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Electrical Energy Consumption Analysis in Tertiary Buildings

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ABSTRACT

The European Energy Performance of Buildings Directive (EPBD) requires a certain Energy Performance Assessment (EPA) to be conducted for each building, to obtain an Energy Performance Certificate. For this purpose several software tools have been developed enabling the audit and assess of either residential, or tertiary buildings and the calculation of the energy needs and energy consumption in line with EPBD. In practice, however, significant differences between the calculated results and measurements are usually recorded, especially for the electrical consumption, since most of the EPA tools calculate only part of the electric energy consumption in a building. Scope of the paper is to present field measurements for the electrical consumption for different buildings in a University Campus in Greece. The recorded data are analyzed and compared for a specific building with the corresponding obtained by an EPA software. Differences between the two approaches are discussed, while interesting remarks are made concerning the electrical load profiles of University buildings and the rational use of lighting and air-conditioning systems during non-working hours. From the analysis of the results proper electric consumption control strategies of the electrical loads can be proposed, utilizing intelligent control systems.

1 INTRODUCTION

The European Directive (2002/91/EC) on the energy performance from buildings - EPBD [1], [2] contains a range of provisions to improve energy performance in buildings. EPBD requires all EU countries to update their building regulations and to introduce proper energy certification schemes. According to EPBD an Energy Performance Assessment (EPA) calculation is conducted for each building, based on building data, meteorological data, building use and, in some cases, available energy consumption data.

In most cases however there are significant discrepancies between the results obtained by the EPA and the measured data, where available. This is most common for the electric energy consumption, since according to the most country legislations only specific electric energy consumption, mainly for lighting, is taken into account in the EPA of a building [3]. On the other hand, measurement results include all the electrical energy consumption, such as electric energy used in office equipment, electrical appliances etc, as well as losses and possible electric energy waste [4] – [6].

This paper presents results of electrical consumption measurements of different University buildings of the Aristotle University of Thessaloniki (AUTH) Campus in Greece. The data is obtained by the installed Supervisory Control and Data Acquisition (SCADA) system in the University Campus. Data processing of the recorded electrical load profiles for each building reveals significant amounts of electric energy consumed during non-working hours and on holidays. The analysis is further extended and focused on a certain building of the AUTH Campus, the

Hydraulics building of the Polytechnic School, where electrical consumption measurements are compared to the results for the electrical energy consumption, as calculated by the EPA analysis. The calculated results are obtained using the EPA-NR software tool [7], which is suitable for the EPA of Non-Residential buildings.

The analysis and comparison of the obtained results show that there are significant discrepancies between the electrical energy consumption resulting by an EPA for a tertiary building, and the actual electric energy consumed. These discrepancies are due to a number of reasons. First, only part of the actual electrical energy consumption is calculated in the usual EPA of a tertiary building. Even this partial consumption calculation is based on assumptions, regarding the use of the building, which can be in some cases arbitrary. And finally there are other electrical energy losses and waste which cannot be calculated. Proper electrical energy consumption measurements can be a very useful tool, in order to acquire the exact electricity footprint of the building and also to calibrate properly some of the EPA parameters for groups of similar buildings. Also, further processing of real electricity consumption data can lead to the implementation of proper control strategies that can improve the rationale use of electrical energy and the cut-off of electricity waste in tertiary buildings, a policy which may prove to be more cost-effective compared to other energy saving policies.

2 METHODOLOGY DESCRIPTION

The Campus of AUTH covers an area of approximately 430.000 m^2. In 2009, a SCADA system for the monitoring and control of the heating systems was installed. The monitoring and the proper control of the Campus heating system resulted in significant reductions in thermal energy consumption. In 2010, the SCADA system has been extended to monitor electrical energy consumption in the University buildings [8].

This University SCADA system has been used to record the electrical power consumption profiles of four (4) Campus buildings, using a sampling rate of 15 minutes. The examined buildings are: Building D and the Hydraulics Building belonging to the Polytechnic School, the building of the Veterinary Medicine School and the School of Dentistry building.

