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Electrical load analysis in a hospital complex

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Abstract-- **The present paper has the main aim of illustrating some main results obtained from a wide electrical load research performed on a large metropolitan hospital in the city of Rome in Italy. The reported results demonstrate how important is an accurate load monitoring activity in order to identify typical demand and consumption patterns. The availability of such patterns allows identify effective strategies of load and energy management as well as operational or functional inefficiencies in the electric load that can be easily and cheaply resolved with preventative maintenance interventions and retro-commissioning actions.**

I. Introduction

EUROPE is currently facing new energy challenges resulting from both increased import dependency and concerns over supplies of fossil fuels worldwide. In spite of this, energy waste due to inefficiency reaches at least 20%.
The annual improvement in energy efficiency in the 1990's was 1.4 % per year, but this rate has declined since and is now stationary at 0.5 %, showing current efforts are proving insufficient [1].

According to numerous studies [2,3], Europe could save the above mentioned 20 % of its present energy consumption in a cost-effective manner, equivalent to 60 billion euro per year.

Both private and public hospitals and hospital buildings in a Country spend billions euros per year on energy by consuming energy in different forms and ways on a very large scale. Hospitals are 2-3 times more energy intensive than other institutional buildings since they are functioning 24 hours a day, all through out the year. They are generally large building complexes incorporating most types of technical systems encountered in other types of buildings with a high level of heat being generated internally.

However increasing healthcare facilitation costs leave little or no space to incorporate further investments for energy savings in a hospital budget [4].

Moreover, patient comfort and quality patient care is of great importance in a modern hospital and cannot be compromised by cost-cutting measures that may effect the quality of service. Therefore, an effective measure seems to encourage energy management aimed at improving energy efficiency, which can reduce monthly energy bills even significantly.

Effective energy management actions should ensure that energy use and costs are as low as possible while maintaining high standards of comfort, service and productivity [5].

It is well known that a good starting point for creating an energy management plan is to develop a baseline of the facility's energy consumption. This usually involves identifying where and at what rate energy is used, areas of energy waste and potential energy-saving measures. Furthermore, when conducting an energy use analysis, it is useful to understand facility trends, patterns and superior performance values. But since it is well known that anything not measured cannot be controlled, a wide energy auditing stage has been planned and organized providing that efficiency and energy consumption of every appliance, medical instruments, and other utilities are measured.

To this aim, a wide monitoring campaign has been performed on the electrical distribution grid supplying the various end users operating in the hospital.

Several specific load aggregations and operational areas have thus been identified and continuously monitored during a year. Both the overall demand and energy consumption could be therefore analysed in detail.

The load diagrams thus obtained have been statistically processed in order to identify typical load patterns that can be used as benchmark daily load diagrams for the different functional areas of the hospital and for the different days and time-bands [6].

The availability of such reference daily load shapes is of great interest for:

- identifying and planning possible actions aimed at load or demand controlling
- predicting the possible impact of any energy management action directly on the daily load profile

II. The S. Giovanni – Addolorata Healthcare Complex

The complex is located in a downtown area of the city of Rome in Italy. The healthcare activities inside the complex are distributed into four adjacent areas as illustrated in Fig. 1 a.

The administrative activities are hosted in a separate 5-store office building . Recently another private 200 beds hospital operating in the area (Calvary Hospital, formerly directed by an Irish noons order) has been integrated in the complex. Thus, actually the whole complex provides the following buildings or precincts: S. Giovanni hospital , Addolorata hospital, S. Maria presidium, Calvary hospital, Monumental area, Administrative office building.

The area occupied by the complex is of exceptional

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archaelogical interest for the City of Rome. Indeed, in a square chilometer area centered in the complex, it is possible to find archaelogical sites of outstanding interest such as the Colosseo complex, the S. Giovanni in Laterano cathedral, the S. Stefano Rotondo basilica, etc.. The same S. Giovanni hospital is built on the remains of "Domus Annorum", the house of Domithia Lucilla, emperor Marco Aurelio's mother.

The whole S. Giovanni - Addolorata healthcare complex hosts about 1000 beds distributed among the various hospitals.

