings must always be guaranteed. In addition, retrofitting needs inevitably crash with the Public Administration's (PA) necessity to operate within the mandatory budget constraints.
The European Union Directive 2012/27 [1] on energy efficiency states that member countries need to develop and implement an efficiency plan regarding "heated and/or cooled buildings that are owned and occupied by their Central Government". The main goal is to retrofit at least 3% of the useful floor area per year until 2020, starting with buildings that currently show the highest energy consumptions.
Finally, the most influencing factor when considering retrofitting PA buildings is the difficult collection of information and data about the buildings and their related energy facilities. This is due mainly to the old age of buildings and the fact that administration changes through years. This paper focuses on the analysis of energy consumptions of buildings owned by the City of Turin, in Northern Italy.

2. Objectives

The main goal of the analysis is to provide to decision-makers of the City of Turin an instrument for addressing future investments on retrofitting interventions on public owned buildings. This analysis is thus aimed at (1) identifying the most energy consuming buildings (2) collect energy consumption and engineering facilities data and (3) analyze the collected data for identifying the most promising managing and retrofitting interventions. This analysis targets in particular the energy-use inefficiencies that affect the total energy consumption of the buildings, most of which could be solved with low-cost interventions that do not require significant economic efforts and long stops of the activities within buildings.

3. Methodology

The City of Turin owns and manages about 800 buildings with different uses; among these buildings, the most relevant categories are "Offices" and "Schools", both in terms of pure numeric value and buildings' gross volume. The largest part of these buildings consumes energy in the form of electricity (for lighting and appliances) and fossil fuels, mainly natural gas, for heating purposes; an increasing fraction of buildings is heated through the District Heating network of Turin. Most of Offices and Sport Facilities buildings use electricity also to run chillers for cooling purposes, while Schools do not have any significant cooling facility.

3.1. General Analysis

The analysis of buildings' energy consumption has been carried out on a two-level basis: the first level ("general analysis") studies all the buildings owned and managed by the City of Turin and it is aimed at giving large-scale information about energy consumption and expenses for the different buildings categories. The result of the general analysis is the choice of a subset of five buildings on which the second level ("detailed analysis") will be applied; this detailed analysis is focused on electricity and fuels / thermal energy consumptions for each specific building.

The general analysis has been developed as follows:

1. Data collection of monthly consumptions and expenses for both electricity and natural gas for all the buildings owned by the City of Turin.
2. Technical meetings with Facility management and the City of Turin's Maintenance and Operations Department, in order to collect geometry and buildings' management data;
3. Analysis of collected data, which consisted of:
   a. Normalization of energy consumption data, in particular the calculation of fuel energy consumption for the different types of fuel using reference Lower Heating Value (LHV).

   b. Calculation of specific energy consumption (kWh/m^3 referred to the gross heated volume) for the considered energy vectors (electricity and natural gas).
   c. Comparison of calculated specific energy consumption with benchmark reference values by literature;
   d. Evaluation of total energy- related expense for each building.
4. Selection of the buildings suitable for detailed analysis based on (1) energy consumptions (2) total energy-related expense and (3) category of use.

3.2. Detailed Analysis

The methodology applied for the detailed analysis is here described:

1. Creation of a specific dataset populated with meters readings for electricity and natural gas consumptions.
2. Parsing and Missing Data Points (MDP) research of the given databases (see next paragraph).
3. Programming of a specific software for the automatic analysis of the energy consumption data in order to identify probable bad controls and set-ups that could increase the energy consumption of each building. Such hypotheses are then summed up in a proper checklist. The specific outputs of this phase will be graphs reporting:
   a. Energy consumption profiles at different time-scales;
   b. Energy consumption cumulates at different time-scales;
   c. Histograms with annual consumption values;
   d. Energy signatures at different time-scales. The energy signature is a graph that reports on y-axis the given energy consumption and on the x-axis the external temperature at the same time-scale. This tool is used to evaluate the thermal energy consumption variability during the year.
4. Inspection at the specific building site for the verification of proposed hypotheses by the defined checklist.
5. Preliminary estimate of possible energy savings and consequent economic savings.

