Reducing Energy Costs in IT Infrastructure: the Case Study of the University of Brescia

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Abstract: In the next future, the IT (Information Technology) infrastructures will increase due to the development in manufacturing management. The "Manufacturing 4.0" program advises that the IT infrastructures will grow, maybe differently, in every company. Consequently, the IT infrastructure costs will increase considerably and the related energy requirements and costs will increase, too. The aim of this paper is to apply an energy-economic analysis to evaluate the impact that the improvement of energy efficiency at the server rooms of the University of Brescia have had on the IT costs. To do that, an energy audit was performed before the IT improvement actions, as well as an energy audit after their implementations. At first, an economic analysis have shown the savings reached, based on the NPV (Net Present Value) and PBT (Pay Back Time) analyses. Successively, the PUE, Power Usage Effectiveness, has been evaluated, so as to appreciate the impact of the energy improvement actions on the performance of the server rooms. To make the PUE value comparable between the previews and the current configuration of server rooms of the University, a metric is provided. Finally, the DCIE, Data Centre Infrastructure Efficiency, is calculated and discussed.

Keywords: Energy-Economic Analysis, Server Rooms Energy Costs, IT Efficiency, PUE, DCIE

1. Introduction

Energy efficiency is of main interest in order to reduce carbon footprint and its consequences on the climate changes. European Directives (as the EU Directive 20-20-20) stated that each European Country has the task to implement specific actions to reduce energy consumption and to increase energy efficiency. In the latest years, the Information Technology (IT) has grown very quickly and, until recent years, the energy consumption of these infrastructures was considered as unavoidable. In Italy, it is estimated that about 3.000 Data Centres exist, accounting for about 1 GWh of annual electric energy consumption. It means that 1/50 of the national energy consumption is necessary for Data Centres operations, as stated in the report of Fondazione Politecnico di Milano. Thus, it is clear how, once considered the increasing trend due to the "Manufacturing 4.0", the energy consumption and the related costs of Data Centres assume a primary perspective. In fact, in Manufacturing 4.0, the IT and IoT (Information of Things) are the actors managing the whole manufacture, from the purchasing, to the production, logistics and client service. The IoT will manage the entire supply chain and it is easy to foresee that the IT infrastructures will increase rapidly. Consequently, the IT costs will increase, too, for both Production and Service Companies. The costs related to the IT infrastructures are the costs of hardware, software, the cost of the electric energy powering the system, the cost for refrigeration and the cost for hardware and software maintenance.

The scope of this work is to illustrate the experience, at the University of Brescia, in reducing its IT costs. In fact, the University of Brescia belongs to the RUS Group (Rete delle Università per lo Sviluppo sostenibile), a network of Universities aiming at a sustainable development. In this field, the Universities compared each other to implement sustainable projects following the topics of Wastes, Mobility, Emissions and Energy Efficiency. The results, reached by the Universities, will represent best practices to address other practitioners in reducing and managing wastes, improving energy efficiency and mobility.

The University of Brescia, during the last 3 years, implemented efficiency-improvement projects in its server rooms and IT infrastructures. As a result, the server rooms' costs were reduced, the energy efficiency was improved and the spaces of the University buildings were optimized. Moreover, some devices, decommissioned by the server rooms, have been reused without new expenses.

In this work, we present an economic-energy analysis, used to appreciate the validity of the IT projects implemented, that could be useful for reviewing new projects at the University of Brescia or other companies.

In the analysis, attention was paid to the energy costs of the IT infrastructure and on how the University of Brescia reduced them. The energy audits, before and after the improvements, are presented in order to define the energy consumption, the costs saving, and the reduction of CO_2 emissions achieved. Successively, two analyses are presented: the first one shows the economic validity of the improvements implemented; the second analysis illustrates the variation of PUE and DCIE before and after the IT efficiency project.

Usually, NPV and PBT analyses are performed before the technical actions, after the first (As Is) energy audit, to evaluate the profitability of the investments and to decide what investments are preferable. The improvements were implemented between the years 2014 and 2016. The present study could start once all the improvements were completed, i.e. in 2017, when it was decided to verify the profitability of the investment summaries. The aim is to assess a method to analyse, both in the economic and energy perspectives, the improvements achieved by the actions on the IT infrastructures.

