Energy consumption characterization as an input to building management and performance benchmarking – a case study

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Abstract:
The present paper aims at describing the methodology and presents some final results of a work developed in the field of building energy benchmarking applied to the buildings of the Polytechnic Institute of Leiria, based on a thorough energy performance characterization of each of its buildings, looking specifically at the typology of canteen. Developing building energy performance benchmarking systems enables the comparison of actual consumption of individual buildings against others of the same typology and against targets previously defined. The energy performance indicator was computed based on two different relevant elements, the net floor area and number of served meals. Then, the results were ranked according to the percentile rules previously established, and compared. An environmental analysis based on equivalent CO_2 emissions was also performed for each building.

Keywords:
Building energy benchmarking; decision making, energy management, higher education buildings.

1. Introduction

The building sector is very heterogeneous, both in terms of energy consumption and energy end-uses, including highly efficient buildings and others with a high potential for improvement of its energy usage. Overall, buildings are responsible for over 40% of the total final energy consumed in the European Union. In Portugal, residential and service buildings represent about 60% of the electricity consumed, and about 30% of the total primary energy.

Higher education institutions generally own a large stock of buildings which results in a significant overall energy consumption and associated high financial costs. Besides this, it implies overall high emission of CO_2 and its associated consequence on the environment. Good energy management practices results into buildings with better energy performance. One of the ways to achieve this is through monitoring and targeting of energy consumption, which consists in the use of management techniques to control energy consumption and cost (BRESCU 2000).

To implement actions that improve buildings energy efficiency, it is necessary for the building operation to be associated with an effective energy management methodology, as well as an efficient facilities management procedure. The implementation of any energy management system should start with an energy audit (Turner & Doty 2004). An energy audit is a detailed examination of the energy usage conditions in an installation; it is the vital tool that gives the managers the information to support decision making on improving energy performance (Thumann & Younger 2003). Energy audits are not only essential for improving energy efficiency and performance, but also represent a key step in the process of reducing greenhouse gas emissions from buildings, facilities, industrial processes and transport.

The instruments to measure how the energy is consumed, both at the micro and the macroeconomics level, are the energy performance indicators. The energy efficiency indicators can be grouped into two categories according to their objectives: descriptive indicators and explanatory indicators.

The overall performance of a building can be crudely expressed as an energy performance indicator, usually described as a ratio between the total amount of primary energy consumed and a relevant element (e.g. net floor area, number of meals, number of tons produced). The most common indicator in terms of primary energy is energy per net surface (kgoe/m2) and in terms of greenhouse gas emissions is carbon dioxide emissions per energy (kgCO2e/kgoe). The analysis is normally performed on annual data, allowing comparison amongst buildings and with published benchmarks to give an indication of efficiency.

Although performance indicators for buildings are generally rated in terms of net floor area, building volume and the amount of trade (e.g. number of meals) are sometimes used as normalizing factors. Indicators, adjusted according to weather and/or occupancy are often called normalized performance indicators (EVO 2010). This ‘normalization’ is intended to improve comparison between buildings in different climatic regions or with different occupancy patterns. However, this approach should be used with care as it can often distort the data and mask real patterns in consumption (CIBSE 2004).

In recent years, energy benchmarking in buildings has gained prominence with the adoption of the Energy Performance of Buildings Directive (EPBD) in 2002, more specifically the implementation of the Directive through requirements for Operational Rating Certificates and Display Energy Certificates. However, long before EPBD, benchmarks were widely recognized as important for comparing the operational energy efficiency of buildings and for influencing energy policy within building management (Liddiard et al. 2008).

One of the objectives of a benchmarking process is to set targets that will stimulate management to make improvements. These targets must be realistic and achievable, taking into account the likely savings from improvements in people behavior, maintenance and other efficiency measures. Management should use a consultation process to agree individual targets, rather than simply impose arbitrary figures. Targets should be reviewed periodically and set for each cost center, in order to stimulate a positive management attitude (CIBSE 2004).

Energy Benchmarking helps to consistently improve the standards through healthy competition by shifting markets to better performing levels. The potential beneficiaries for Energy Benchmarking include designers, owners, users, building developers, operators and policy makers (Kumar et al. 2010).

2. Methodology

The Polytechnic Institute of Leiria, Portugal, took the initiative of ordering a wide energy performance characterization of its buildings in the several campi. After a thorough energy audit was performed in each building, in order to characterize energy consumption, the buildings were grouped into different typologies, according to the main end-use activity there developed, into pedagogic buildings, canteens, residential buildings, libraries and office buildings. Then, it was required to establish a metric to compare the buildings energy efficiency.

