Assessing the energy performance in the tertiary building sector. On-site monitoring of large-scale retail chain.

Jacopo Toniolo, Marco Masoero, Chiara Silvi

[1]DENERG - Politecnico di Torino

Abstract

The paper addresses the challenges of monitoring and benchmarking the energy performance of HVAC systems and other electric loads in the tertiary building sector. This information is necessary in many areas to enable the recast EPBD to achieve its full impact in reducing energy use in Building Technical Systems. The analysis covers hourly data analysis and benchmarking based on monthly data. The collection and processing of energy performance data could be part of the inspection of HVAC systems, aimed at identifying technically feasible and cost-effective Energy Conservation Opportunities (ECO's), as required by EPBD.

The paper is based on the IEE iSERVcmb project (www.iservcmb.info), which intends to monitor, for periods of at least a year, the sub-hourly energy consumption of 1600 HVAC systems installed in buildings around the EU Member States. One of the main aims of the project is to produce ranges of benchmark performance for the energy use of HVAC systems and components relative to the activities that are being served. The paper presents the pros and cons of existing benchmark schemes for HVAC systems, and discusses the strategy to be adopted for the production of these iSERVcmb HVAC energy consumption benchmarks.

Introduction

Energy efficiency in buildings is definitely arising as a primary energy conservation tool on the path of sustainability of cities and human agglomerates. Air conditioning systems can account for up to 50% of the energy used in a building, and have therefore been specifically targeted by energy legislation in the last decades. The last Energy Performance of Buildings Directive (EPBD), published in 2010, requires regular inspection of air-conditioning systems [1]. While it is evident that a well controlled and maintained HVAC system is more efficient than a poorly controlled and maintained one, it is not proved that Inspection alone can ensure such conditions. In Europe, IEE Harmonac project shows that HVAC inspections, even if developed with a high level of detail, are not sufficient to ensure system efficiency. In addition, the presence of a Building Management System (BMS) is not a sufficient condition to achieve a satisfactory HVAC system efficiency. To reach this result, the BMS needs a correct design and commissioning, a frame dedicated to energy monitoring and a properly instructed operator.

ISERVcmb project, funded by European Commission in the framework of Intelligent Energy for Europe program (IEE), is mainly focus on HVAC system consumption. The basic idea is that a well monitored system would allow more specific inspections and energy audit and, in addition, gives the possibility to decrease mandatory inspections frequency. The project is intended to collect energy consumption data from end users (building owners and managers) continuously: it was possible to collect data from different tertiary sector buildings at a 15 minutes frequency (mainly electric consumption of different loads). In this paper we focused on the large-scale retail channel buildings. We were able to collect hourly data of electric consumption, disaggregated by different loads. Data acquired permit to verify actual control of lighting and HVAC systems (Diagnosis) and to compare building consumption on a monthly and annual basis (Benchmarking).

To improve efficiency of Heating, Ventilation and Air Conditioning (HVAC) systems, it is essential to understand which are the energy conservation opportunities (ECO) with the best benefit/cost ratio. Intending the ECO as a large group of actions (from changing the schedule to replacing the main chiller/boiler) an adequate statistical basis of data is needed, in order to understand which part of the system is more consuming and which part could be improved with small effort. In the past twenty years a large number of papers about energy consumption in buildings were written; nevertheless a comprehensive and accepted specific set of data on energy uses for different activities in the tertiary sector is still lacking. The main reasons for this lack of data are mainly linked to data collection. Due to the variety of building and HVAC systems, it is difficult to standardize collected data, on the other hand end users are often reluctant to provide their energy consumption data.