4. Results

4.1. General Analysis

4.1.1. Thermal Energy

There are 776 currently active thermal consumers, with a total heated volume of about 7.7 Mm^3. Among these, Schools account for about 3.4 Mm^3 and Offices for 1.1 Mm^3; these two categories represent therefore more than 57% of total heated volume of the City of Turin. The total annual energy consumption for heating and DHW, calculated considering different types of fuels, is 288,4 GWh / year (heating season 2011/2012). Both absolute consumption and specific consumption are calculated for the considered categories and distinguished between heating only and heating + DHW purposes. These indicators are summarized in Table 1.

Table 1. Absolute and specific thermal energy consumption by category.

Energy Consumption (MWh)					**Specific Energy Consumption (kWh/m^3)**			
Categories	**N.A.**	**Only Heating**	**Heating +DHW**	**Total**	**N.A.**	**Only Heating**	**Heating + DHW**	**Average**
Cultural Centres	1.809	8.575	3.345	**13.728**	19,5	48,9	83,8	**51,1**
Sport Centres	266	3.875	48.123	**52.264**	83,2	35,3	103,8	**86,7**
Non-classified	-	548	-	**548**	-	10,9	-	**8,2**
Multi-function	-	8.614	35.747	**44.361**	-	36,8	57,1	**47,2**
Residential / Shops	-	1.604	555	**2.158**	-	63,1	2,9	**21,2**
Schools	-	94.726	25.146	**119.872**	-	39,3	53,3	**42,3**
Social Housing	-	184	140	**324**	-	38,7	174,8	**65,9**
Social Welfare Centers	176	2.856	19.692	**22.725**	29,4	40,7	76,3	**58,2**
Offices	1.154	17.923	13.332	**32.408**	9,2	41,4	50,6	**42,9**
Total	**3.405**	**138.905**	**146.079**	**288.389**	**26,1**	**41,0**	**62,6**	**48,8**

If the values of specific thermal energy consumption are compared with established benchmark values, it can be seen that about 72% of the total heated volume for Schools and about 58% for Offices exceed such benchmark values. In Figure 1 specific energy consumption values distribution can be compared with established benchmark values of 33 kWh/m^3 (Schools) [2,3] and 40 kWh/m^3 (Offices) [4]; note that 4 buildings with specific consumptions higher than 300 kWh/m^3 have been excluded to make the figure more readable.

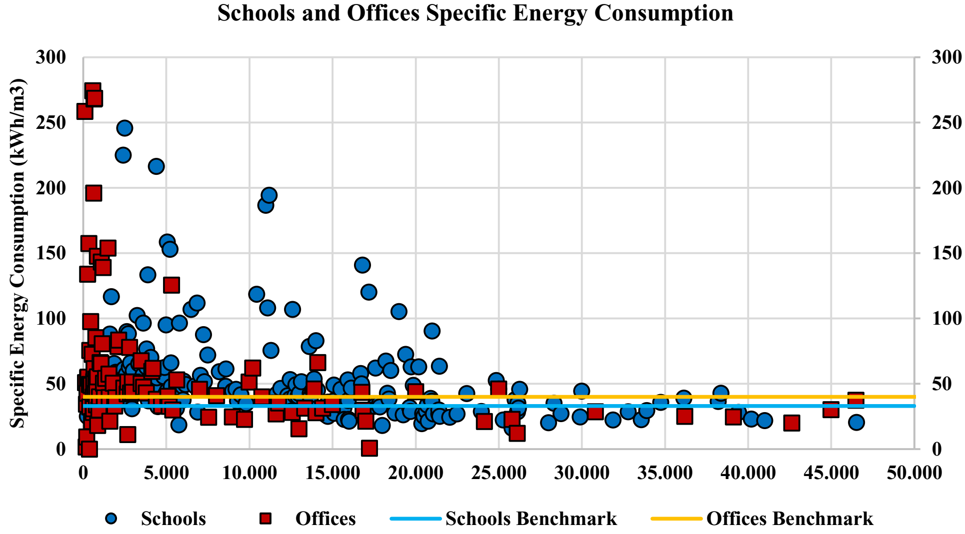

Figure 1. Specific thermal energy consumption - Offices.