In particular, Section 2 will analyse the background and Section 3 will describe the energy audit before the technical improvement, and the second energy audit, after the implementations, to assess the savings reached, thus showing the efficiency of the project. Section 4 will present the metrics for the PUE, the DCIE evaluation and the results of the two KPIs (Key Performance Indicators), to appreciate the effectiveness of the project. Finally, in Section 5, conclusions and future steps will be offered.

2. Background

The data centre energy consumption is concentrated in high-performance computing, low-power servers, energy conservation of computer rooms and renewable energy application, as stated by Rong H. et al. in 2016. The authors provided a general energy-saving framework to find optimization opportunities, meeting the user's expectations. Moreover, they used popular indicators, such as PUE, to have a guide to select air conditioning, power supply, distribution system, and so on.

The PUE is a metric commonly used to evaluate the energy efficiency of Data Centres. Belady et al. in 2007 defined the PUE as the metric that "characterizes the fraction of the total data centre power used for IT work". After their contribution, the PUE has been used as the first indicator to evaluate the effectiveness of a Data Centre, the efficiency of improvements into the same Data Centre and as a benchmark among Data Centres. In 2011, Lu et al. used the PUE to evaluate the effectiveness of different options for energy efficiency in the cooling system of Data Centres in Finland. They concluded that, even though the PUE showed a relatively high-energy efficiency, the same results could be obtained by the energy saving potential. During those years, many works used the PUE to evaluate the effectiveness of energy efficiency improvements and to compare different Data Centres. In 2016, Hadid et al. evaluated the effect of the set-point temperature of a cooling system using the PUE as the efficiency indicator. The objective was to find the optimal set-point to reduce the energy consumption of the cooling system of the Data Centre. These works considered "big" Data Centres, where the IT infrastructure is considered as "untouchable", and the actions to improve were focused on the cooling system, i.e. auxiliary services. The largest proportion of the PUE formula is accounted by the cooling system, so the largest energy savings are related to air conditioning system improvements. Wahlroos et al., proposed a project to reuse waste heat of Data Centers in district heating. So as to measure energy efficiency, they used the PUE as the total annual energy, divided by the total annual energy used in the IT. Horner et al., 2016, stated that the PUE is "an incomplete metric, failing to address hardware efficiency, energy productivity, and environmental performance". In fact, also Wahlroos et al. considered other energy performance indicators in their analyses. Moreover, in our opinion, the evaluation of the PUE itself, without other analyses, could be misleading in the evaluation of energy efficiency improvements. Horner et al., 2016, argued that the PUE could increase even though energy efficiency actions took place. Additionally, for small Data Centres, i.e. Server rooms, the evaluation of PUE is easier than for Big Data Centres with shared resources, but often it is not enough to evaluate the efficiency of improvements and the energy saving reached.

The scope of this contribution is to evaluate the effectiveness, efficiency, and productivity of the technical improvements in server rooms at the University of Brescia. Consequently, we have introduced, at first, an economic analysis and, successively, the PUE, i.e. the energy analysis, has been calculated.

3. Energy Audits and Economic Analysis

The economic analysis was performed to appreciate the impact on costs of the improvement actions as well as their effectiveness. Therefore, as a first step, the energy audit was performed before and after the implementation of the IT efficiency project, thus accounting the energy savings, the cost and the environmental (CO_2 emission reductions) savings.

In this work, the server rooms costs considered are:

- Electrical energy costs,
- Thermal energy costs,
- Maintenance costs.

Thus, the first step of the auditing was to identify all the resources using energy and accounting the energy used, too. We considered three types of resources: the IT resources (i.e., the hardware necessary for the IT infrastructure), the auxiliary services (necessary for the server room operating, as the cooling system), and the general services (the resources dedicated to the server room, but not directly linked to the work of the server room itself, as the lighting and power generator). During the auditing, two types of energy requirement were identified: electrical, for each resource, and thermal, for the cooling system. In fact, the district heating and cooling network of the city of Brescia supplies the University, providing cold water for chilling. Before the energy efficiency improvements, there were nine server rooms, placed in different departments of the University buildings.