The S. Giovanni hospital (SGH) is the main hospital of the complex that provides emergency medical care, intensive cares, hospitality, labs, diagnostic and surgical care. It provides also general services such as laundry, food preparation and delivery, personnel restaurant. It is structured in the main buildings evidenced in fig. 1 b, that are mainly dedicated to the following activities:

- Building A: emergency treatment spaces, trauma center, general intensive care
- Buildings B and D: patient room divisions, protective and infectious isolation rooms, surgical and obstetrical delivery suites and associated support spaces, nursery, neonatal intensive care unit, intensive care units for various specializations
- Building C: diagnostic care, surgical care, operating scenario (20 operating rooms with relevant intensive care rooms), clinical analysis labs
- Building E: pharmacy, food storage and kitchen, personnel restaurant, technological area

III. The S. Giovanni hospital electric power system

The hospital is supplied at medium voltage level (20 kV) from the service main entrance that is located in the building D. A ring MV distribution system is provided which supplies five MV-LV transforming sub-stations, dedicated to electricity supply of each building of the hospital. Every transforming sub-station is equipped with an emergency power supply system (EPSS) of adequate capacity: two 400 kVA in parallel for building A, one 1000 kVA for buildings B and D, one 1350 kVA for building C, one 400 kVA for building E.

The clinical equipment that are critical for a power outage even of a short period of time (10 seconds or less) are supplied by uninterruptible power supply (UPS) systems. A centralized UPS system made by two paralleled 250 kVA units has been provided for uninterruptible supply of building C. A centralized system is also provided for building A. Smaller units have been also installed in critical end-use areas such as intensive care units, operatory rooms, and in some diagnostic rooms such as angiography and nuclear magnetic resonance.

The electricity distribution system is summarily illustrated in Fig. 2, where with dots are also evidenced the monitoring points provided for the analysis.

IV. In-field audit and monitoring activities

Because of the energy requirements associated with supporting 24/7 operations and other unique needs, hospitals face a growing challenge in managing and controlling their energy use and demand without negatively impacting the quality and cost of their services.

Since the last years S. Giovanni Addolorata healthcare complex administration has started a medium-long term plan for energy management and electric load control. The plan aims at reducing electric energy consumption but also at controlling and managing electricity demand for peak shaving and local electric load shifting and balancing [5].

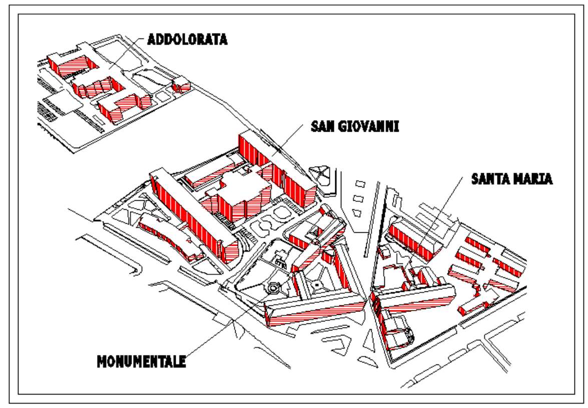

Fig. 1 a) - The S. Giovanni – Addolorata Healthcare Complex in Rome

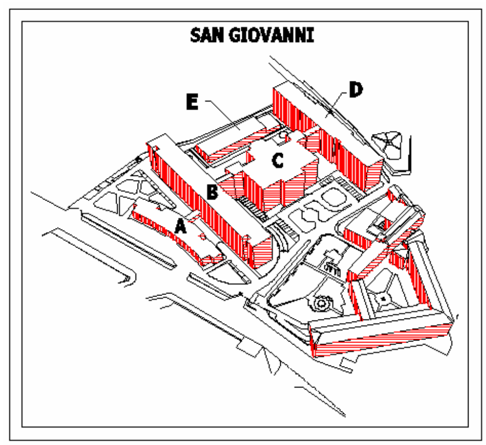

Fig. 1 b) - The S. Giovanni hospital (SGH)

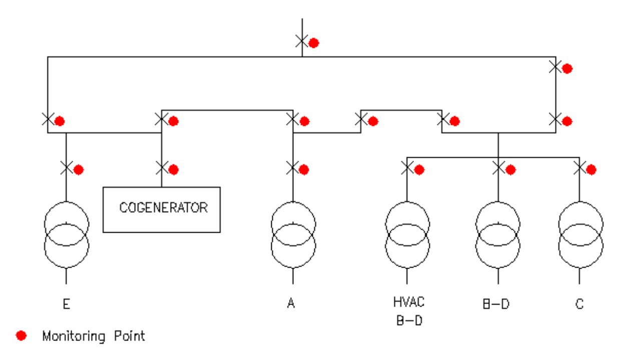

Fig. 2 - Electricity distribution system serving SGH.