Table 2 reports the annual economic expenses of the City of Turin for the supply of fuels.

Table 2. Annual Economic Expenses for supply of fuels and thermal energy.

Category	O&M Costs (€/year)	Energy Costs (€/year)	Total Cost (€/year)	Total Cost (+VAT) (€/year)
Cultural Centres	225.056	1.163.224	1.388.280	**1.679.819**
Sport Centres	456.648	4.413.973	4.870.621	**5.893.451**
Non-classified	31.813	38.871	70.684	**85.528**
Multi-function	677.728	3.768.117	4.445.845	**5.379.472**
Residential / Shops	42.188	145.981	188.169	**227.684**
Schools	2.191.570	10.073.087	12.264.656	**14.840.234**
Social Housing	5.906	23.930	29.836	**36.102**
Social Welfare Centres	556.468	1.909.645	2.466.113	**2.983.997**
Offices	845.939	2.766.039	3.611.978	**4.370.493**
Total	**5.033.315**	**24.302.867**	**29.336.182**	**35.496.780**

4.1.2. Electricity

The number of active users in the buildings owned by City of Turin is currently about 1,200, and the total annual electricity consumption is 79,6 GWh (year 2012), of which about 33,6 (42,2%) for Offices and 19,5 (24,5%) for Schools.

Since both Schools and Offices present normal working schedules that are concentrated at daytime and during weekdays, it is particularly interesting to analyze the electricity consumption subdivided by time-bands [5]. If the time-bands subdivision for F0 buildings (that account for a marginal share of the total) is hypothesized to be the same as for non-F0 buildings, a theoretical total amount of energy that is consumed in the three time-bands for all the buildings in the City of Turin can be calculated. These energy consumptions are shown in the following Table 3. The total expense for electricity in the City of Turin† is also shown in Table 3.

Table 3. Electric Energy Consumption and Expenses by categories.

Category	F1		F2		F3		Total	
	kWh	€	kWh	€	kWh	€	kWh	€
Cultural Centres	749	172.156	383	88.042	478	102.644	1.609	**362.842**
Sports Centres	4.162	957.423	3.300	759.186	4.676	1.005.477	12.139	**2.722.087**
Others	1.926	443.295	1.296	298.267	1.947	418.721	5.169	**1.160.283**
Markets	211	48.570	148	34.133	243	52.443	602	**135.146**
Schools	9.577	2.201.391	3.968	912.043	5.917	1.271.394	19.462	**4.384.828**
Social Welfare Centres	1.003	230.728	584	134.376	903	194.135	2.489	**559.239**
Offices	14.825	3.410.264	6.859	1.577.875	11.883	2.555.408	33.567	**7.543.546**
Total	**32.452**	**7.463.827**	**16.538**	**3.803.921**	**26.047**	**5.600.222**	**75.037**	**16.867.971**

4.2. Detailed Analysis

4.2.1. Buildings Selection

The general analysis preliminary results allow individuating a sub-set of buildings that (1) show high values of relative and absolute energy consumptions, both for thermal and electric energy (2) show high energy-related expenses belong to the two analyzed categories and (3) belong to the two studied categories. These criteria, together with data availability, led to the definition of a sub-set composed as described in the following Table 4.

Table 4. Buildings sub-set for detailed analysis.

Building Identifier	Category	Heated Volume (m^3)
S1	School	39.126
S2	School	36.144
O1	Office	74.000
O2	Office	62.338
O3	Office	48.146

In the following, the most relevant results of detailed analysis carried out through the developed software are shown and commented for each of the studied buildings; the hypotheses made through the data analysis have been verified thanks to on-site inspections of each building.

† The analysis does not include the electricity consumption for public streetlights and traffic lights.