Table 1: Energy audit results, before improvements

TIER Classification	ID Building	Energy consumption [TOE/year] for IT	Energy consumption [TOE/year] for Auxiliary service	Energy consumption [TOE/year] for General Service	Total Consumption of Server Room [TOE/year]	Maintenance costs [€/year]
TIER I	E01	5,64	7,97	0,00070	13,61	€ 1.301,00
TIER I	E31	2,47	1,64	0,00027	4,11	€ 300,00
TIER III	E10	11,17	7,16	0,02014	18,35	€ 6.301,00
TIER I	E05	0,32	1,64	0,00043	1,96	€ 1.000,00
TIER I	E03	1,40	1,24	0,00007	2,63	€ 600,00
TIER I	E06	0,42	2,46	0,00013	2,88	€ 200,00
TIER I	E12	0,88	1,64	0,00027	2,52	€ 1.200,00
TIER III	E09	3,66	12,84	0,02014	16,52	€ 3.060,00
TIER II	E14	3,70	1,64	0,00043	5,34	€ 1.950,00
Total Consumption [TOE/year]		29,66	38,21	0,04259	67,92	
Total Energy Cost [€/year])		€ 27.868,55	€ 35.905,09	€ 40,01	€ 63.813,65	€ 15.912,00

For each server room, the power of the installed resources was recorded and the energy consumption was then calculated, considering the real working hours of the devices. The unitary cost of electrical energy, for all of the analysis, was set to 0.175 [€/kWh]. i.e. the unitary costs paid by University of Brescia. After, the yearly cost for the maintenance of each resource was accounted and the total cost of each server room was calculated, as well. The heating district of the city supplies the server rooms E09, E10 and E14. Consequently, the quantity and the cost of the thermal energy used during the summer period were calculated. Since there is only a distributed thermal energy system, a breakdown of the total consumption was based on cubic meters, to calculate the energy used by each server rooms. The two contributions (thermal and electrical) were conveniently converted to sum the quantities of energy used overall.

The results of the energy audit, before the IT efficiency project, are summarised in Table **1**.. The yearly cost for the server rooms accounted for about € 79.000, facing an energy consumption of about 68 TOE per year. Figure 1, instead, shows the distribution of energy consumption between the three types of resource identified: IT, Auxiliary Services, General Services. It is interesting to note that the Auxiliary Services account for the major consumption of energy. As stated before, the cooling system is of main importance for operating the IT infrastructure and, often, these devices are oversized to reduce the probability of high temperature occurrence in the server rooms.

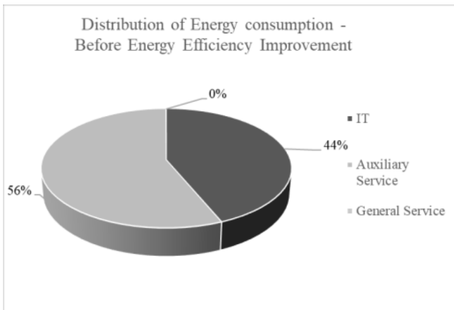

Figure 1: Distribution of energy consumption, before improvement

Table 2: Energy audit results, after improvements

TIER Classification	ID Building	Energy consumption [TOE/year] for IT	Energy consumption [TOE/year] for Auxiliary service	Energy consumption [TOE/year] for General Service	Total Consumption of Server Room [TOE/year]	Maintenance costs [€/year]
TIER III	E10	7,41	3,21	0,0201	10,64	€ 4.400,00
TIER III	E09	0,39	5,75	0,0201	6,16	€ 1.200,00

TIER II	E14	3,70	1,64	0,0004	5,34	€ 1.950,00
Total Consumption [TOE/year]		11,50	10,60	0,0407	22,15	
Total Energy Cost [€/year])		€ 10.806,93	€ 9.962,33	€ 38,25	€ 26.407,52	€ 5.600,00

