TÉCNICO LISBOA

# Analysis of energy consumption performance in buildings

Case study: office buildings

**Carolina Sopas Costa**

Thesis to obtain the Master of Science Degree in

## Civil Engineering

Supervisor: Professor Doctor Maria Cristina de Oliveira Matos Silva

Supervisor: Professor Doctor Vítor Faria e Sousa

## Examination Committee

Chairperson: Professor Doctor Jorge Manuel Caliço Lopes de Brito

Supervisor: Professor Doctor Vítor Faria e Sousa

Member of the committee: Professor Doctor Inês Dos Santos Flores Barbosa Colen

January 2021

# Analysis of energy consumption performance in office buildings

Carolina Sopas Costa


## ABSTRACT

Buildings have associated an energy consumption and the development of society has generated the increase of this consumption. Since most of the energy comes from non-renewable sources, the environmental impact is substantial.

Current studies are mostly carried out on residential buildings, but the increase of total energy on offices buildings requires an appraisal. This master's thesis aims to contribute to the knowledge of energy consumption in commercial buildings, through the analysis of a database provided by EDP Distribuição with a sample of 104 offices distributed throughout Continental Portugal and a specific case study with photovoltaic panels.

In the general analysis of the sample, an evaluation is made of which buildings have the highest energy consumption at district level and the respective consumption patterns. It can be concluded that the annual average consumption is 94,4 kWh/m$^2$ and 2500 kWh/employee and it is estimated that between November and April the energy consumption index is higher than the sample average.

A more detailed analysis was made at one of the offices, where the contribution of the renewable energy source was assessed, as well as how energy consumption evolved over the years, a decrease is observed, accentuated by the containment measures imposed by the appearance of the pandemic in Portugal.

Statistical analyses were carried out to understand whether variables such as useful area, number of employees, solar radiation, outside temperature, ... explain the indicators of energy consumption and how strong the correlation is. The daily energy consumption is shown to have the highest correlation.


**Keywords:** Energy consumption, consumption patterns, offices, energy needs

## 1. Introduction

Energy consumption has shown an increase trend worldwide, but the commercial sector is the one that has shown the biggest increase [1][2]. According to the authors Vance et al., energy consumption increases with the growth of the world population, from 1965 to 2012 the energy consumption increase was 232%. This consumption is responsible for environmental impacts, such as greenhouse gas emissions from non-renewable sources used [3].

In order to have energy sustainability, changes and improvements need to be made, like the introduction of renewable sources. In 2019 Portugal managed to obtain more than half of the energy produced through renewable sources [4].

The perception of energy consumption variability is a type of analysis that has been carried out in residential buildings, but there is an urgent need to understand energy consumption in other types of buildings, including office buildings. Therefore, this master thesis aims to study this particular energy consumption sector.

**Previous works**

In the United States of America, all sectors show an increase in energy consumption. From 1949 to 2019 the growth of the commercial sector was 54%, and among the commercial buildings, offices represent the ones that consume the most [1]. The European Union (EU) countries, specially Portugal, do not show an increase in energy consumption in all sectors, but the commercial one stands out as the one that has increased the most, 27% and 74% respectively EU and Portugal [2].

Based on the analysis of articles, it was observed that some factors that can influence energy consumption beyond the location and typology of the building, such as the human behavior, the environmental conditions, the sun exposure, among others.

Given the preference of a user in an office, Naspi et al. [5] concluded that the worker prefers natural light and in the article of Antoniadou et all. [6] the building's internal temperature and $CO_2$ concentration also influence the worker preference, and that variation may depend on the use of air conditioning systems. At the level of sun exposure, there are several references of variables that have proven to influence energy consumption, namely the window/wall ratio (WWR), the degrees-days (DD), the thermal transmittances (U-value), the g-value and shading.

There is a set of variables that can be studied and then managed to reduce energy needs in order to contribute to energy optimization. The use of statistical and physical models is very common to facilitate and optimize the representation of variables.