Data acquired and Buildings

Consumption data were collected by in situ electric meters installed in the main electrical boards. Due to the design of electric system, sometimes more electric meters are needed to measure a specific load (is the case of lighting, often partially served by UPS). Electric meters are nowadays quite cheap (300-600 € + Installation costs), nevertheless the cost of data acquisition and analysis is still variable and relatively high (200-500 € per year per meter). The large-scale retail channel company analyzed has around 200 buildings in Italy, with around 30 Large-scale retail buildings (building with more than 6'000 square meters of Gross Internal Area, GIA). Twenty of those buildings are monitored, while we focus on 9 buildings (Table I). In some of those buildings was not installed specific load metering due to complexity of electric panel and electric distribution: to collect all the lighting lines could be necessary more than 10 electric meters. This implies that for some buildings we had just some specific load metered (Figure 1).

The buildings share the design of space distribution and activities: typically the main sale area is surrounded by specific food preparation area such as bakery, fish shop, grocer's, etc. The main sale area has refrigerated cabinets served by two centralized systems. One system serves food refrigeration at 20°C, while the other serves food refrigeration at +4 °C. Both systems have reciprocating electric compressors and are air condensed.

All the buildings analyzed are served by air HVAC system based on rooftop units. Some buildings have gas boilers and air condensed chillers that provide respectively hot and cold water to the rooftop heat exchangers. In some case the rooftops have a gas boiler and an electric chiller onboard. The buildings are open 7/7 for the whole year, and the working hours are typically from 09:00 AM to 09:00 PM.

Table I:Yearly specific consumption of different electric loads (kWh/m2)

SHOP	LOCATION	SALE AREA (m^2)	LIGHTING	Refrigeration (4°C)	Refrigeration (-20°C)	HVAC	OTHER LOADS	TOTAL
A	Teramo	8877	69.8	47.3	12.2	81.3	279.5	490.1
B	Monza	7250	N/A	86.9	41.8	100.3	460.3	689.3
C	Pavia	12576	172.4	N/A	35.1	17.7	218.7	443.8
D	Udine	7000	38.7	51.1	16.4	45.1	348.8	500.0
E	Cesena	13000	54.2	57.8	46.2	55.7	195.3	409.2
F	Milano	5403	123.2	93.5	57.2	97.8	458.5	830.2
G	Pescara	8123	72.2	52.8	18.4	37.5	352.4	533.2
H	Chieti	5900	72.7	16.8	35.5	17.5	414.6	557.0
I	Bergamo	13400	N/A	55.6	19.9	62.9	399.3	537.7
mean		9058.8	86.2	57.7	31.4	57.3	347.5	554.5
std.dev.		3132.7	46.1	23.9	15.5	31.2	97.9	130.1

Yearly data show a moderate variability of global electric specific consumption among the different shops. The variability is high for HVAC and other systems, demonstrating that electric consumption could not be forecasted just based on square meter of sales area (other typical factors affecting consumption are occupation, climatic conditions and internal loads).