Table 3: Investments, Savings obtained and Economic analysis

Type of Operation	Energy Consumption Before [TOE/year]	Cost/year	Energy Consumption After [TOE/year]	Cost/year	Investments (I0)	Energy Saving [TOE/year]	Cost Saving [€/year]	CO2 Saving [kgCO2eq/year]	NPV	Simple PBT
E-mail server Virtualization	1,26	€ 2.675,43	-		€ 15.000,00	1,26	€ 2.675,43	2.196,44	€ 5.658,99	5,61
Server Centralization	2,27	€ 3.644,42	0,41	€ 750,48	€ -	1,86	€ 2.893,94	3.255,59	€ 22.346,25	0,00
Server Virtualization	25,10	€ 29.979,86	6,96	€ 11.052,42	€ 130.000,00	18,15	€ 18.927,44	31.712,82	€ 16.152,67	6,87
Firewall Virtualization	1,08	€ 10.331,80	-		€ -	1,08	€ 10.331,80	1.882,66	€ 79.779,42	0,00
Switch Consolidation	3,47	€ 3.262,96	-		€ -	3,47	€ 3.262,96	6.068,70	€ 25.195,71	0,00
TOTAL					**€ 145.000,00**	**22,34**	**€ 34.828,61**	**39.047,51**	**€ 123.937,33**	**4,16**

Energy costs are higher, because the IT devices need energy 24 hours per day, and the devices requiring maintenance show a limited maintenance cost per year, with respect to the energy consumption.

The actions implemented for the optimization of the IT infrastructure are described hereafter.

The IT efficiency project was foremost allowed by a consolidation of the IT services and personnel, previously allocated in six different and autonomous departments. Thus, a single IT infrastructure was consolidated, serving all departments in a centralized way. Then, the efficiency improvements were based on the following five actions:

1. E-mail service moved to cloud: initially there were six different systems for the e-mail service: four at the departments, one at the administration and one dedicated to the students. These servers needed a large amount of storage devices to store all messages. With this project an external cloud service was configured to provide the e-mail service for the whole University. This service migration in cloud allowed removing all the six existing systems, substantially removing energy consumption and maintenance costs. The global energy consumption is not totally removed, because the servers of the Google Data Centre require energy on their turn. But we consider that the Big Data Centres are more efficient than small server rooms, as the ones considered. Moreover, it was also allowed to reduce the dimension of the data storage, since the e-mail backup was a large portion of it.
2. Server centralization: before the improvements, most services (such as DNS, DHCP, RADIUS, LDAP, VPN, web services) were located on dedicated servers for each department. With the centralization, many services could move on smaller physical servers, each one providing the same service for the whole University, rather than a single department. It is to be noted that all these services require limited CPU power, so it was also possible to consolidate them onto fewer servers, each one still using about the same amount of electrical energy, but managing all departments. Therefore, this operation reduced the number of servers and the related energy consumption.
3. Server virtualization: about one hundred physical servers, the remaining ones after the previous improvements, were virtualized on a virtual system, made up of three hardware hosts and one unified storage. The virtualization allowed the removal of all the physical servers, replacing them with virtual machines based only on three hardware hosts, with the result of energy consumption and maintenance cost reductions.
4. Firewall virtualization: at first, there were six hardware firewalls, one for each department or structure. After the improvements, they have been located on only one firewall, based on an open source software, which has been virtualized, too.
5. Switch consolidation: the number of switches, distributed on the different areas of the University of Brescia, have been reduced by the use of VLAN and the switches decommissioned have been utilized in other buildings or departments without any additional technical expense for new hardware or software.

After the technical actions, a new energy audit was performed. We considered only the modified configurations to estimate the energy savings determined by the improvements themselves. Thanks to the centralization and virtualization, the hardware located in nine server rooms was removed and/or reduced. Now, the same actions are performed on few hardware units located in three server rooms: E09, E10 and E14. In

Table **2,** the results of the energy audit are shown. After the improvements, the yearly cost for the IT infrastructure has been reduced to about € 50.000 per year, thus achieving a reduction of 67% of energy and maintenance costs, as in **Table 4**.