4.2.1.1. School S1

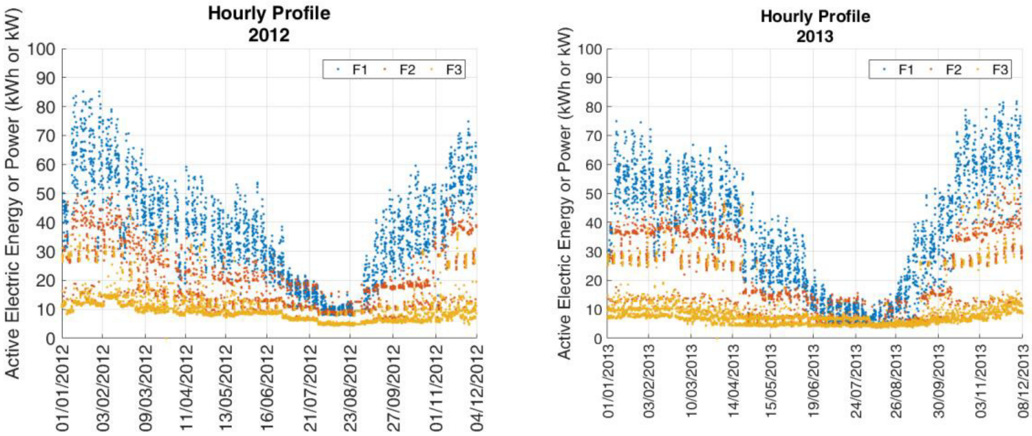

Figure 2. School S1 - Hourly Electricity Consumption Profile for 2013 and 2014.

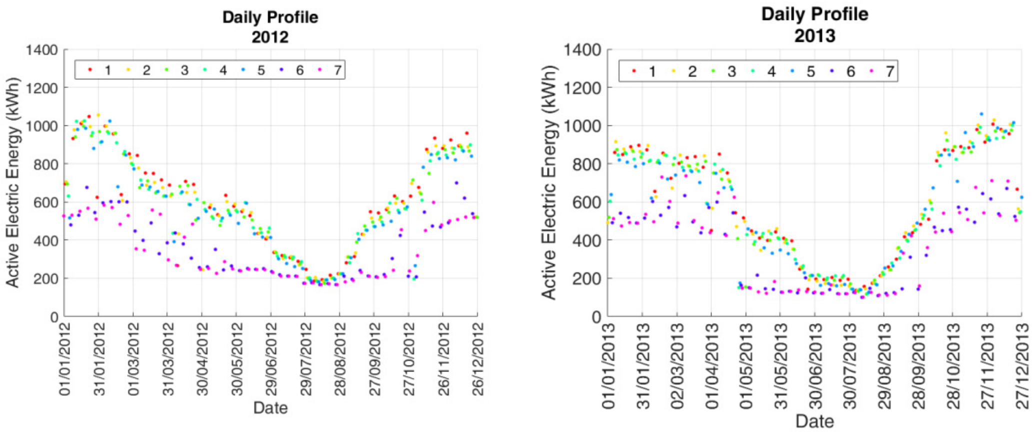

Figure 3. School S1 - Daily Electricity Consumption Profile for 2013 and 2014.

Figure 2 and Figure 3 show two distinctive interesting behaviors:

- A constant electric load of about 7-10 kW during any hour of the year, therefore determining a “base-load” consumption of about 60-90 MWh/year that is not justified by any normal activity carried out within the school. These loads are hypothesized to be related to appliances that are not shut-off after use (e.g. lights and computers) and 24/7 working appliances (e.g. beverage distributors). The on-site inspection reveals the presence of more than 200 personal computers, 15 printers and 9 beverage distributors and refrigerators. These last appliances alone could justify a large fraction of the measured “base-load”. The school works on Saturdays and during the evening, thus justifying the higher consumptions in F2 but not those in F3, which should be close to zero, since no significant electric appliance should be operating.

- A significant increase of electricity consumption during heating season with respect to the non-heating season. This can be seen in both working days (1-5), when the total values are about 1000 kWh/day (heating) and 200-600 kWh/day (non-heating), and weekends (6-7), when the values pass from about 500 kWh/day to about 200 kWh/day. The only possible explanation for such behavior is the presence of fixed-velocity pumps that are switched on/off at the beginning/end of heating season and determine such high values of consumed electricity.

If hourly consumption profiles are shown for four example months (Figure 4), it can be seen that during the heating season weekends electric pumps absorb about 30 kW with schedule 8-22.