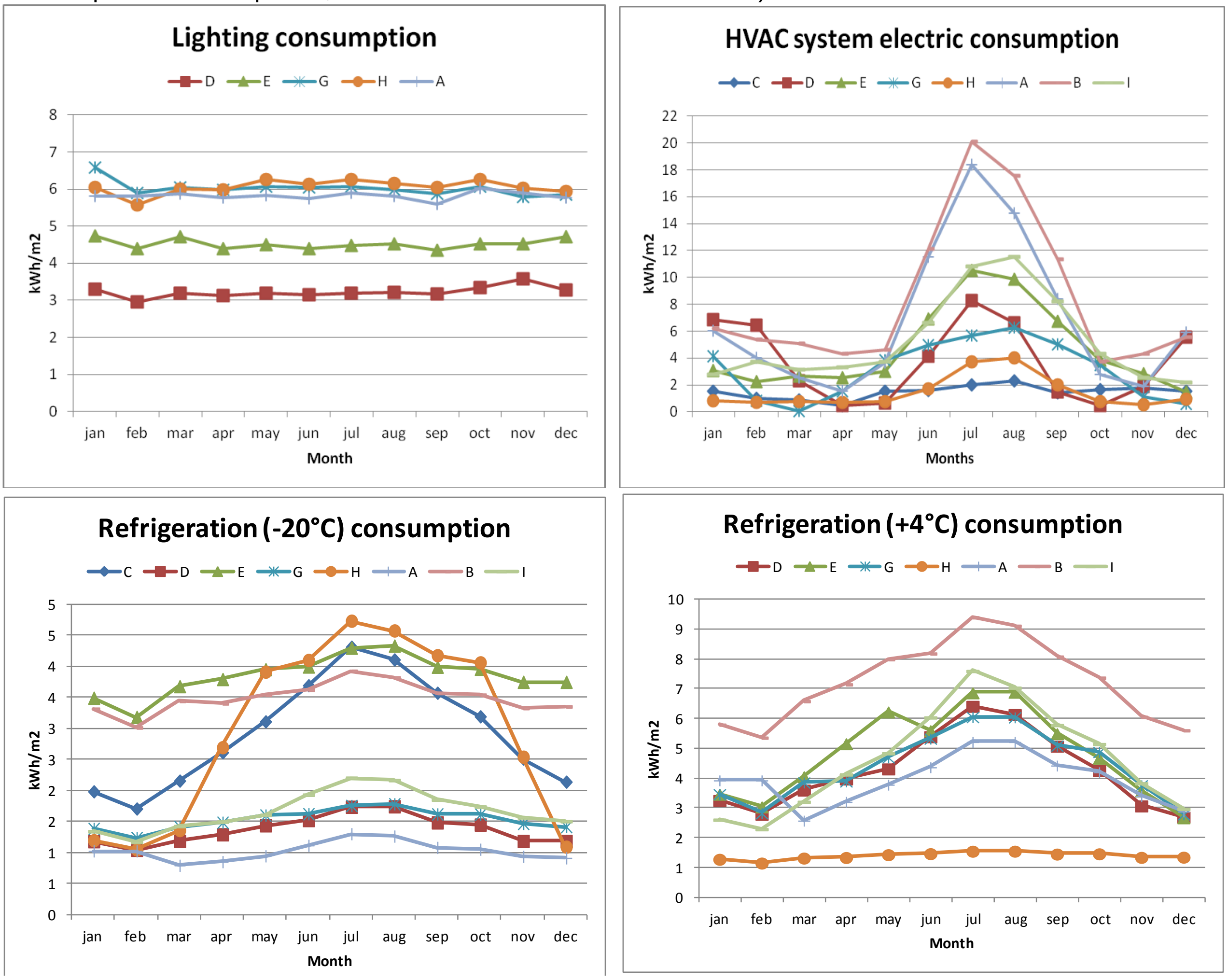

Figure 1: Monthly specific consumption of different electric loads (kWh/m2)

Monthly consumption analysis shows different behaviors for specific loads, depending on climatic conditions and working days (Figure 1). The lighting consumption shows an almost constant behavior, demonstrating that the buildings analyzed do not have automatic control of light flux. Since the average consumption is about 86 kWh/m^2 per year the possibility to dimmer the lighting power in accordance with measured light intensity has to be evaluated. HVAC system consumption shows the highest variability, as expected, demonstrating that the systems control are working at least sufficiently, decreasing the consumption during the middle season. Two of the buildings analyzed show exceptional high consumption during summer. The A building is situated in the center Italy (42°52' N), while the B building is located in the northern Italy (45° 35' N). The high consumption is related to the specific condition of the Chiller units, which suggests an inspection and verification.

Food refrigeration systems have different behaviors. Taking into account food refrigeration at -20°C, generally the consumption is relatively stable, except for the building situated in location with high temperature difference from Summer to Winter. Food refrigeration at 4°C is more affected by external conditions. That as to be expected, since the temperature difference between the condenser and evaporator will vary more in food refrigeration at 4°C system than in the food refrigeration at -20°C. In the graph are clearly visible two buildings with anomalous consumption. H building shows extreme low consumption, if compared with the average, which could imply a small amount of food refrigeration at -20°C cabinet in respect of sale area. On the other hand B building shows higher consumption than the average: it has to be analyzed if this is due to the number of cabinets or to a poor efficiency of the system.