For this study the specific consumption was chosen as the reference energy efficiency indicator. The calculation of the indicators for each building was fed by the data collected in energy audits. Then, the buildings of each typology were ranked and classified into three different categories: Good, Average and Bad. When the measured values present an adequate statistical distribution, the categorization process can be done by quartiles, and so approximately 50% of the sample should categorized as Average, with the respective range limits set to the 25^{th} and 75^{th} percentiles. The specific consumption values in the first quartile (percentile 25^{th}) were categorized as Good and those in the fourth quartile (percentile 75^{th}) were categorized as Bad.

The specific consumption was computed based on two different relevant elements, the net floor area and number of served meals. Then, the results were ranked according to the percentile rules previously established, and compared.

Conversion factors may have a significant influence on building energy consumption and greenhouse gases emission assessment, both in absolute and relative terms, especially when it comes to accounting for electricity. The conversion factors to primary energy used, according to Portuguese norm (Decreto-Lei 80/2006), were the following: 0,290 kgoe/kWh for electricity and 0,086 kgoe/kWh for other types of fuels, parameters defined due to the energy mix of the country. To compute the greenhouse gas emissions, the factors used are the following, according to Portuguese norm (Despacho 17313/2008): 0,47 $kgCO_2$/kWh for electricity and 2683,7 $kgCO_2$/toe for natural gas.

3. Data collection and analyzing

Higher education buildings have specific characteristics that differ from other buildings. They usually are grouped together into campi. Since, in most cases, the systems/buildings are not equipped with partial energy meters, the task of determining individual consumption is a true challenge. Besides, these buildings usually have longer opening hours, resulting in longer occupancy when compared with other services buildings. They can also be equipped with laboratories that sometimes resemble industrial facility rather than services building, even if those equipments do not operate continuously.

In the study performed, 25 buildings of the Polytechnic Institute of Leiria were analyzed. These buildings have different locations in the central region of Portugal and were grouped into campi. The main locations are the cities of Leiria, Caldas da Rainha and Peniche. Table 1 summarizes the main characteristics of the buildings analyzed and their typologies.

Table 1: Buildings characteristics.

Building	Typology	Net floor area [m^2]	Energy consumption [kgoe]	GHG emissions [$kgCO_2e$]
C1_Building_A	Pedagogic	4.358	76.111	123.352
C1_Building_B	Pedagogic	1.385	8.797	14.257
C1_Building_C	Office	591	3.953	6.407
C1_Canteen_1	Canteen	842	28.279	56.598
C2_Building_A	Pedagogic	12.063	243.050	434.941
C2_Building_B	Office	3.135	54.221	102.046
C2_Building_C	Research	1.320	37.826	79.782
C2_Building_D	Pedagogic	8.851	274.184	475.605
C2_Building_E	Pedagogic	507	30.378	49.233
C2_Health_School	Pedagogic	4.438	122.670	198.810
C2_Library	Library	3.333	162.246	277.277
C2_Canteen_2	Canteen	2.336	100.281	203.924
C2_Canteen_3	Canteen	1.484	69.146	131.234
C3_Building 2	Pedagogic	2.085	12.422	20.133
C3_Canteen_4	Canteen	1.193	66.133	124.659
Students_Residence_RBP	Residence	1.990	33.755	74.161
Students_Residence_MAD	Residence	1.753	38.867	87.436
Students_Residence_Peniche	Residence	1.019	19.467	43.433
C4_Building_ESTM	Pedagogic	6.542	110.529	184.712
C5_Building_1	Office	2.045	37.280	66.687
Administration_building	Office	2.616	47.813	77.491
Students_Residence_A	Residence	1.460	41.551	86.098
Students_Residence_B	Residence	1.452	38.426	90.419
Students_Residence_ C	Residence	1.744	69.445	133.002
Students_Residence_ D	Residence	1.300	33.173	78.861

Since for the typologies Research and Library there is only one building for each, they will not be subject to analysis.

In Fig. 1 is shown the breakdown of energy consumption by typology of building. For the present paper the focus is the typology of Canteen.