In all cases the consumption period was divided into two non-working periods, the first one is 00:00 – 08:00 and the second 16:00 – 00:00, while the working hours were assumed to be from 08:00 to 16:00. All buildings operate from Monday to Friday, thus a different consumption period for the weekends is also assumed.

Data for all buildings are available for January 2011, while for the building of Hydraulics, electric profiles almost for the whole year 2010 are also provided.

3 ELECTRICITY CONSUMPTION OF UNIVERSITY BUILDINGS

In Figs. 1a – 1d the active power consumption of Building D, Hydraulics building, building of Veterinary Med School and the School of Dentistry building are presented, respectively, while in Figs. 2a - 2d the corresponding power factors are shown. Curves correspond to a whole week starting on Monday 10th January 2011 at 00:01 until Sunday 16th January 2011 at 23:59. Table 1 shows the consumed electrical energy for a whole week and the corresponding percentage split between the official working- and non-working hours for each building. Also, Table 1 depicts the percentage of the consumed electrical energy during the weekends.

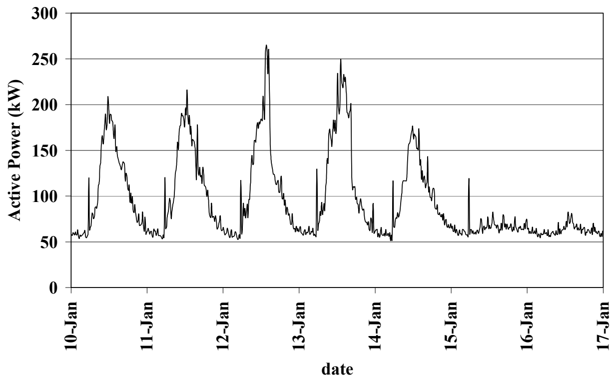

Figure 1a: Building D Active Power Consumption

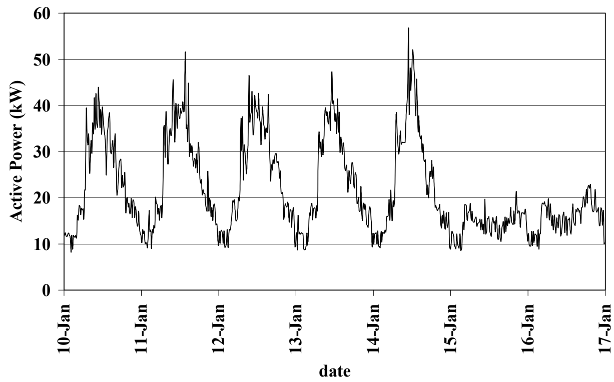

Figure 1b: Hydraulics Building Active Power Consumption

Building D of the Polytechnic school is a nine-storey building, where offices and some laboratories of three Departments (Chemical Engineering, Electrical & Computer Engineering and Mechanical Engineering) are located. The main electric loads are lighting, computers and peripherals, office equipment (copiers, phones, faxes etc) and split type individual air-conditioning units. In the basement of the building the Laboratories of the Depts of Electrical & Computer Engineering and of the Mechanical Engineering are located as well as the boiler room. From Fig. 1a it is evident that the electrical energy consumption during non-working hours remains significant and the base load during both weekdays and weekend is always higher than 50 kW. Therefore, the corresponding non-occupancy energy consumption is 49.21 % of the total, while 22.29 % of the total electrical energy is consumed during the weekend. This type of behavior is attributed mainly to lighting and also to computers and other devices not switched-off during the night [4] – [6]. The power factor of the building is high, since it is on average 0.96 (lagging) and the minimum recorded value is 0.84 (lagging).