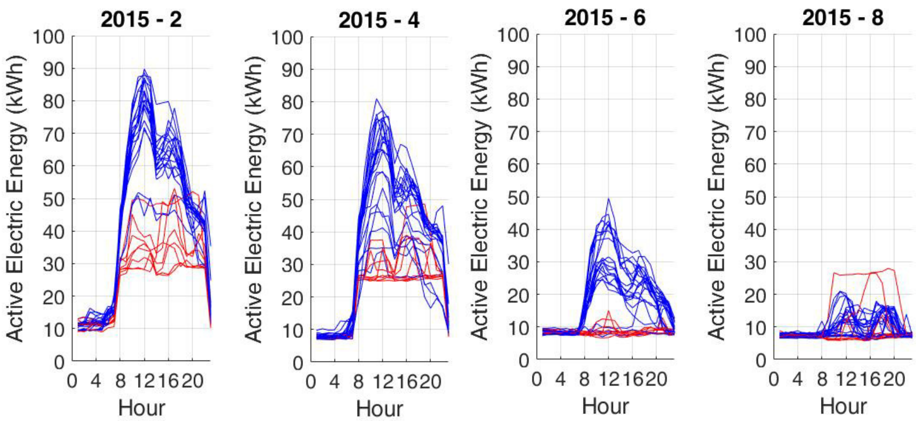

Figure 4. School S1 – Hourly Profiles for February, April, June and August 2015.

Considering thermal energy consumption, the daily thermal energy signature of the building is reported in Figure 5. This shows immediately that the thermal energy consumption of the school during Saturdays and Sundays is similar to that of working days, or just slightly lower. This clearly shows that the operation of the natural gas boiler serving the school is not optimized and continues to heat the school even when not necessary.

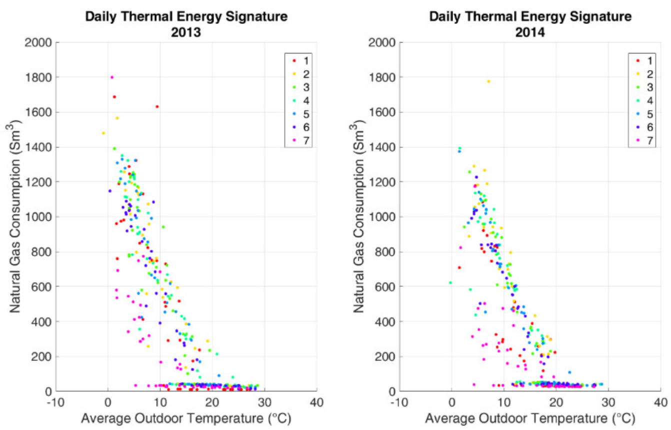

Figure 5. School S1 - Daily Thermal Energy Signature for 2013 and 2014.

Subsequent hypotheses can be made about possible low-cost energy efficiency interventions within the school; these are summarized in the following table, reporting both conservative hypothesized achievable energy consumption reductions and indicative economic savings associated.

Table 5. Hypothesized interventions with indicative energy and economic savings.

Energy Vector	Intervention	Potential Energy Saving Effect	Energy Savings		Economic Savings	
			MWh$_{el}$/year or Sm^3/year	% of the total	€/year	% of the total
Electric Energy	Temporization of non-necessary appliances for sundays and nights switch-off	90% reduction in F3	40	19%	5.400	13%
	Temporization of non-necessary appliances for saturdays and evenings switch-off	50% reduction in F2	23	11%	3.000	7%
	Substitution of current pumps with variable speed pumps	40% pumping energy saved	18	9%	2.400	6%
		80% pumping energy saved	36	17%	4.900	12%
Natural Gas	Enhance heater control for sundays switch-off (or minimum load)	80% reduction of natural gas consumption during sundays and holidays	15.165	10%	10.300	10%