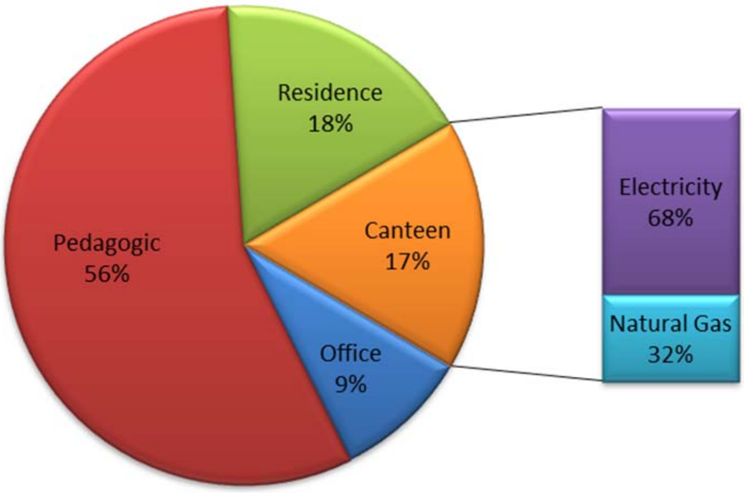

Fig. 1. Breakdown of energy consumption by typology of building.

In Polytechnic Institute of Leiria there are 4 canteen buildings that are responsible for 17% of the total energy consumption. These canteens are fueled by electricity and natural gas and all of them have a centralized system for preparation of domestic hot water fueled by natural gas and supported by a thermal solar system. Table 2 presents the main characteristics of the typology of canteen buildings.

Table 2: Main characteristics of canteen buildings.

Building	Net floor area [m^2]	Number of meals	Energy consumption [kgoe]	GHG emissions [$kgCO_2e$]
C1_Canteen_1	842	89.972	28.279	56.598
C2_Canteen_2	2.336	128.008	100.281	203.924
C2_Canteen_3	1.484	134.711	69.146	131.234
C3_Canteen_4	1.193	57.253	66.133	124.659

On Fig. 2 is shown the fuel breakdown for typology of canteen by each building in terms of electricity and natural gas.

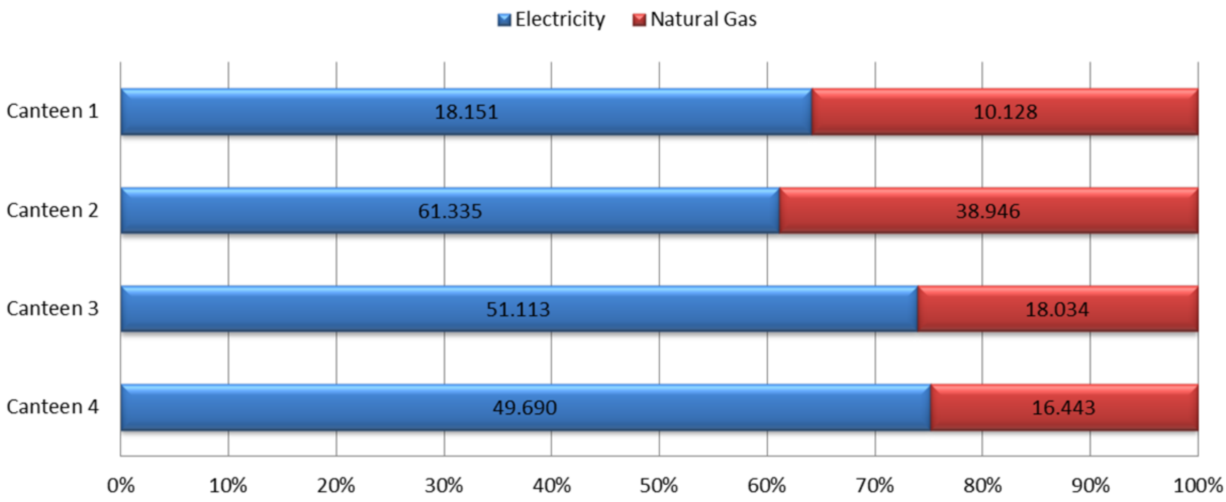

Fig. 2. Fuel breakdown of the typology canteen by each building.

Water and energy usage in canteens are areas that can offer cost savings without compromising hygiene or resources. Managing energy use can often have the additional benefits of improving the quality of the food produced and a better working environment for kitchen staff.

4. Results

The overall results are presented here firstly by showing the relation between energy consumption and net floor area and then the relation between the energy consumption and number of meals. Then, the indicators for both energy and greenhouse gases emissions.

Fig. 3 shows the relation between total primary energy consumption and the net floor area for the typology of canteen. Each mark represents one building.