Method

Hourly Data analysis

Data availability permits to define to type of analysis. On the beginning it's possible to evaluate if the hourly consumption of specific load shows possible energy conservations opportunities. In the supermarket activities specific inefficiencies was addressed, concerning HVAC system, food refrigeration system and lighting. This type of analysis, using carpet plots shows in a qualitative ways the frequency of inefficiencies along the weeks.

It is also possible to verify the results of different type of refurbishment or retrofitting. In this paper we will show the effect of glass covering of the refrigerated cabinets.

Monthly Data analysis

To define a possible benchmarks for electric consumption, of specific loads, in the supermarket activities, we define a method to normalize the HVAC consumption in respect of different variables. Generally the variables needed are [2,3]:

- Internal gross area
- External climatic conditions
- Working hours
- Type of HVAC system

In our study we do not consider as an input variable the HVAC system, because we want to visualize the difference between different systems. On the other hand we consider has an input the internal electric loads, to better define the consumption due to HVAC system. To do that we utilize a simple Multiple Linear Regression, in its typical form:

$$E(Y \mid X) = \alpha + \beta_1 \mathrm{X}_1 + \beta_2 \mathrm{X}_2 + [...] + \beta_n \mathrm{X}_n$$

We define a model without internal electrical load (3 variables model) and one with internal electrical load (4 variables model).

Results of hourly analysis

This section will show hourly data analysis for specific loads of some buildings. Some sample, among the most representative, were chosen.

HVAC consumption verification

As seen in the monthly analysis, two buildings (A and B) present exceptionally high consumption during summer. With the hourly data it is possible to check if this is due to poor schedule control or to efficiency/system layout. As shown in further figure, the schedule control appears to be correctly related to working hours. It is possible to determine that the specific HVAC system has a poor efficiency with respect to the other buildings. The hourly analysis of the B building HVAC system shows the same result.

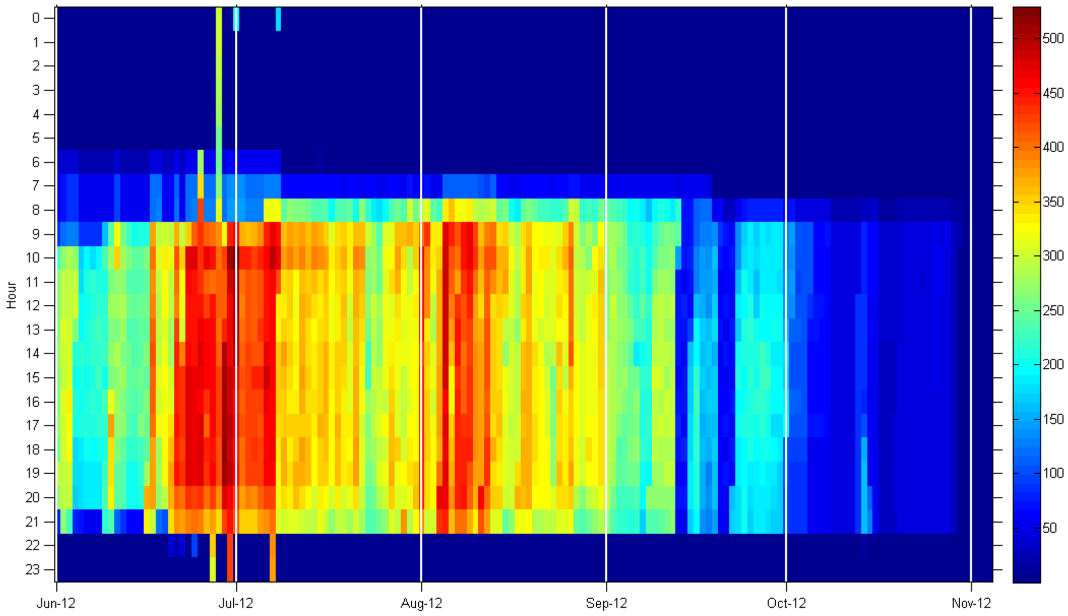

Figure 2: Rooftop electric consumption of building A (kWh)

Lighting efficiency

As for the HVAC system, also in this case is possible to evaluate if the schedule or the system is efficient. Data show that the cause of inefficiency are mainly two:

1. Poor schedule control
2. High base load

In the first case the schedule is not well controlled during night, causing consumption even in non-working hours, as seen in Figure 3.