# 2. Analysis of building sample

## 2.1. Methodology

This analysis has the goal to measure the energy consumption in a sample of offices in Portugal, to understand the consumption pattern in a sample and identify energy behaviors.

Through statistical analyses, it was evaluated whether there are explanatory variables for energy consumption and what correlation there may be between them, the SPSS program was used to determine better relationships between variables. To be able to conclude the correlation between the variables and whether they are significant. The statistical analysis was conducted in two level: the unidimensional and multidimensional analysis.

In the unidimensional analysis, Kolmogorov-Smirnov and Shapiro-Wilk tests allow us to determine whether the variations are normal distributions. Levene test is used to confirm whether variation it is homogeneous, and thus inform which correlation tools should be used. To know if the variables are significant and what are the values of the correlation, the Spearman and Kendall's tau tests were use.

For the multidimensional, analysis generalized linear model (GLM) and artificial neural networks (ANN) were uses. GLM is just a generalization of typical linear regression multiplies. The ANN is a kind of special non-linear multiple regression, in traditional regression it's necessary to know the mathematical function that relates the variables at the start and then the algorithm discovers the coefficients of the regression, the neuronal network estimates at the same time both mathematical function and coefficients.

## 2.2. Sample introduction

The entity's initial database consists of several buildings identified by the CPE's (Delivery Point Code), a total of 166 CPE's. However, a building can consist of more than one CPE, so the final sample consists of 104 buildings distributed by Mainland Portugal.

Analyzing all the information provided, there was a lack of various data, both in terms of the number of employees and the useful area of the buildings. The energy consumption of buildings was provided in several years, classified in two ways: by the invoiced records or by the direct reading of the counter (described in **Table 1**), at this stage of the analysis it was only possible to evaluate monthly. Although the annual evolution in the possible buildings was analyzed, the lack of data did not allow any relevant conclusion.

**Table 1** – Sample data

| Number of sample buildings with information of: | | Measurement form |
|---|---|---|
| Area [m$^2$] | 58 | - |
| Nº Employees | 59 | - |
| Annual Energy 2015 [KWh] | 41 | Billed |
| Annual Energy 2017 [KWh] | 6 | Reader |
| Annual Energy 2018 [KWh] | 12 | Reader |
| Annual Energy 2019 [KWh] | 14 | Reader |
| Annual Energy 2019 [KWh] | 96 | Billed |
| Energy certificate | 42 | - |

**Source:** [7]

Since location and climate can affect energy consumption, through the hierarchical system of dividing the Portuguese territory in regions, called NUTS ("Nomenclature of Territorial Units for Statistical Purposes") two types of sample division were carried out: NUTS II and climate zoning (NUTS III).

As shown in the **Table 2**, one third of the sample is in the Norte area (considering the classification of NUTS II). Dividing by the summer or winter climatic zone classification, is verified in the summer classification that the sample does not have any building with classification V1 and that more than half corresponds to V2, in the case of winter more than half is situated in zone I1.

**Table 2** – Quantification of the sample by dividing into a group of NUTS II and climatic zone (NUTS III)

| Division | | Amount | |
|---|---|---|---|
| | | Numeric | Percentage (%) |
| NUTS II | Norte | 39 | 37.50 |
| | Centro | 23 | 22.12 |
| | Alentejo | 13 | 12.50 |
| | Algarve | 6 | 5.77 |
| | A.M de Lisboa* | 23 | 22.12 |
| Climate zone | V2 | 66 | 63.46 |
| | V3 | 38 | 36.54 |
| | I1 | 60 | 57.69 |
| | I2 | 38 | 36.54 |
| | I3 | 6 | 5.77 |

*Área Metropolitana de Lisboa **Source:** [7]

Positioning the buildings considering the classification by the NUTS II and combining with the climate zone classification, it is found that all buildings classified as I3 correspond to Norte buildings and with I2 are presented buildings at Norte and Center. All buildings that correspond to the Alentejo, in the winter weather zone correspond to classification I1 and summer V3. Due to the large number of buildings classified Norte and with winter zoning I1 it is expected greater needs of heating and/or lighting.