Table 4: Saving obtained

Description	Saving €
TOE/year	45,77
€/year (ee.)	43.006,113
€/year (maint.)	10.312,00
€/year (ee+maint.)	53.318,13

As expected, the percentage of energy consumption among the three types of resources changed, too. In fact, all the efficiency operations were applied on the IT devices, reducing the server rooms and the amount of energy necessary for cooling the decommissioned rooms, too. After the second energy audit, it was possible to define the savings reached by implementing the IT efficiency actions.

Table 3 summarizes the savings obtained. In columns 2 and 3, the consumption and costs of each unit before the operations are shown, while columns 4 and 5 refer to the situation after them. After the operations, only the server units present an energy consumption. Moreover, only the e-mail and server virtualizations required some investments, as summarized in column 6. The investment in the e-mail server virtualization was due to the technical staff involved in the operation, while the server virtualization needed also an investment in new hardware. Thanks to the operations implemented, some savings were reached in energy consumption: the server virtualization accounts for the most important energy saving, because of the decommissioning of several servers. The total energy savings accounts for 22,34 TOE/year, and about 39.000 kg of equivalent CO_2 emission. The total investments for the operations account for 145.000 € and the total yearly savings account for about 35.000 €.

The Net Present Value was calculated to appreciate the profitability of the improvements and the Pay Back Time allowed the appreciation of whether the investments could be returned in a reasonable lapse of time.

The formulae used for the two Indicators, summarized in columns 10 and 11, are shown respectively in equations (1) and (2):

$$NPV_i = \frac{(\sum_1^n CS_i)}{(1-r)^n} - I0_i \quad (1)$$

$$SimplePBT_i = \frac{I0_i}{CS_i} \quad (2)$$

Where:

i is the operation considered,

CSi are the cost savings reached per year, for the operation i, in literature called as the cash flow,

n is the number of years of the analysis (the time horizon, in this analysis, set to 10 years),

r is the interest rate (in this analysis, 5%),

I0,i is the investment for the operation i.

In Table 3, the row "TOTAL" summarizes the investments, savings and pay back time for the full IT efficiency project. It has to be noted how, given a total investment of 145.000 €, about 35.000 € were saved per year. Therefore, considering the entire project, the total Simple Pay Back Time is about 4 years. Figure 2 shows the NPV considering ten years of useful life of the IT infrastructure. The Pay Back Time is the Discounted one, which differs from the Simple PBT less than one year.

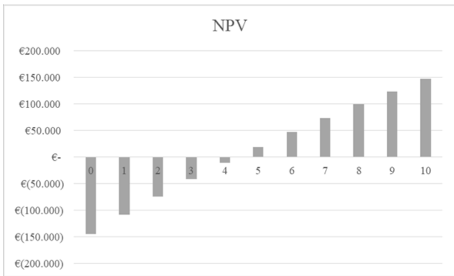

Figure 2: Net Present Value

Once the economic analyses have been performed and the savings have been confirmed, the second step was performed, i.e. the Energy Analysis. The following section describes it in detail.

5. Energy Analysis: PUE, DCIE

The Energy Analysis consists of the evaluation of the effectiveness and efficiency of the server rooms, before and after the IT efficiency project. The PUE, Power Usage Effectiveness, is defined as the ratio between the total power to run the data centre facility (the server room) and the total power drawn by all the IT equipment, as in equation (3).

$$PUE = \frac{\sum P_{IN}}{\sum P_{IT}} \quad (3)$$

Where:

P_{IN} is the power in input at the system, including the power necessary for the auxiliary and general services,

P_{IT} is the power necessary to run the IT equipment.

The second key performance indicator evaluated is the DCIE, the Data Centre Infrastructure Efficiency, i.e. the reverse of the PUE, which accounts for the efficiency of the server room. Equation (4) shows its plain calculation:

$$DCIE = \frac{1}{PUE} = \frac{\sum P_{IT}}{\sum P_{IN}} \quad (4)$$

As stated by Horner et al., 2016, the PUE metric is very useful for reporting energy performance of data centres; however, it can be an incomplete one, given that it does not address the important energy and environmental performances.