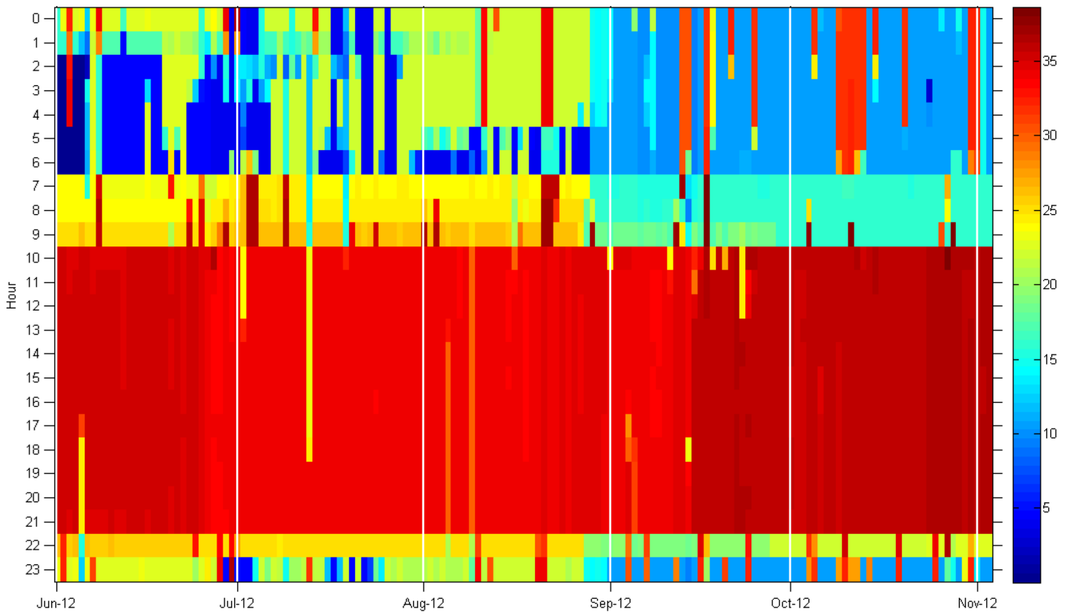

Figure 3: Lighting electric consumption of building G (kWh)

On the other hand some system shows high base loads during nights, as seen in Figure 4.