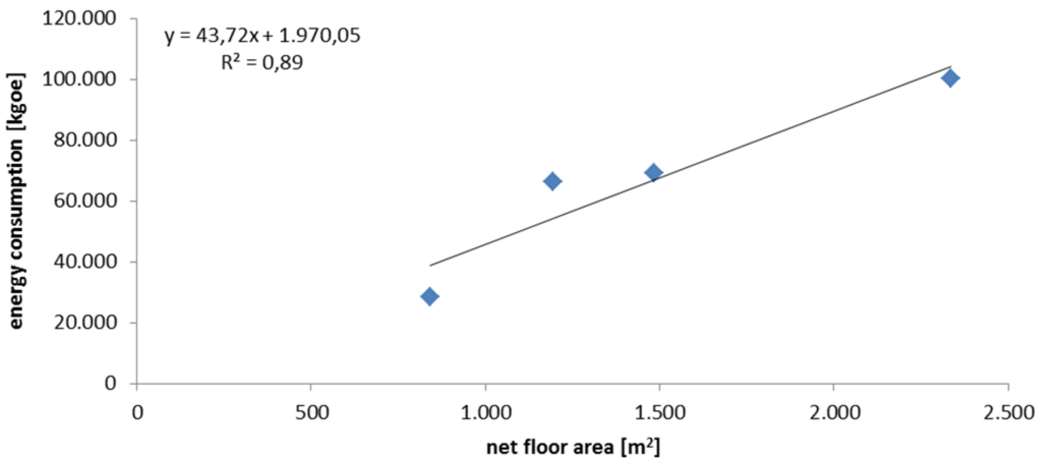

Fig. 3. Variation of primary energy with net floor area.

Fig. 4 shows the relation between total primary energy consumption and the number of served meals in each building for the typology of canteen. Each mark represents one building.

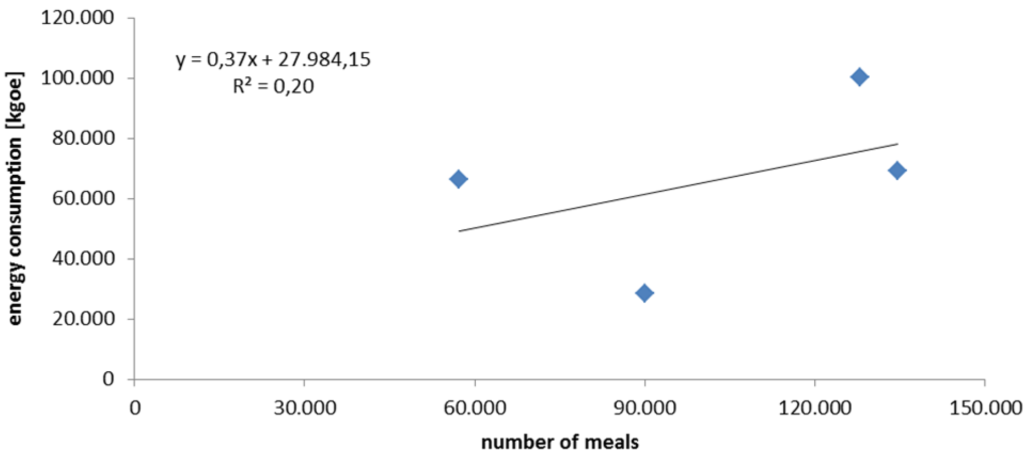

Fig. 4. Variation of primary energy with number of meals.

Analyzing the plots above and looking for linear regression model, it is visible that energy consumption increases with the net floor area of the buildings and with number of meals. However, the plots demonstrate that the relation between energy consumption and the number of meals has widely spread values than the relation between energy consumption and net floor area. The data seems to suggest a reasonable correlation between energy consumption and net floor area, due to the high value of R^2, which suggests that the relation between energy consumption and net floor area is stronger than the relation between energy consumption and the number of meals.

It is normally necessary to reach sample sizes greater than 100 buildings in each building category as this usually provides acceptable frequency distributions and hence reasonably reliable benchmarks. The benchmarks presented should therefore be viewed within this frame of mind and could be regarded as less reliable. However, due to the fact that these buildings are geographically close, and are managed by the same institution, data coherence is enhanced and the results obtained for the main sectors/typologies, where useful data was collected, will be of interest for building managers.

Table 3 presents the performance indicators computed for the typology of canteen. It is patent that different buildings have different specific energy consumptions. For GHG emissions, the differences are not so significant.