According to the scope of this work, a simple and common metric has been considered to compare the server rooms before and after the energy efficiency improvements. At the University of Brescia, each server room has both dedicated auxiliary and general services, consequently the procedure for allocating the consumption was simplified. The thermal energy, used for cooling the server rooms in buildings E09, E10 and E14, was calculated dividing the total consumption and cost for each building by the cubic meters of the pertinent server room.

Therefore, the PUE was calculated according to the following equation (5):

$$PUE = \frac{\sum P_{IT} + \sum P_{AS} + \sum P_{GS}}{\sum P_{IT}} \quad (5)$$

Where:

P_{IT} is the power of each IT equipment

P_{AS} is the power for all of the auxiliary service devices

P_{GS} is the power for the general service devices.

Using equation (5), the PUE, before and after the IT efficiency project, was found. Table 5 summarizes the power for each resource and the PUE, before and after improvements.

Table 5: PUE and DCIE [kW], before and after the IT efficiency Project

	Before [kW]	After [kW]
IT	18,107	7,021
Auxiliary Service	51,369	31,062
General Service	43,262	42,760
PUE	6,23	11,514
DCIE	16%	9%

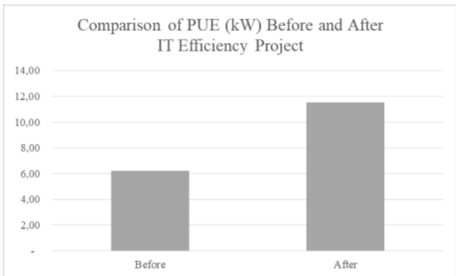

Figure 3: PUE before and after IT Efficiency Project [kW]

As in Figure 3, the PUE worsens after the efficiency improvements. The improvements performed on the IT equipment reduced the power installed in the server rooms, but these actions impacted on the auxiliary and general services, too. The power of the IT equipment is present at both the numerator and the denominator [equation (5)]; moreover, the power needed for the services was modified. Consequently, the deterioration or the improvement depend on the percentage of reduction of the power of the IT equipment and on the percentage of reduction of the power of the services, before and after the improvements. In the case described, the percentage of power reduction of the IT equipment was 61%, while the percentage of reduction of the service devices was 22%.

A sensitivity analysis has been performed to understand the performance of the PUE in the case under examination. As first, the power value [kW] of the IT equipment was varied, from a saving percentage of 10% to 75% starting from the original IT power value, i.e. 18,1 [kW]. The power of auxiliary and general services was maintained the same. As a result, reducing the IT power installed, the value of PUE increases (Figure 4). This fact could mean that, while improving the IT equipment, the effectiveness of the server rooms will decrease. The motivation is that the PUE offers the power required by the service devices to operate the server room, with respect to the IT equipment power. Increasing the power of auxiliary and general services, with respect to the IT equipment power, the PUE increases. In Figure 5, the IT equipment and general service powers remain the same, while the auxiliary service power decreases from 10% to 75% with respect to the original value before the improvements, i.e. 51,3 [kW]. Decreasing the auxiliary service, the PUE decreases. The same effect is obtained while varying the value of the general service, as in Figure 6.