4.2.1.2. Office O2

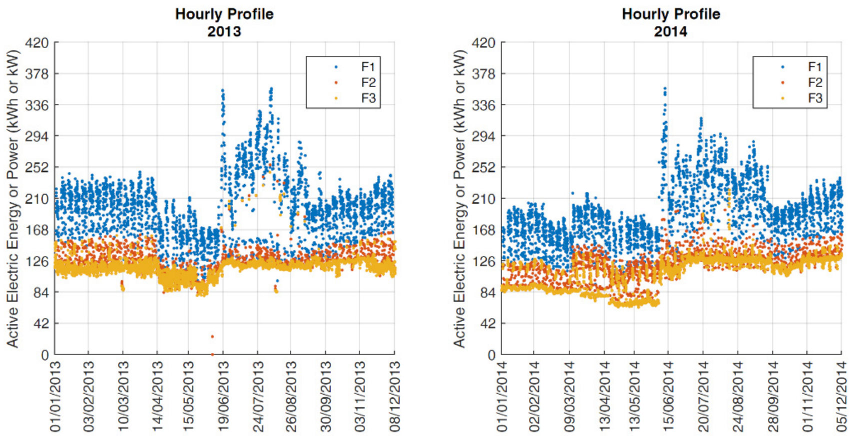

Figure 6. Office O2 - Hourly Electricity Consumption Profile for 2013 and 2014.

Figure 6 shows that in 2014 the electricity consumption of the studied office occurs for 35% in F3 and for 21% to F2. In addition, a constant electric load of about 100-120 kW during any hour of the year, therefore determining a “base-load” consumption of about 870-1050 MWh/year that is not justified by any normal activity carried out within the office. These loads are hypothesized to be caused by appliances that are not shut-off after use (e.g. lights and computers) and 24/7 working appliances (mainly chillers and servers.

The on-site inspection reveals many different aspects that could concur to the present situation and to the anomalous base-load consumption:

- The wiring for lighting management is not optimally designed, since a single switch operates several individual offices and even entire areas for each floor. For this reason, a large number of lights is never switched-off.
- A large number of pumps for heating and cooling purposes is present. A fraction of these works 24/7 since the control device is broken, for a constant absorbed electric power of about 23 kW.
- A small server and switchboards room is present and constantly cooled through six dedicated chillers for a total power of about 27 kW and low set-point temperatures (22-24°C).

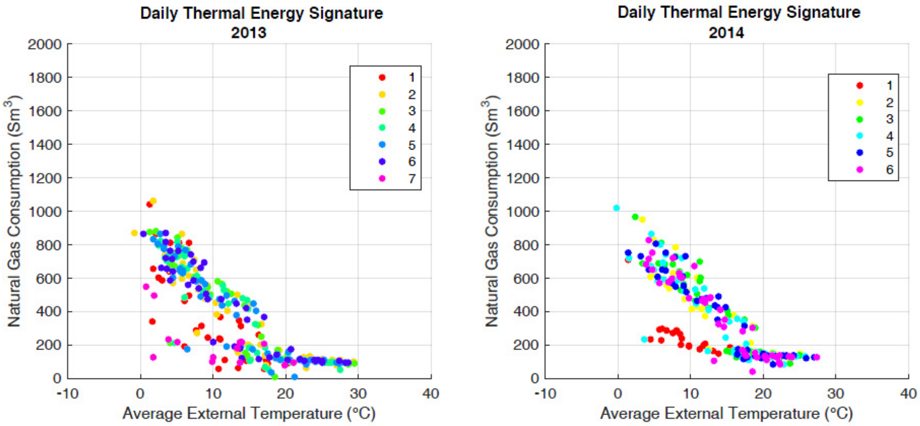

Figure 7. Office O2 - Daily thermal energy signature.

The natural gas heaters are not used during Sundays (during which probably the heater is switched off) in 2014, but on Saturdays the consumed natural gas values are equivalent to normal working days, even if the building is not operational during the weekend.