## 2.3. Results and discussion

The analysis carried out in Chapter 2 corresponds to the energy consumption billed in 2019, given the scarcity of data in other years, as can be seen by **Table 1**.

The sample is distributed throughout the territory of Mainland Portugal and in a first instance was studied, at district level, where the offices with the highest energy consumption per useful area and by number of employees are located (**Figure 1**). The average annual energy consumption per area is 94.4 KWh/m$^2$ and per number of employees 2500 KWh/employee.

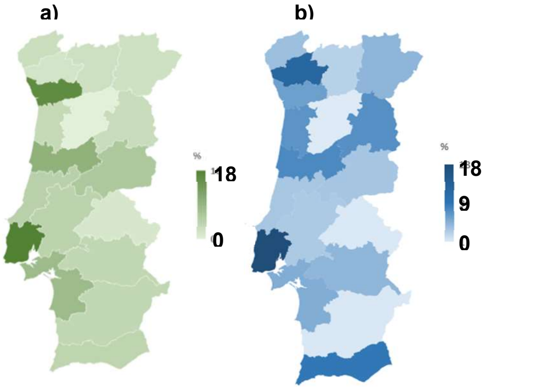


**Figure 1** - Percentage distribution of energy consumption per area [**a)**] and per number of employees [**b)**]. [7]

Lisbon, Porto, and Coimbra correspond to the districts with the highest energy consumption per area, respectively with a weight of 17.7%, 16% and 10% of total consumption. The districts of Lisbon and Coimbra have the highest energy consumption in 2019 and also represent those with the largest useful areas, compared to the total sample. The Guarda district has the largest area, but with a low energy consumption compared to the total consumption. So, it does not correspond to a district with higher energy consumption. These types of events prompted to try to understand the correlation between variables. The same assessment was made for energy consumption per employee: the districts with the highest representativeness are Lisbon (17.9%), Braga (12.4%) and Faro (9.1%). As in the previous study Lisbon and Coimbra represent the districts with the highest energy consumption, but also those with the highest number of employees and in this case.

Since there is information of monthly energy consumption, the pattern of monthly energy consumption by area and by number of employees of the sample was study, through the calculation of the average monthly index. Thus, it allowed to know which months are higher than expected by the average, represented by indices with values higher than 1. As it can be seen on **Table 3** there is agreement in both analyses, the months that have higher rates and consequently present higher consumption compared to the other months of the year, are November to April. The differences presented can be justified by the fact that the buildings that have information of the useful area are not the same ones that have information on the number of employees. The months with higher consumption rates correspond to times of the year with lower temperatures and lower solar radiation, which may justify the existence of higher heating and lighting needs, which in turn promotes higher energy consumption.

**Table 3** - Monthly average consumption indexes

| | Energy consumption per | |
|---|---|---|
| **Month** | Area | Employees |
| January | 1.27 | 1.23 |
| February | 1.40 | 1.40 |
| March | 1.25 | 1.18 |
| April | 1.03 | 1.05 |
| May | 0.84 | 0.90 |
| June | 0.92 | 0.92 |
| July | 0.97 | 0.97 |
| August | 0.93 | 0.95 |
| September | 0.96 | 0.96 |
| October | 0.96 | 0.93 |
| November | 1.09 | 1.01 |
| December | 1.17 | 1.15 |

**Source:** [7]

To verify if there are explanatory variables, first the unidimensional statistical analysis was performed. This studied prove that variables are non-parametric, according to the method used in chapter 2.

**Table 4** shows that are statistically significant variables in most cases. Although in consumption (day) per worker and summer climate are not statistically significant.

There are statistically significant correlations between the various indicators of energy consumption. In this analysis, it was indicated which correlations were performed, how much the correlation coefficients were and what degree of significance was obtained between the variables and the indicators studied.