For measuring and verifying the hospital's energy footprint a wide monitoring activity of end-uses has been implemented in order to give a solution to the problem "You can't save what you don't measure." To this aim a complex activity of distributed in-field monitoring has been designed and implemented to identify energy consumption patterns as well as electrical load profiles that typically cannot be provided by the master utility billing meter at the main electrical service entrance. The following activities have been therefore implemented:

- Analysis, measurement, verification and benchmarking of peak demand (kW) and consumption (kWh) of as many as possible areas or load aggregations
- Time-of-use metering of demand
- Load comparisons
- Multi-site load aggregation and real-time historical monitoring of energy consumption patterns.

For the purpose a pre-existing remote centralized control system of the MV electricity distribution system serving the SGH has been opportunely modified. The system was originally aimed at managing and controlling the protection system of the MV electric network. The electric protections in field are equipped with electronic equipment that allow current, voltage and power demand instantaneous recording and transmitting to the centralized control platform. The tele-control system software had to be partially modified in order to calculate energy consumption values from the in-field readings. In this way, several electric load monitoring points have been made available in the electrical grid (at MV level) that allow to identify local areas for which electric load profiles have been obtained continuously and simultaneously.

A detailed analysis of electricity usage patterns help to pin down advice regarding how power usage characteristics could be modified, without impacting hospital's activities in any negative manner. The accumulation and careful analysis of real-time load monitoring data can help make the correct choice about various energy and load management strategies.

A portable device has been used to monitor power demand for time intervals ranging between 1 and 15 minutes, while recording ambient conditions such as temperature, major equipment duty cycles, and other factors which might affect power usage characteristics. Data produced by load monitoring equipment can noticeably help save energy.

Finally, data collected from the SGH energy consumption metering system have been made available for a whole year.

V. Analysis of Energy Consumption

The daily electric energy consumption figures as metered for SGH have been collected thus obtaining an interesting historical trend. In Fig. 3 the daily energy consumption time series has been reported for the whole year between October 2007 and September 2008.

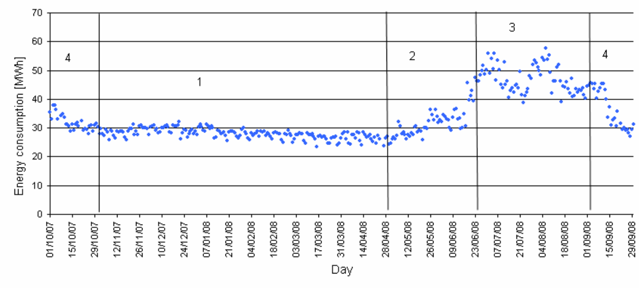

Fig. 3 – Daily energy consumption values monitored for SGH complex

By analyzing data, four different periods could be identified in the trend (1-4 in Fig. 3). The periods, classified in terms of both energy consumption level and variability, could be approximately identified with the different seasons of the year. Thus the energy consumption of the SGH is characterized by a certain weather dependency.

The period 1, shows a nearly constant daily level with an average value in the whole period of 27.9 MWh and a standard deviation value of 1.9. The maximum of 32.2 MWh and the minimum level 23.4 MWh have been respectively recorded on 21/12/07 and 16/03/08.

Results of similar analyses for the further periods thus identified are reported jointly with those for period 1 for comparison purpose in Table I.

TABLE I

Period	Avg./St.dev.	Max	Date	Min	Date
1	27.9/1.9	32.2	21/12	23.4	16/03
2	34/7.08	51.6	28/06	24.5	1/05
3	46.8/4.85	57.7	6/08	38.8	23/07
4	34.7/5.67	45.8	3/09	27.1	28/09

Statistical analyses have been also performed for the different periods. The relevant results for periods 1 and 3 are respectively shown in Figs. 4 and 5.