The Hydraulics building belongs to the Civil Engineering Department of AUTH. It is a two-storey building, mainly comprising offices, a small amphitheatre and some laboratories, whereas in the basement there are also some offices and the boiler room. In Fig. 1b the base electrical load of the Hydraulics building is estimated at 10 kW, while the average peak electrical consumption is 45 kW. In this building, more electricity is consumed during the non-working hours (51.92 %) than during working hours (48.08 %) and the percentage of the electrical energy consumed during the weekend against the total energy is 23.8 %. These results show a significant energy saving potential. Considering the power factor profile, as in the previous building case, it is significantly high, since its average value is 0.96 (lagging).

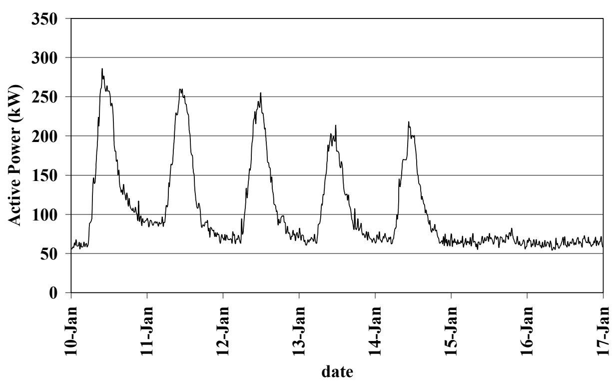

Figure 1c: School of Veterinary Med Building Active Power Consumption

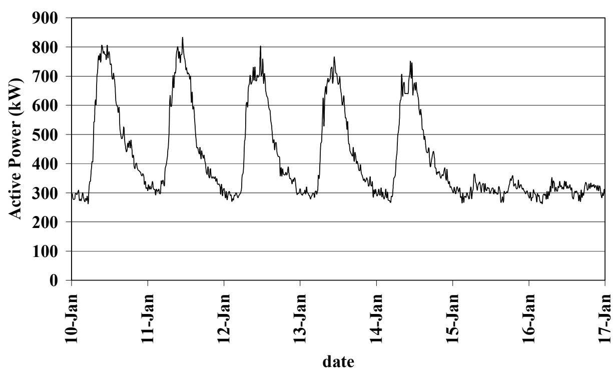

Figure 1d: School of Dentistry Building Active Power Consumption

Similar levels of electrical energy consumption to Building D are also recorded for the building of the School of Veterinary Medicine, since the base load is higher than 50 kW and the peak active power during the weekdays takes values from 200 kW to 300 kW. The amount of electrical energy consumed during the hours that the building is not occupied is significant (47.08 %), while the electrical energy during the weekend corresponds to the 20.36 % of the total electrical energy. In this building it is worth mentioning the low power factor, especially from 17:00 to 06:00 and during the weekend, since during the weekday morning hours it acquires values higher than 0.86. This is probably due older types of fluorescent lamps perhaps without compensation capacitors which lead to extra power losses due to the high reactive power absorbed.

In Fig. 1d the active power profile for the School of Dentistry building is presented, where it is observed that the base load is slightly lower than 300 kW and the corresponding peak values during the weekdays, recorded at 11:00, are higher than 700 kW and may reach 830 kW. Therefore, the energy consumed during the non-working hours corresponds to the 53.01 % of the daily electrical energy, while during the non-working hours of the weekdays we have the 24.3 % of the total electrical energy. As in the case of the Hydraulics building, significant energy saving potential can be identified for this building, considering the huge amount of the energy consumed during non-working hours, which according to Table 1 is 124,250.45 kWh per week. The average power factor in the building of the Dentistry School is 0.86, which means that there is also possibility for improvement.