**Table 4** - Non-parametric distribution comparison results

| **Energy consumption indicator** | **Variable** | | | | |
|---|---|---|---|---|---|
| | Location | Energy Class | Summer Climate | Winter Climate | Climate |
| Consumption | Y | Y | Y | Y | Y |
| ConsumptionDay | Y | Y | Y | Y | Y |
| Consumption per area | Y | Y | Y | Y | Y |
| ConsumptionDay per area | Y | Y | Y | Y | Y |
| Consumption per Workers | Y | Y | N | Y | Y |
| ConsumptionDay per Workers | Y | Y | N | Y | Y |

Y – statistically significant; N – not statistically significant

**Source:** [7]

The positive correlation coefficients indicate that the correlation between the two variables for example if one of them increases the other one will increase as well, however in the case of presenting negative coefficients, when one variable increases the other one decreases. The correlation coefficients have, in most cases, low values, which can be explained by the diversity of functions and typologies of buildings in the database. **Table 5** displays the highest correlations values founded for each case of the continuous variables. Highest correlation was between daily energy consumption and the useful area with 59% and between daily energy consumption and the number of employees with 73.3%.

**Table 5** - Extract from table of non-parametric correlation

| | | | **Area** | **Workers** |
|---|---|---|---|---|
| Kendall' s tau | ConsumptionDay | Correlation Coef. | 0.424** | 0.567** |
| | | Sig. (2-tailed) | 0.000 | 0.000 |
| | ConsumptionDay per area | Correlation Coef. | -0.332** | **-0.007** |
| | | Sig. (2-tailed) | 0.000 | **0.768** |
| Spearman | ConsumptionDay | Correlation Coef. | 0.591** | 0.733** |
| | | Sig. (2-tailed) | 0.000 | 0.000 |
| | ConsumptionDay per area | Correlation Coef. | -.490** | **0.000** |
| | | Sig. (2-tailed) | 0.000 | **0.994** |

**Correlation is significant at the 0.01 level (2-tailed). **Source:** [7]

In multidimensional statistical analysis, the performance of the GLM and ANN models was compared for the independent variables, it is verified that through the values of $R^2$, the neuronal network model is the one that explains better the variation of the data of these variables (**Table 6**).

**Table 6** - GLM and ANN models performance (sample case)

| Coefficient of determination ($R^2$) | **Models** | |
|---|---|---|
| **Independent variable** | GLM | ANN |
| ConsumptionDay | 0.475 | 0.963 |
| ConsumptionDay per area | 0.403 | 0.941 |
| ConsumptionDay per worker | 0.117 | 0.787 |

**Source:** [7]

For GLM model it was found that even if the correlation has low coefficients, it does not mean that it is not significant. For example, it was found that the area and the number of employees correspond to statistically significant variables in the model for daily energy consumption per area but have a low coefficient of determination. Considering the relative importance on the GLM model of daily energy consumption, the variable that presented the greatest relevance was the number of employees and for the model of daily energy consumption per area was the energy class (**Figure 2**).

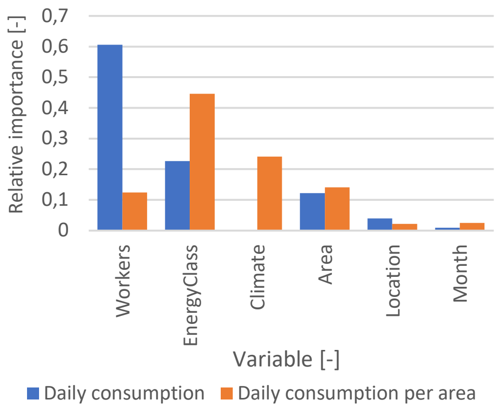


**Figure 2** - Relative importance of independent variables in the GLM models (sample case). Adapted from Costa [7]

After the analysis, the significant increase in the performance of the ANN models stands out. This fact corroborates the existence of interaction between the predictors and the non-linear nature of the relationship, with energy consumption.

## 3. Analysis of the specific building

### 3.1. Methodology

To obtain a more detailed analysis, an evaluation is made to a specific sample building.