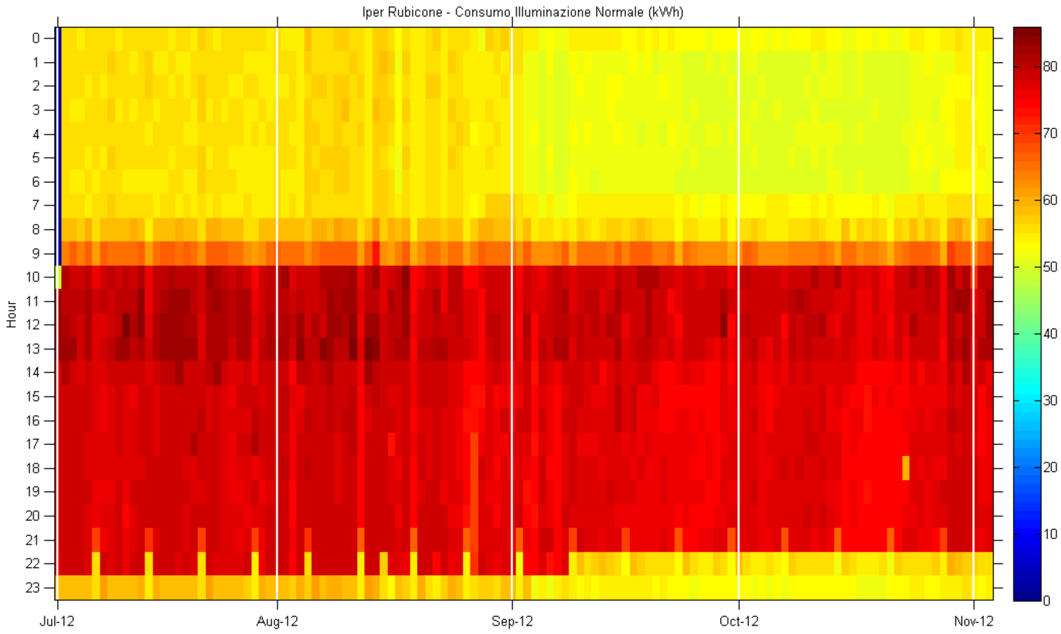

Figure 4: Lighting electric consumption of building E (kWh)

Measuring energy saving from cabinet glass covering

Hourly data permit to verify potential energy efficiency measures for the specific activity. In some of the buildings analyzed the refrigerated cabinets were refitted with a glass covering. Refrigerated cabinets are a sensible task in retail chains: it is obvious that open cabinets are inefficient but marketing theory is still unwilling to impose any physical obstacle between potential customer and products. In the building analyzed the daily economic income was calculated before and after the glass covering, finding no explicit correlation between products sell and covered cabinet. Some test were also made to understand if the customers would close the cabinet: evidence showed that at the end of the day all the cabinet was closed without workers intervention.

The cabinet analyzed where covered with a double glazing system. The composition of the covering packet is 6mm glass (hot side) 10mm of air and 4mm glass (cold side) with low emissivity coating. The thermal transmission of the double glazed cover is 1.5 W/m^{2}K. Where the cabinet are connected to a centralized refrigeration system, the glass covering will not modify air conditioning consumption in summer. Stand-alone cabinet instead, impose a huge thermal load to the conditioned space; in this case covering them will diminish also air conditioning consumption. The energy saving related to this measure was about 22% on the fod refrigeration at 4°C system electric consumption, hourly data shown in Figure 5. It is clearly seen that at the end of August the cabinets were retrofitted.

Main findings from hourly analysis

The monitoring data and analysis shows the following results about the buildings considered:

- There is a relatively small variability in specific global electric consumption.
- There is a big variability in specific loads consumption (HVAC, food refrigeration, lighting).
- Lighting system is not well managed.
- Installing double glass on refrigerated cabinet has huge impact on electric consumption.