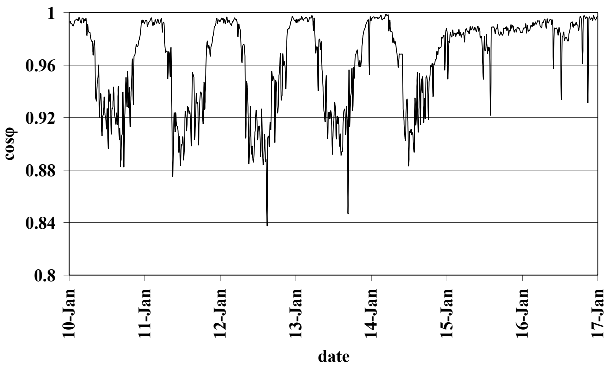

Figure 2a: Building D power factor

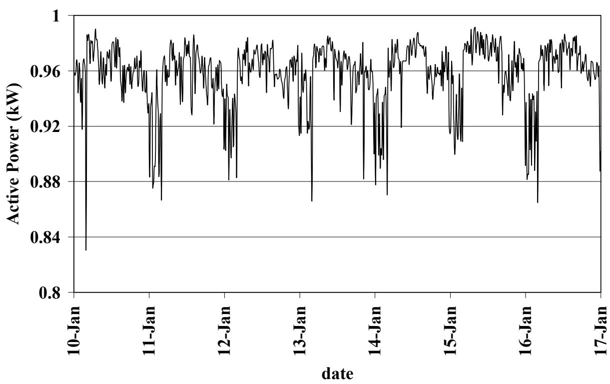

Figure 2b: Hydraulics Building power factor

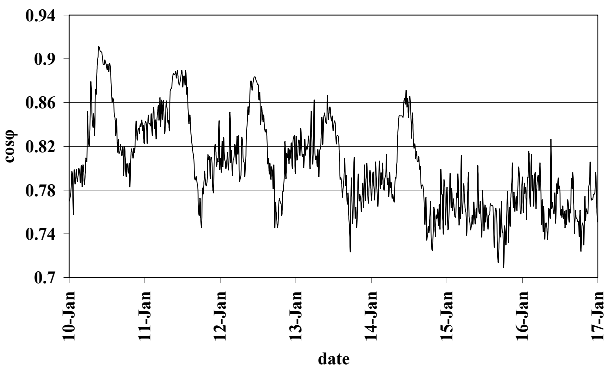

Figure 2c: Veterinary Med School power factor

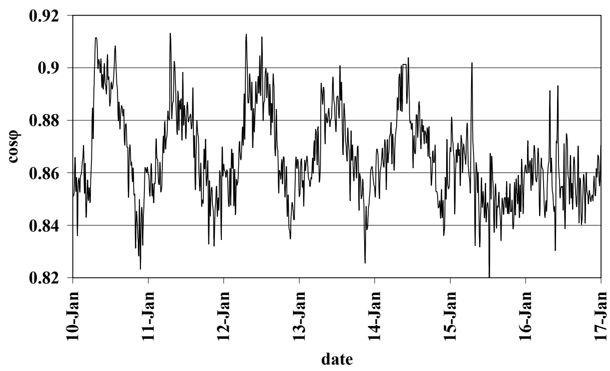

Figure 2d: Dentistry School power factor

Table 1 Analysis of consumed electrical energy in the AUTH Campus buildings

	Energy (kWh) during non-working hours (00:00-08:00)	**Energy (kWh) during non-working hours (16:00-00:00)**	**% Average Consumed Energy during non-working hours**	**% Average Consumed Energy during working hours**	**% Average Consumed Energy during weekends (non-working hours)**
Building D	11,091.30	15,202.50	49.21	50.79	22.29
Hydraulics	2,701.80	3,280.40	51.92	48.08	23.80
Veterinary Medicine School	13,818.84	14,646.47	47.08	52.92	20.36
Dentistry School	61,125.20	63,125.25	53.01	46.99	24.30

4 THE HYDRAULICS BUILDING CASE

4.1 Description

The rest of the analysis is focused on the Hydraulics building, since it represents a typical electrical energy consumption profile and also several detailed data, such as building plans and past data of the heating and electricity consumption are available for this building.

The building of Hydraulics was built in 1963. It consists of two similar floors, a ground-floor, a basement and a chamber where 29 offices, 6 laboratories and 2 small lecture halls are lodged. The building total surface is 2639 m^2 and location in the south side of the AUTH Campus is shown in Fig. 3. The wall thermal insulation material is Heraclith and asphalt coating on the walls of the basement. The heating of the building is provided by a natural gas boiler, whereas there are not any central ventilation and cooling systems installed, just individual split type air-condition units in almost every room.