Therefore, the energy consumption in several years is characterized, evaluated the existing energy needs in this office are evaluated and the consumption patterns are identified. In this case the data is obtained every 15 minutes, in some buildings telemetry consumption measurement systems are used, resulting from the installation of photovoltaic panels, which has made substantially more refined the auto-read records available.

Since this building has photovoltaic panels, a data analysis is performed, considering energy production and energy consumption (both networks, from electricity and self-consumption from photovoltaic panels). Solar radiation and the appearance of the pandemic are examples of new variables that may influence energy consumption. So, a new unidirectional and multidimensional statistical analysis was carried out with new variables, using the same methodologic as in Chapter 2.

### 3.2. Case study

The case study corresponds to a sample building analyzed in Chapter 2 and corresponds to ID: Building073. The office is located in Vila Nova de Gaia, in plant with an L format, in the longest part of the "L" the building consists of 3 floors and in the other part consists of a basement and 2 floors, the useful area of the establishment is 3197.07 m$^2$. It is an older building, since it was built in 1980, it holds electric cars and 2 exterior chargers and in 2017 photovoltaic panels (PV) were installed.

At staff level, the establishment consist a total of 101 employees (2019) in which 60% are operational workers and the rest belong to administration. The business hours of these workers are between 8am and 8pm, closing at weekends and public holidays.

### 3.3. Results and discussion

The evolution of energy consumption over the years 2015 to 2019 tends to maintain a constant consumption pattern, on average about 66.7 KWh/m$^2$.year, as can be seen by the **Figure 3**. However, it shows a decrease in energy consumption between 2015 and 2019 (purple and orange curves).

In 2019, two types of energy consumption (meter reading and invoiced) are observed, which may be due to adjustments made to the energy consumption billed throughout the year.

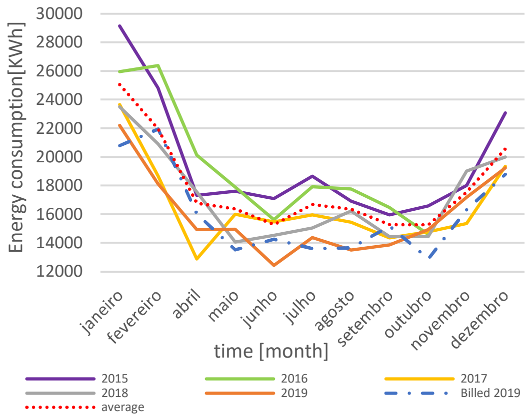


**Figure 3** - Comparison of monthly energy consumption between 2015 and 2019. [7]

When assessing the variability of energy consumption on network in these years, it is verified that from 2015 to 2019, on a monthly average, there is a reduction of 20.6%, which confirms the conclusion made previously. However, looking year by year, there has not always been a decrease in consumption, as are the cases between the years 2015 to 2016 and from 2017 to 2018. The largest monthly reduction in energy consumption was between 2016 and 2017 (17.7%) and the largest increase between 2017 and 2018 (5.3%).

This building has got photovoltaic panels, so the energy production is entirely used for total energy consumption, since there is no injection in the network. Therefore, the production will be equal to self-consumption. There is still a very low contribution of this renewable energy, and at most it can be obtained approximately 4% of this contribution in the year 2019.

The months where there is greater energy production is between May and August (**Figure 4**), which represented almost 50% of all production in 2019. In this period corresponds to the largest solar radiation in Portugal.

It is also observed in the **Figure 4** a depression in the curve of the average self-consumption in May and June, which may be motivated by the fact that in these months, in the year 2017, there was the regularization of the installation of PV and energy production was low. If you only compare the Months of May and April in the years 2018 and 2019 there is an increase and not the other way around.

Considering the energy certificate, it is possible to identify that before the building considers the contribution of renewable energy, total consumption was higher than the reference, which would make it have an energy class equal to or less than C. The contibuição of renewable energy allowed the passage to a class B- building. It is recognized that the contribution of renewable energy is directed to heating and AQS needs.