Table 3: Computed performance indicators for typology of canteen.

Building	Energy Indicator [kgoe/meal]	Energy Indicator [kgoe/m^2]	GHG Indicator [kgCO_2e/kgoe]
C1_Canteen_1	0,31	33,59	2,00
C2_Canteen_2	0,78	42,93	2,03
C2_Canteen_3	0,51	46,59	1,90
C3_Canteen_4	1,16	55,43	1,88

4.1. Energy indicator

In order to visualize more accurately the range of these differences, Fig. 5 shows 2 boxplots of energy indicator in [kgoe/m^2] and in [kgoe/meal] and Table 4 shows some relevant statistical parameters of energy indicators.

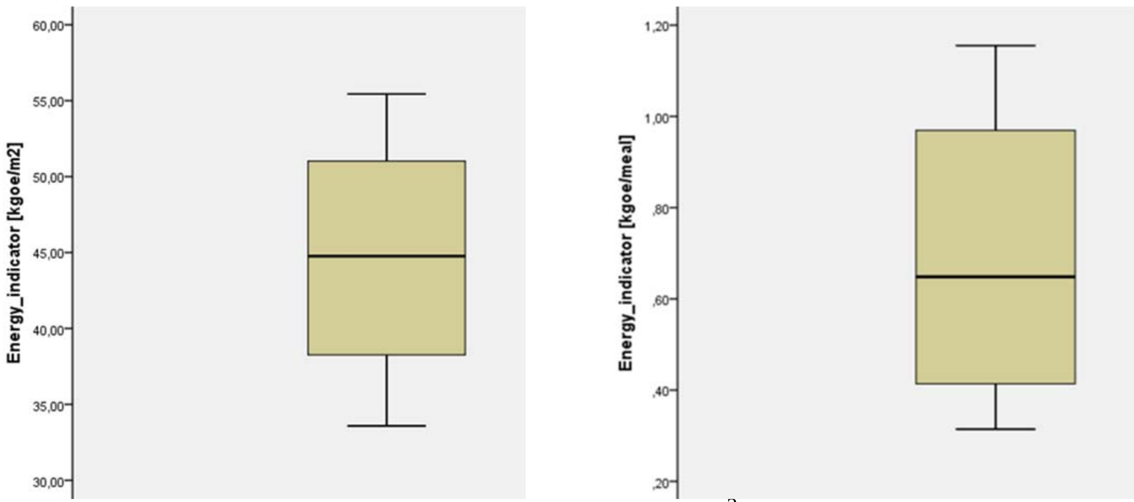

Fig. 5. Boxplot of energy indicator in [kgoe/m^2] and in [kgoe/meal].

The plots demonstrate that when the indicator is computed based on net floor area the data are well distributed along the range, with no outliers and a median near the center of the interval. When the indicator is computed based on the number of meals the interval is asymmetrical and also there are no outliers, which confirms some dispersion of data.

Table 4: Energy indicators for canteen buildings.

Energy Indicator	Sample size	Mean	Standard Deviation	Minimum	Percentile 25^{th}	Median	Percentile 75^{th}	Maximum
[kgoe/ meal]	4	0,69	0,36	0,31	0,41	0,65	0,97	1,16
[kgoe/ m^2]	4	44,64	9,05	33,59	38,26	44,76	51,01	55,43

Applying the quartile-based categorization presented in the second section of the paper, it is thus possible to rank and categorize all buildings using a metric defined accordingly. Fig. 6

presents the buildings, ranked by their energy performance indicator, based on net floor area, and categorized into Good, Average or Bad.

Fig. 6. Buildings ranked by energy indicator [kgoe/m^2].
(Green bars correspond to buildings considered Good, blue bars to Average and red bars to Bad)

Fig. 7 presents the buildings, ranked by their energy performance indicator, based on the number of served meals, and categorized within the rules previously defined.