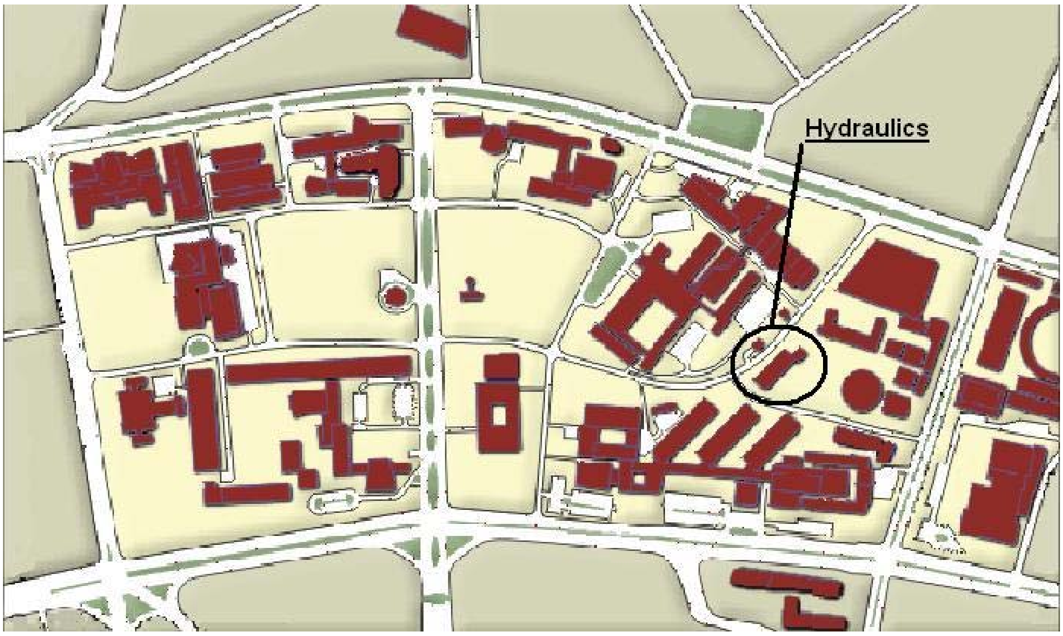

Figure 3: Drawing of the Polytechnic School of AUTH.

4.2 Asset Rating Process

The EPA calculation is performed for the building of Hydraulics following the Asset Rating (AR) approach, using the EPA-NR software [7], which was developed in the framework of the European project Intelligent Energy (IEE) [9] and is suitable for the EPA of existing non-residential buildings. The EPA-NR software is based on a set of tools that enables the audit and assess of tertiary buildings, calculating the energy needs and energy consumption in line with EPBD [1]. The calculations are performed on a monthly basis. The main steps of the calculation procedure are summarized as follows:

- Specify air-conditioned spaces,
- Specify comfort conditions and climate data,
- Acquire data for HVAC, hot water and lighting,
- Partitioning of the building into multiple thermal zones for calculation, including system criteria. Each thermal zone
  - differs in temperature more than 4 K from the other,
  - has a different thermal/cooling system,
  - is characterized by a different operation profile.
- Specify outer and internal heat sources,
- Determine the energy use for heating and cooling, as well as delivered energy for hot water, lighting, ventilation, etc.,
- Calculation of heating/cooling periods,
- Combination of calculated results for each time step for each thermal zone, considering the electromechanical system,
- Calculation of building energy needs and consumed energy, taking into account the losses.

The input parameters of the EPA-NR software include libraries, which contain typical regional data for building construction and weather, as well as investment costs and applicable systems data, which are maintained by the user [7], [10].