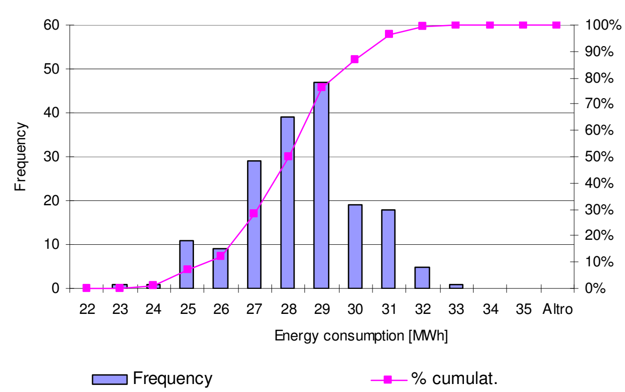

Fig. 4 - Frequency distribution of energy consumption in the period 1.

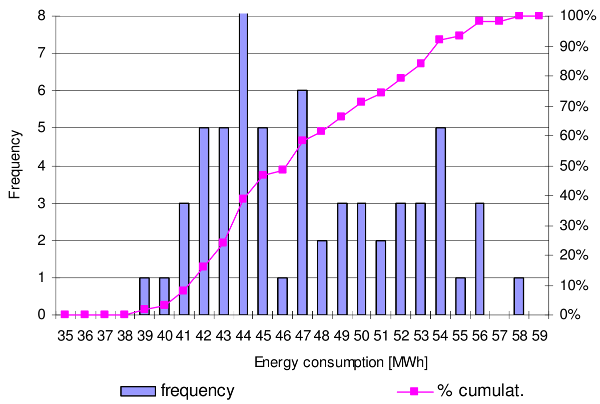

Fig. 5 - Frequency distribution of energy consumption in the period 3.

For the different periods a cross-correlation analysis with weather dependent variables such as daily temperature and humidity values has been assessed. For period 3, the one found with maximum correlation levels, the correlation trend is shown in Fig. 6.

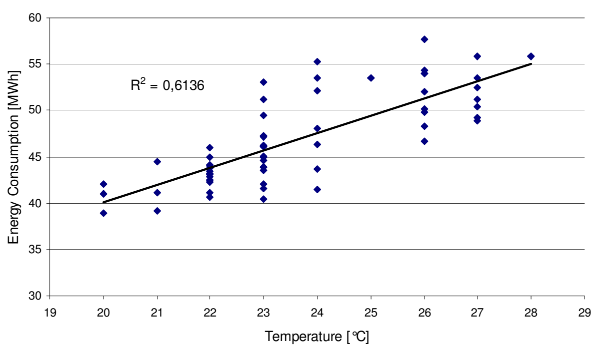

Fig. 6 - Cross-correlation analysis results for period 3.

The monitoring system implemented at SGH has allowed the possibility of using distributed sub-metering points at every main load area of the hospital as evidenced in Fig. 1 b). Thus, the individual contribution of each area to the overall consumption could be easily obtained vs. time, as illustrated in fig. 7.

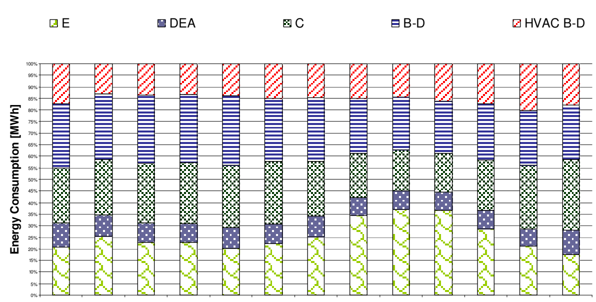

Fig. 7 – Average energy consumption daily values for the different load areas of SGH and for different months.

VI. Analysis of Demand

The centralized tele-control system in operation at SGH has provided a bulk of data that have needed a careful analysis and reading. Data have been therefore duely processed in order to select and eliminate bad data due to corrupted transmission or other. Even data obtained from portable energy monitor have been opportunely analyzed and selected.

The set of recorded demand for a whole year has been processed thus obtaining the frequency distribution shown in Fig. 8. In particular the maximum and minimum instantaneous demand values of 3040 kW and 800 kW have been recorded respectively at 17:00 of 06/08 and at 04:30 of 07/05.

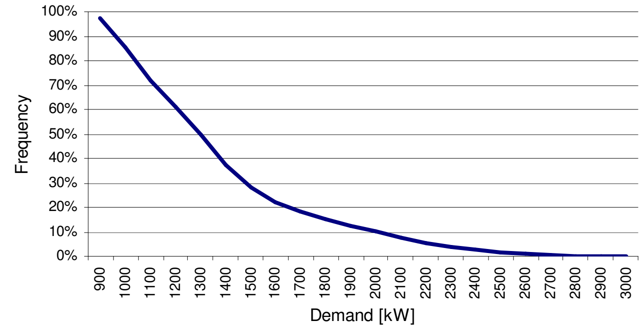

Fig. 8 - Frequency distribution of recorded demand for a whole year.