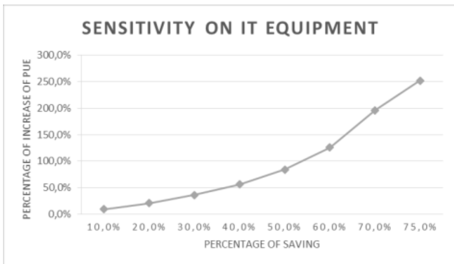

Figure 4: Sensitivity analysis on IT equipment

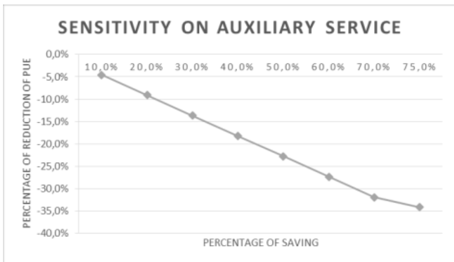

Figure 5: Sensitivity analysis on Auxiliary Service

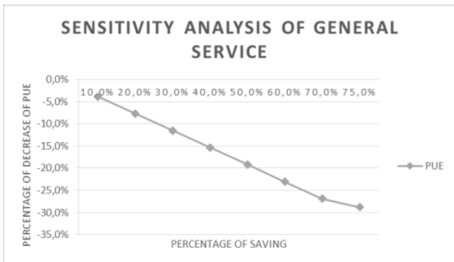

Figure 6: Sensitivity analysis on General Service

The sensitivity analyses show how the improvements of the IT equipment, implemented at the University of Brescia, have had an impact greater than the effect on the service infrastructure and, consequently, the effectiveness of the server rooms have been reduced.

However, since the reduction of energy consumption and costs were confirmed by the economic analysis, the PUE was calculated without considering the power installed, but using the energy consumption during one year of analysis, as in Wahlroos et al..

Table 6 summarizes the PUE and DCIE values before and after the improvements. The PUE decreased after the improvements and the efficiency increased from 44% to 52% (DICIE).

Table 6: PUE and DCIE before and after the IT efficiency Project

	Before [kW]	After [kW]
IT	29,66	11,50
Auxiliary Service	38,21	10,660
General Service	0,04	0,04
PUE	2,29	1,93
DCIE	44%	52%

Considering the energy consumption, instead of the power installed, the percentage of reduction for the IT equipment confirmed to be 61%, but the percentage of reduction of service devices increased to 72%. Figure 7 shows the effect of the improvements on the PUE calculated in TOE.

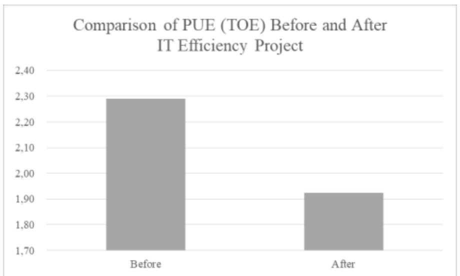

Figure 7: PUE before and after IT Efficiency Project [TOE]

The PUE calculation [TOE] is more useful for the case examined, as well as for all small server rooms. In fact, in the big data centres all the equipment and devices operate all the time (24/24 hours), while in small data centres and server rooms this may not be true. The power generator, for example, has an installed power of 21 [kW], but it operated only 5 hours in a year. The same applies to the cooling system (e.g., winter season). Thus, both auxiliary and general services have a lower impact on the server rooms.

Therefore, we can conclude that the energy [TOE] used for the service devices, with respect to the energy [TOE] used for IT equipment, has been reduced by implementing the efficiency actions presented at the University of Brescia.

6. Conclusion and Future Steps

In this study, an economic-energy method was applied to evaluate the profitability, the effectiveness and the efficiency of improvements in server rooms. The actions implemented at the University of Brescia involved the IT equipment and did not the auxiliary services, as the cooling system. Consequently, the energy consumption and costs were reduced, but the traditional PUE, the effectiveness of the server rooms, increased. A sensitivity analysis confirmed the results on the PUE. To evaluate the effectiveness of the server rooms, the PUE was not evaluated using the power of the equipment installed, but considering the energy consumption [TOE] during a year. The result was the decreasing of the PUE after the intervention, as stated during the economic analysis.

The economic-energy analysis may be applied to evaluate future actions to improve the efficiency of the IT server rooms: it allows the definition of the profitability of the investments, thus deciding whether a project could be implemented or not. The energy analysis, using the PUE [TOE], allows the understanding of the effects that the improvements will have on the effectiveness and efficiency of the server rooms.

Future steps will involve the economic-energy analysis of the profitability, the effectiveness and the efficiency of possible investments, such as the re-sizing of the cooling system, and the virtualization of some dedicate servers for researchers, presently distributed on different positions of the physical hardware of the University. A larger use of the power generator could also be considered as a potential field of study.

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