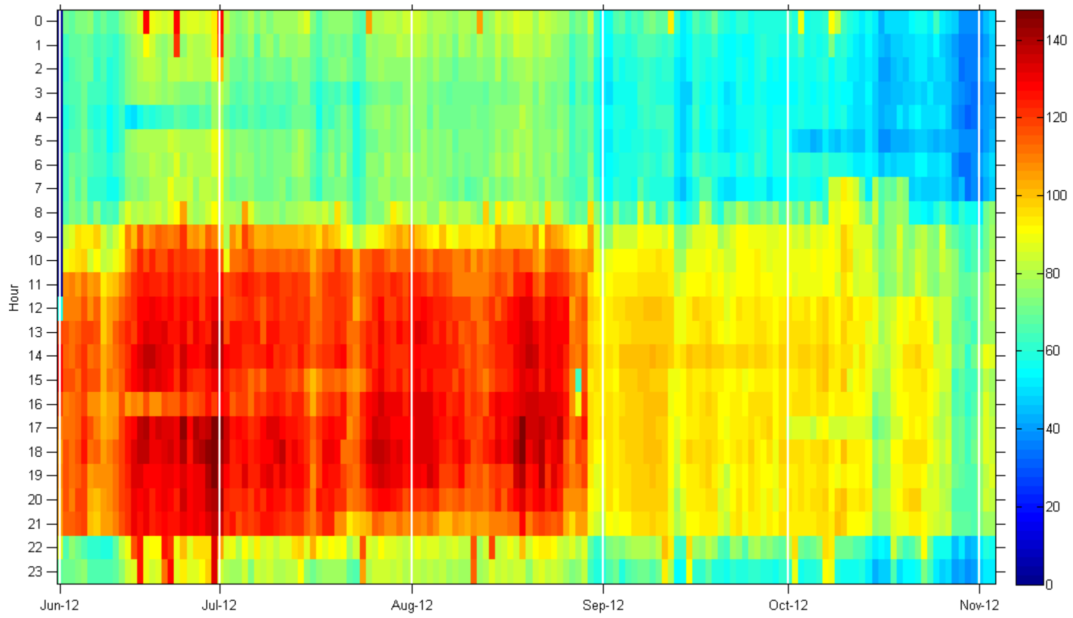

Figure 5: Food refrigeration (positive temperature) chiller consumption in building F (kWh)

Results of monthly benchmark analysis

This section will show monthly benchmark for HVAC system consumption, defined with three and four variables. The supermarket consumption compared is the A.

Focusing on benchmarking evaluation for HVAC consumption, a multi-linear regression was evaluated to describe the HVAC consumption in respect of:

1.	Gross internal area	GIA
2.	Climatic conditions (monthly mean temperature)	ExtT
3.	Working hours	Occ
4.	Internal loads	Loads

Two models were analyzed, one with just three input variables (GIA, ExtT, Occ) and one with four variables (GIA, ExtT, Occ, Loads). The variables were selected based on similar studies [2,3,4,5]. The measured internal loads represent an innovation in this field, since generally the consumption data are limited to total electric income [6]. The 3 variable model does not provide a good output, since the error between the regression output and the measured data is more than 20% (Figure 6). R^2 values is about 0.4.

The 4 variable model, instead, produces good correlation, R^2 values is about 0.8, with the result always below the 20% error (Figure 7). The model proposed work quite well since the buildings belong to the same Company, which has similar distribution of spaces and activities. Significant variability in load intensity was found in previous chapter; hence the model help to select the buildings that has anomalous consumption.

Definitely, HVAC consumption benchmarks without taking into account internal load metering are affected by a large prediction error.

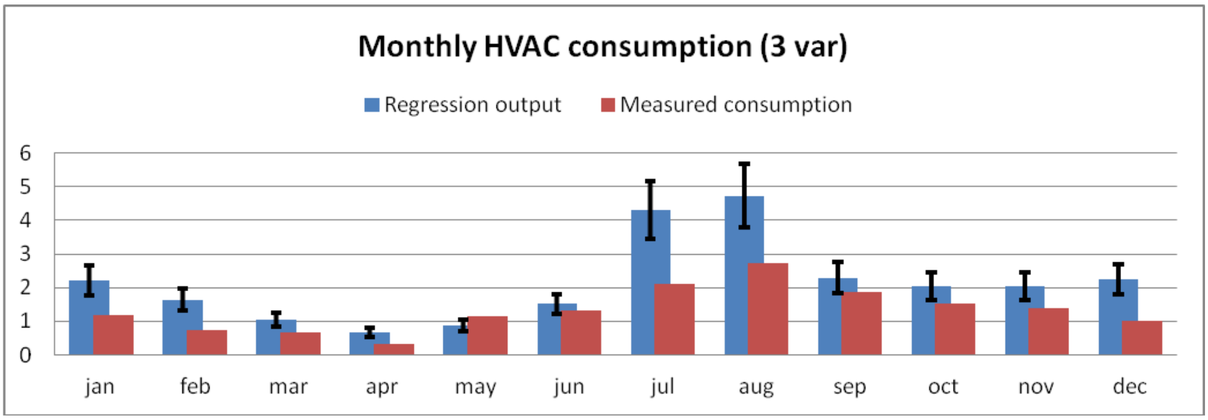

Figure 6: 3 variables model results (kWh/m^2)