In order to implement the EPA process, the typical stages of the assessment process were followed [10]. Initially, an intake/inspection phase was implemented, which included interviews with the users of the building as well as an inspection (audit) of the building and its installations [10]. After processing the selected data, the building of Hydraulics was partitioned into four thermal zones as described in Table 2 and two non-heated spaces of total surface 588 m^2.

Table 2 Thermal zones of the Hydraulics building

Zone name	**Zone surface (m^2)**
1st and 2nd floor offices	11146
Corridors and waiting rooms of ground floor, 1st and 2nd floor	435
Ground floor laboratories	566
Ground floor	483

Table 3 Installed electrical capacity per zone

Zone name	**Lighting (kW)**	**Electrical appliances (kW)**	**Total (kW)**
1st and 2nd floor offices	7.92	194.73	202.65
Corridors and waiting rooms of ground floor, 1st and 2nd floor	2.18	0	2.18
Ground floor laboratories	4.39	45.28	49.67
Basement	2.18	20.77	22.96

Focusing on the electrical energy consumption, the electrical loads of the Hydraulics building can be divided generally to lighting and electrical appliances. Fluorescent lamps of rated power 2x36 W are used mainly for the indoor lighting of the building and the installed electrical capacity per zone is presented in Table 3. The electrical appliances are computers and peripherals, refrigerators, small motors for laboratory purposes and local split type class D air-conditioning units (EER=2.67).

In the EPA-NR procedure, the electrical consumption is the sum of the electricity consumption for lighting, for the HVAC system and for their auxiliary equipment. The electrical appliances influence only the internal heat gains but they are not included in the electrical consumption calculations.

Finally, the heating system of the building consists of a natural gas boiler (500,000 kcal/h), installed in 2000. The heating period is from October to April.

4.3 Electricity consumption results according to the EPA-NR

The monthly electricity consumption per m^2 of the building occupied area, as calculated by the EPA-NR software is presented in Fig. 4. The monthly lighting consumption density is assumed to be constant during the year, since the corresponding factors of the natural and artificial lighting have the same value for the whole year and do not vary on a monthly basis, where the varying daylight period could have been taken into account. The average monthly lighting consumption density is 2 kWh/m^2 per month, corresponding to 122,972 kWh annually as shown in Table 4.

The operation period of the cooling system starts on May and ends on late September, thus the total electricity consumption for the cooling and the auxiliary system is estimated as 64,336 kWh per year. The highest electricity density for the cooling systems is 13.32 kWh/m^2 and is calculated in July, while the average value is 10.21 kWh/m^2. Therefore, the total electricity consumption density during the heating period (October to April) is equal only to the corresponding lighting consumption, while during the cooling period 82 % of the electricity power is consumed for the cooling systems and 18 % for lighting.