The recorded data have been duely processed in order to identify the typical load patterns for the different periods.

In particular, since the electricity distribution contract provides a tri-nomial tariff that identifies the following three different time bands for working days: F1, (peak hours) from 8:00 to 19:00; F2, from 7:00 to 8:00 and from 19:00 to 20:30; F3, from 20:30 to 7:00, a detailed analysis has been performed in order to identify the main figures of the load patterns for the various time bands. The results thus obtained are useful for addressing adequate strategies of load management.

For instance purposes results from a statistical analysis applied to data of periods 1 and 3 is reported in Figs. 9 and 10 for better evidencing differences between electric load during winter and summer conditions.

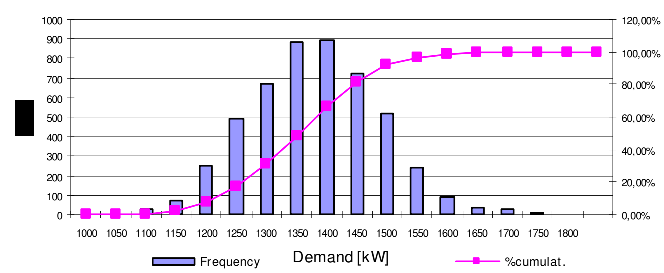

Fig. 9 - Frequency distribution of demand recorded during period 1 (time band F1).

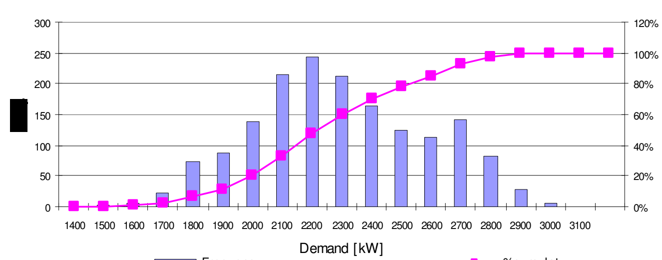

Fig. 10 - Frequency distribution of demand recorded during period 3 (time band F1).

The recorded data have been organized in daily electric load profiles that allowed reveal the pattern peculiarities concerning both day type and season. Thus, the daily load shapes have been processed and some typical patterns could be identified.

In particular, in Fig. 11, the individual daily load patterns for a typical week of period 1 is reported.

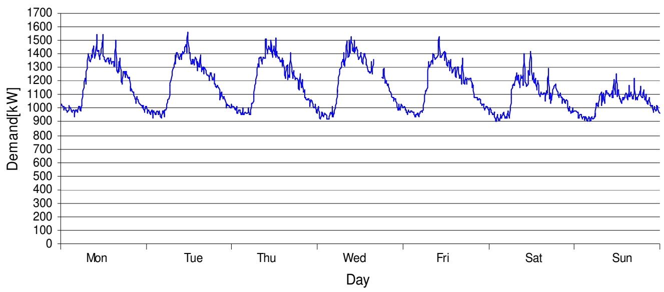

Fig. 11 - Typical daily load patterns of a week for period 1.

The daily pattern demand's variability for the whole period 1 is reported in the diagram of Fig. 12, where the maximum, average and minimum demand values are reported in comparison for every day type.

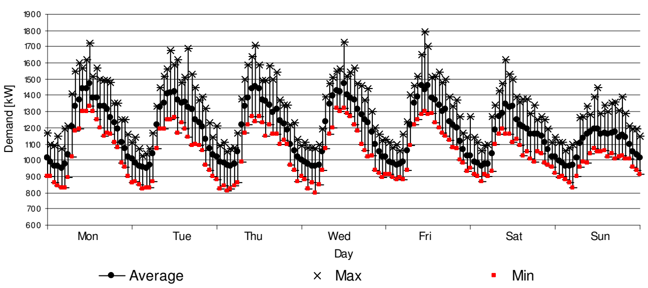

Fig. 12 - Main figures of demand recorded during period 1.

For the daily load patterns of period 3 analogous results are reported in Figs. 13 and 14.