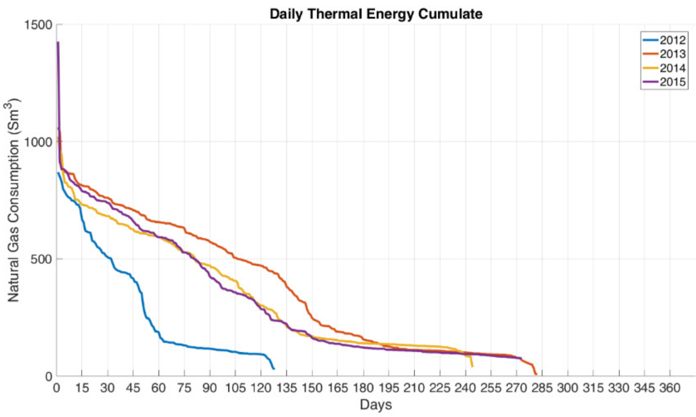

Figure 8. Office O2 - Daily natural gas consumption cumulative.

Figure 8 shows the existence of a natural gas “base-load” that is present even outside the heating season. Through the on-site inspection, the production of DHW is excluded, while 6 AHU for a total of about 60.000 m^3/h of conditioned air are present. The only possible natural gas consumption during the hot season is given by the post-heating batteries of AHU. On the other hand, the given constant level of about 120-160 Sm^3/day of natural gas seems excessive. This high value might be caused by a constant feeding of post-heating batteries (even at night, for example) or by simple bad set-points for air relative humidity.

Some hypotheses have then been carried out, and the obtained results are reported in Table 6.

Table 6. Office O2 - Hypothesized interventions with indicative energy and economic savings.

Energy Vector	Intervention	Effect	Energy Savings		Economic Savings	
			MWh$_{el}$/year or Sm^3/year	% of the total for the given vector	€/year	% of the total for the given vector
Electric Energy	Temporization of non-necessary appliances and lights for sundays and nights switch-off	20% reduction in F3	85	7%	11.600	4%
	Temporization of non-necessary appliances for saturdays and evenings switch-off	20% reduction in F2	47	4%	6.400	2%
	Optimization of chillers operation for the server-room climatization	10% reduction in F2-F3	66	6%	9.000	3%
	Repair of control device on-board of pumps	23 kW reduction during the non-heating hours	42	4%	5.700	2%
	Increase of cooling set-points and use of free-cooling for the climatization of the server room	40% reduction in F3 during winter, 20% during summer	127	11%	17.400	7%
Natural Gas	Enhance heater control for saturdays switch-off (or minimum load)	80% reduction of natural gas during saturdays and holidays	9.099	10%	6.100	10%
	Reduce the consumption of post-heating batteries	30% reduction in hot season	3.600	4%	2.400	4%

5. Conclusions

In this paper, a methodology for assessing the energy consumptions in PA buildings has been presented and applied to the case-study of the City of Turin. This methodology has been developed as a support tool for a PA to prioritize the most effective retrofitting interventions starting from the available data on energy consumption. The quality of the output is proportional to the quality and detail of the monitoring data, which are generally higher for electricity than for heat production systems. A detailed analysis has been applied to few buildings, and the relative results that are here shown for two examples provide an insight on the potentiality of detailed analysis of actual operation of energy plants in public buildings. Some possible improvements have been proposed, mainly at low investment cost, and the consequent efficiency increases and economic costs have been preliminarily estimated.
The proposed methodology could become an interesting support for PA to deepen their knowledge about the potential optimization of their energy equipment operation, which can often lower energy consumptions and related costs without significant investments.

References

[1] Directive 2012/27/EU of the European Parliament and of the Council on Energy Efficiency (amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC) [2012] OJ L315/1.
[2] Bruhns H, Jones P, Cohen R, Bordass B, Davies H. CIBSE REVIEW OF ENERGY BENCHMARKS FOR DISPLAY ENERGY CERTIFICATES - Analysis of DEC results to date. 2011.
[3] Dias Pereira L, Raimondo D, Corgnati S, Gameiro da Silva M. Energy consumption in schools – A review paper. Renew Sust Energ Rev. 2014; 40:911-922.
[4] School of Management - Dipartimento di Ingegneria Gestionale - Politecnico di Milano. Energy Efficiency Report - L'efficienza energetica in Italia: soluzioni tecnologiche ed opportunità di business nell'industria, i servizi e la Pubblica Amministrazione. 2013.
[5] Autorità per l'Energia Elettrica e il Gas. Delibera n. 181/06 e s.m.i. Gazzetta Ufficiale n. 211; 11/09/2006.