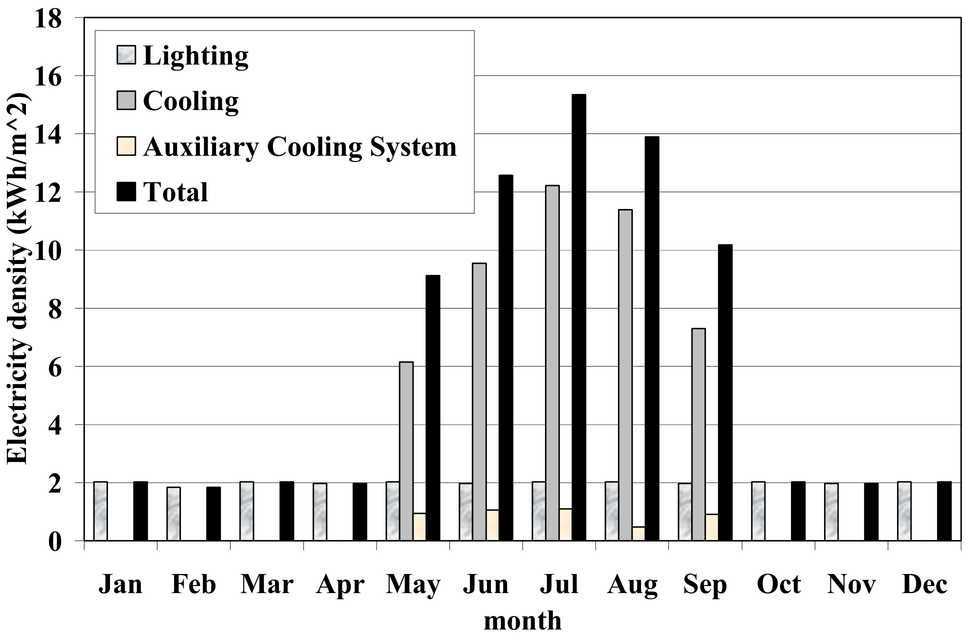

Figure 4: EPA-NR electricity consumption results

Table 4 EPA-NR calculations: annual electricity consumption

Use	kWh/m^2	kWh
Lightning	23.93	122,972
Cooling	46.6	63,149
Auxiliary Cooling System	4.48	1,187
Total	75.018	187,308

4.4 Comparison of monthly electricity consumption results

Next, monthly results calculated by EPA-NR are compared to the recorded measurements for the Hydraulics building. The available active power consumption data from the installed SCADA system are from February 2010 to January 2011 and the corresponding load profiles are presented for three indicative months in Fig. 5. In Table 5 the monthly electricity consumption obtained by EPA-NR and by the SCADA measurements is compared. In Fig. 5 it is shown that the electricity consumption during non-working hours remains significantly high for all months of the year, especially during June, due to possible unattended operation of the air-conditioners during non-working hours. The corresponding measurements for the weekends show that the base load has an average value of 11 kW, almost for all seasons of the year.

Comparing results of Table 5 it is shown that significant differences are recorded between the electricity consumption calculated by EPA-NR and the SCADA system, as expected. During the heating period of the building, from October to May, the measured electrical energy consumption is significantly higher than the corresponding calculated by EPA-NR. This is probably due to the energy consumption of the electrical appliances not included in the EPA-NR, but may also be a serious indication for wasted energy during non-working hours. An initial investigation showed that with a peak load not exceeding 100 kVA during the year, the electrical installation of the building is fed by 2 X 250 kVA transformers, resulting also to significant core losses.

On the contrary, during the cooling period, from May to September, the calculated by EPA-NR results acquire significantly higher values than the measured electrical energy consumption. Per-cent differences between the two approaches surpass even 200 %, especially in July, where, according to EPA-NR, the highest annual electricity consumption is recorded. According to the recorded actual consumption data, July seems to be one of the months of the year with low electrical energy consumption. The differences can be attributed mainly to an overestimation of the operation hours and days of the air-conditioning systems in the EPA-NR modelling, which have been assumed equal to the occupants' working hours. Furthermore, EPA-NR does not take into account the variation of the daylight time through the year as well as the holiday periods, especially during summer.

Finally, the total annual electricity consumption obtained by EPA-NR and from measurements is 198.9 kWh and 156.8 kWh, respectively and the per-cent difference between the two values is 26 %, resulting in a significant overestimation of the annual electricity consumption, using EPA-NR software. The comparison of the calculated results with actual consumption data, either from field measurements or by the metering systems seems to be necessary for the in depth analysis and the proper selection of the corresponding parameters for the building EPA. Also, the analysis of the recorded differences between the calculated and the measured electrical energy consumption data can also reveal cases of possible wasted energy, thus leading to the design and implementation of proper energy saving strategies, as well as it can help in the accurate estimation of the electrical energy consumption footprint of the building or of groups of similar buildings.