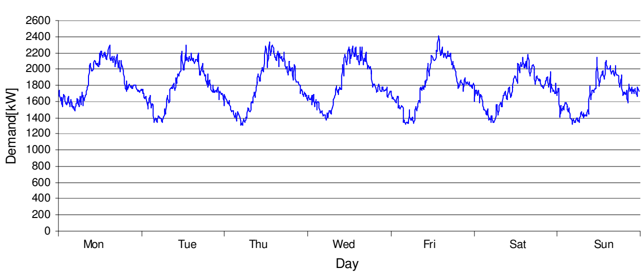

Fig. 13 - Typical daily load patterns of a week for period 3.

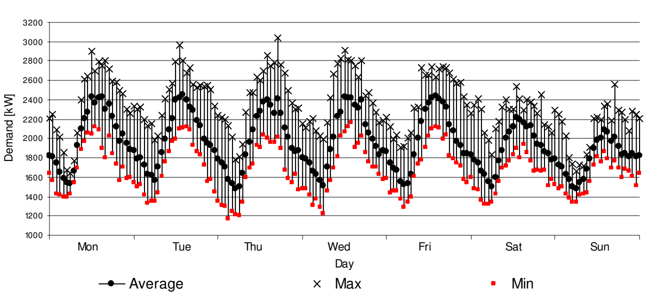

Fig. 14 - Main figures of demand recorded during period 3.

Cross-correlation analyses have been also applied to demand recordings. In particular, the daily peak demand values have been correlated with both temperature and humidity of every period as identified. Even for peak demand as for energy consumption a significant cross-correlation level has been obtained for period 3 for temperature. Fig. 15 shows the main results thus obtained.

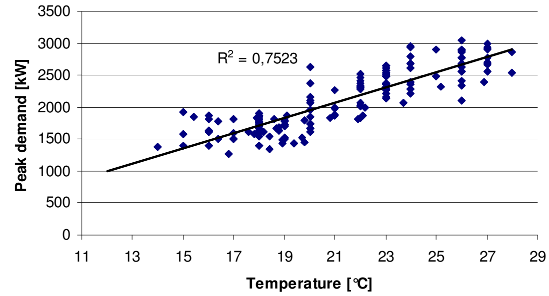

Fig . 15 - Cross-correlation analysis results for period 3.

The electric load during the summer period as identified in time series (period 3) shows a significant weather dependency. In order to better evidence such a circumstance Fig. 16 shows three load patterns recorded for days of period 3 characterized by significant difference of average daily temperature.

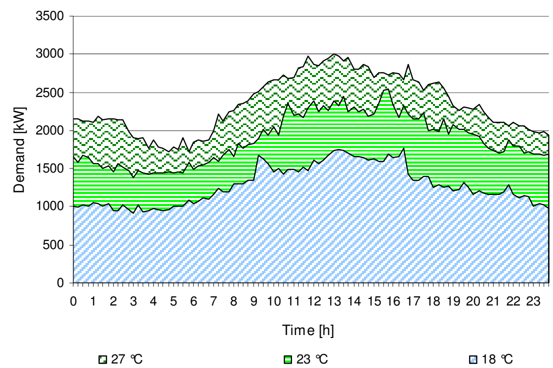

Fig. 16 – Daily load patterns for days of period 3 with significantly different average temperature..

VII. Conclusions

An important Italian public healthcare complex has started a medium-long term plan for energy management and electric load control at his premises. The plan aims at reducing electric energy consumption but also at controlling and managing electricity demand for peak shaving and local electric load shifting and balancing.

In the paper, some selected results of the wide electric load research that is still in progress at S. Giovanni hospital, part of the complex, are reported in due detail.

Since load management concerns are involved in the research, a wide monitoring campaign has been performed on the electrical distribution grid supplying the various end users operating in the hospital. Thus, several specific load aggregations and operational areas have been identified and continuously monitored during a year by means of an available centralized tele-control system of the MV electricity distribution system serving the hospital that should be opportunely modified.

In addition, a load monitoring campaign has been also performed in order to meter individual items of equipment or areas of interest by means of a portable energy monitoring equipment that has been installed at the connection point of some main electric end users.

The load diagrams thus obtained have been processed in order to identify typical load patterns of the whole hospital. In particular, typical daily load diagrams could be determined in function of date and season thus allowing: 1) identify peculiarities, 2) point out and plan possible actions for load controlling; 3) predict the possible impact of any energy management action even directly on the daily load profile.

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