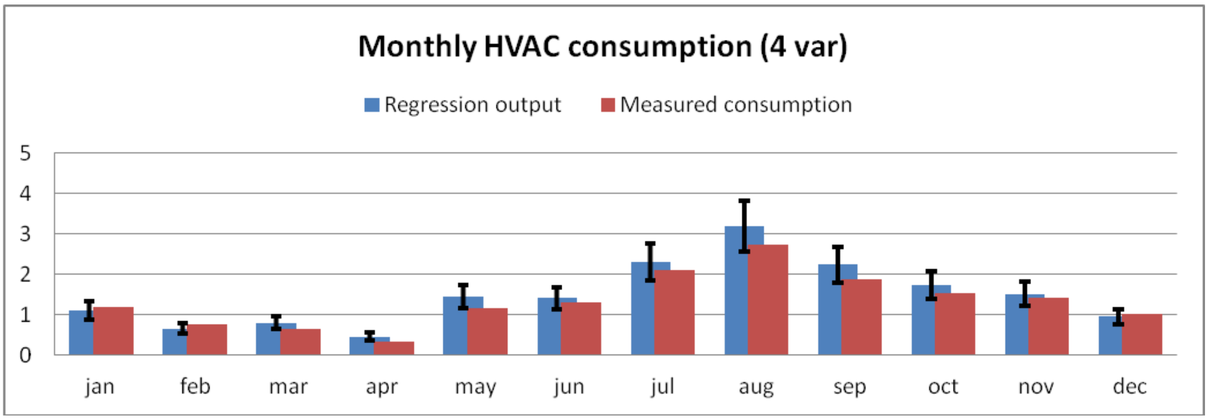

Figure 7: 4 variables model results (kWh/m2)

General Conclusions

Large-scale retail chain buildings have an impressive specific electric consumption. Since they are working 356 days per year, every efficiency measure that could be implemented will save high amounts of energy.
In addition to the first findings, shown by electrical hourly consumption, we can define a set of recommendation from the experience gained. Those recommendation, taken from the work on the total set of Italian buildings, are focused specifically on metering system installation and data availability.
The information on building and system varied sensibly. Also the reliability of metered data is depending on those factors:

- Presence of an Energy Manager;
- Age of the building and system;
- Presence of an ESCO managing the HVAC system.

An important help in energy metering should be the BMS, if properly designed and installed. BMS can effectively perform energy metering (provide energy metering functions are clearly indicated among the design specifications of some BMS). Our experience indicates, however, that adding such capability to an existing BMS implies sometimes high costs and technical problems that are difficult to overcome. The experience gained in using existing BMS for HVAC energy monitoring has yielded several hints which may eventually lead to a complete specification. The following is a non-exhaustive list of point to the designers and installers that need attention:

- Electric meter characteristics (type of data collected, accuracy, data storage) and number (e.g. separate chillers + cooling tower, pumps, AHU).
- Thermal energy meters: specifications for hot water and chilled water flow rate and temperature measurements.
- Environmental data measurements: indoor and outdoor air temperature and RH.

- Time coding: the data acquisition time interval should be specified by the user, typically in the range from 15 minutes up to 1 hr, depending on the type of data; the time sequence of collected data should never be interrupted, which means that, if for any reason the data are not collected at a given time, a conventional figure should be recorded. Daylight saving time should be managed in a non-ambiguous manner.
- Data format: the correspondence between data and physical quantities should be clearly specified with alphanumeric codes that make the identification easy to the inspector.

Data showed that HVAC improvements are possible, but for those activities also lighting and food refrigeration need measures of energy efficiency. Building simple models to compare an average consumption with the actual one is possible, but internal load consumption data are necessary.

References Heading

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