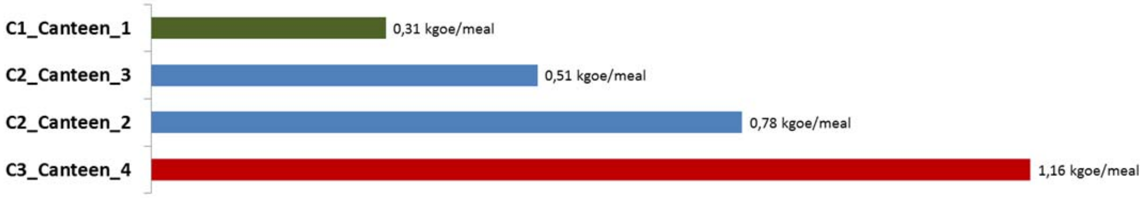

Fig. 7. Buildings ranked by energy indicator [kgoe/meal].
(Green bars correspond to buildings considered Good, blue bars to Average and red bars to Bad)

From this point it is possible to observe each ranking separately, to find curious situations. The best and worst energy performance building remained, but the intermediate changed if the energy performance indicator is calculated based on net floor area or based on the number of served meals. For office buildings, all are similar except for one, and the small size of the sample clearly distorts results. Except for some unapparent exception, the best-ranked building may set an example to the others of its topology, leading building managers to draw the pertinent conclusions.

4.2. GHG emissions indicator

Fig. 8 and Table 5 repeat the previous analysis, for the greenhouse gases emissions indicator for canteens.

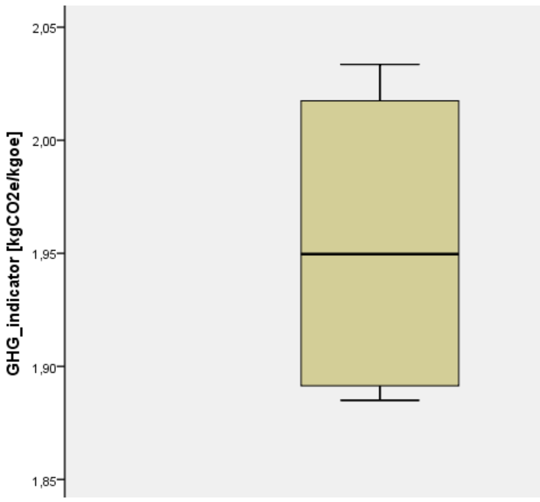

Fig. 8. Boxplot of GHG emissions indicator.

Compared to the previous indicator, this one presents smaller intervals and no outliers, revealing that similar buildings, even with different energy performance, present similar specific GHG emissions. There is some asymmetry in the distribution of the data, since the values are concentrated in the first quartile.

Table 5: GHG emissions indicator for canteen buildings.

GHG Indicator	Sample size	Mean	Standard Deviation	Minimum	Percentile 25th	Median	Percentile 75th	Maximum
[$kgCO_2e/kgoe$]	4	1,95	0,07	1,88	1,89	1,95	2,02	2,03

Applying the quartile-based categorization presented previously, it is thus possible to rank and categorize all buildings using a metric defined accordingly. Fig. 9 presents the buildings, ranked by their GHG emissions indicator, and categorized into Good, Average or Bad.

Fig. 9. Buildings ranked by GHG emissions [kgCO2e/kgoe].
(Green bars correspond to buildings considered Good, blue bars to Average and red bars to Bad.)

According to the previously results it can be seen that the building that have the worst energy performance indicator is the best in terms of environment and GHG emissions and the building with better energy performance indicator belongs to the worst ones in terms of GHG emissions. In terms of environmental performance the better buildings are those which have less natural gas consumption.

5. Conclusions

Performance indicators give only a broad indication of building efficiency and therefore must be treated with caution. It should not be assumed that a building with a ‘good’ performance indicator is in fact being operated as efficiently as is possible, or offers no scope for cost-effective savings. Overall performance indicators can mask underlying problems with individual end uses of energy.

The study performed is useful to identify if the buildings energy performance is poor, average or good comparing to the same type of buildings and to provide a useful first indicator for support decisions on the implementation of actions that improve buildings energy efficiency. When considered as a whole, the results allow further knowledge on the overall energy consumptions of a set of buildings, which in term may aid the decision-making process, for instance when evaluating different investment options, or when ordering a list of priority of interventions according to each actual effectiveness and pertinence.

At the beginning of the study it was expected that the energy consumption has stronger dependency with the number of served meals than with net floor area, but that was not true for Polytechnic Institute of Leiria. This may be due to the small number of buildings available to study or perhaps suggest that the matter requires further studying to be performed in order to assess the best indicator to use. Nevertheless, similar studies should be performed with a larger number of buildings, from different typologies, in different sectors of the economy. For example, it would be very interesting to perform a study of this nature throughout the higher education sector of Portugal.

Energy efficiency in buildings operation only can be achieved through a continuous energy monitoring and management system. So, energy benchmarking is also useful to give the measure of the progress over time.

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