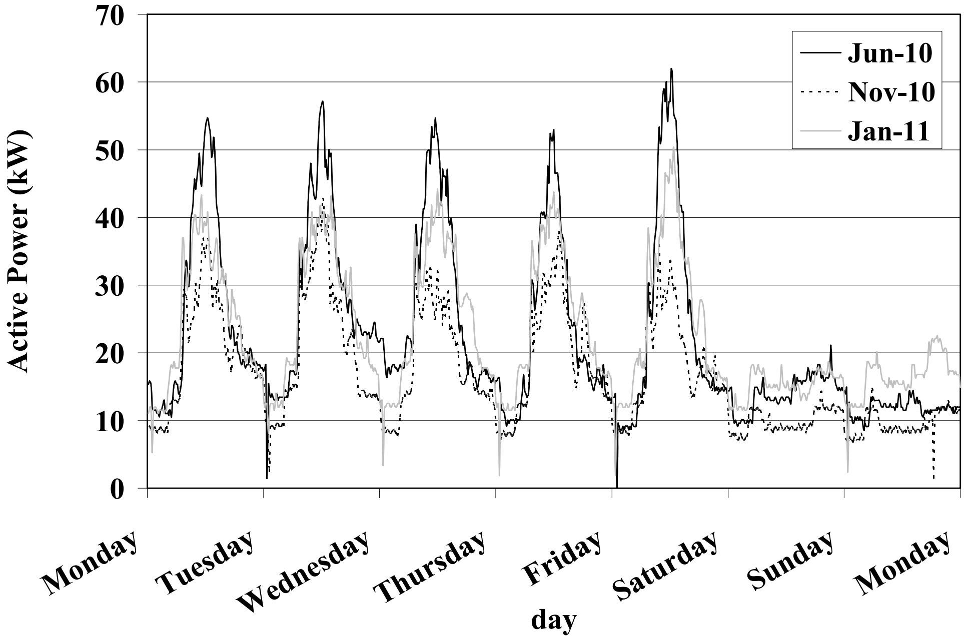

Figure 5: Hydraulics Building active power consumption for different moths

Table 5 Comparison of monthly electricity consumption (kWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
EPA-NR	5.35	4.86	5.36	5.19	24.1	33.2	40.5	36.6	26.9	5.4	5.2	5.4	198.9
Meas.	15.3	14.6	13.6	12.3	11.1	16.4	11.9	11.5	12.1	13.4	12.1	12.6	156.8

5 CONCLUSION

In this paper field measurements of the electricity consumption of four University buildings of the Aristotle University of Thessaloniki Campus are presented. Results show that almost half of the total electrical energy is consumed during non-working hours and weekends. A significant part of this consumption may be due to lighting, air-conditions and office equipment which remains switched on during these periods, or it may also represent high power losses. Therefore, proper electric energy consumption monitoring may reveal a significant potential for energy saving by applying proper electric consumption control strategies or by changing the present day building occupants behaviour.

The analysis is further extended to a specific AUTH Campus building, the building of Hydraulics. The calculated results from the building EPA as calculated using the EPA-NR software, are compared to the corresponding by the SCADA system. Although differences are expected, since the EPA-NR electricity consumption estimation takes into account only the electricity consumption for lighting, HVAC and the corresponding equipment, the recorded differences cannot be justified by the rest of the electric loads of the building. Several estimation parameters which have been used in the EPA-NR calculation need therefore to be properly revised to represent better the actual building performance. One of the main parameters which can calibrated more accurately according to actual consumption data is the operational time for the different electric equipment (lighting, air-conditioning) throughout the year.

The comparison of the results between the two approaches reveals that for the accurate EPA of tertiary buildings, electricity consumption measurements are very important. The electricity consumption in tertiary buildings with offices depends strongly on the daily behaviour of occupants during the working and non-working hours as well. Therefore, this type of consumption cannot be estimated from the available software for the EPA of buildings.

Furthermore, the analysis of the measured data for the electric consumption can help in the identification of possible electrical energy waste and in the design and implementation of proper electric consumption control strategies of the electrical loads, utilizing modern automated, low-cost and intelligent systems. These strategies can include the rational use of lighting and air-conditioning during working hours and the minimisation of waste during no-working hours.

Electrical consumption control systems in tertiary buildings can lead to significant energy savings in tertiary buildings and may prove more cost-effective compared to other energy saving policies such as building shell improvement or use of Renewable Energy Sources, in improving the building energy performance.

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