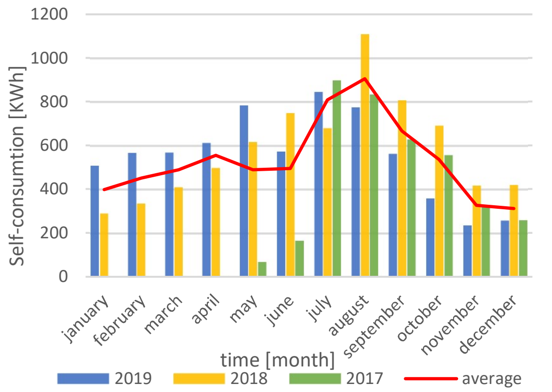


**Figure 4** - Self-consumption throughout the years 2019, 2018 and 2017. [7]

The most significant energy need is lighting, and only then with a significant difference the heating, which meets the identified in the buildings of the EU.

Each building has its way of behaving energetically and it is possible to identify patterns throughout the year, month, etc. Based on the method used in Chapter 2, several consumption indices were calculated at various time scales. In what concerns the monthly energy consumption index, represented in the **Figure 5**, it is observed that the months in which there was an above average consumption were between the months November and February, which reinforces the idea that in a building in Portugal there are greater needs for heating or lighting, since these months correspond to the season with lower outside temperatures and shorter daylight durations. In the remaining months there was an energy consumption below average. The lowest consumption index was in June with 0.8.

Evaluating the daily consumption index in each month turned out to be a complex assessment, since it is known that the establishment closes on weekends and holidays, creating several peaks of consumption.

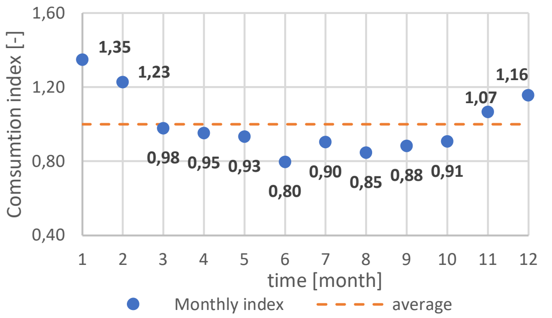


**Figure 5** - Average monthly energy consumption index in 2019. [7]

To better understand the daily consumption index, a weekly analysis was made, and the conclusion was the expected as the daily consumption index at the weekend is much lower than the other 5 working days. Next, the pattern of hourly consumption was carried out in these two types of days (working day and weekend/holiday), the evolution of hourly energy consumption was analyzed, reaching the curves presented in the **Figure 6**.

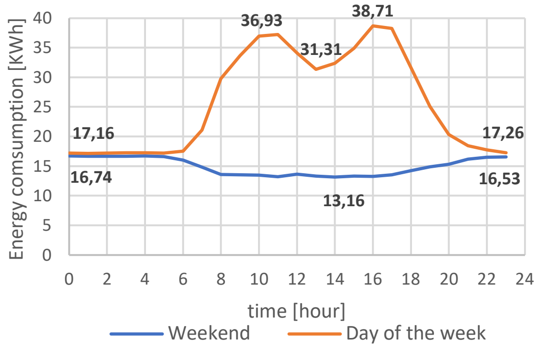


**Figure 6** - Average trend of hourly energy consumption over the course of a day. [7]

In a first evaluation it is evident on the working day what are the working hours, between 8am and 8pm. The depression that occurs in the line of energy consumption on a working day corresponds to the lunch time. In this time the energy needs for computer power, air conditioning and even lighting is reduced, as employees can choose to eat outside the building. This building has a great number of employees who work operationally, so as most teams do not belong to administration and it is normal that the behavior is not so linear.

When the establishment is not in working hours, there is still an energy expenditure necessary to maintain some equipment throughout the time, but it a lower consumption volume corresponds to the weekend. There was a little significant decrease in energy consumption at the weekend in the period between 9:00 pm and 6:00 am, this variation may be due to the existence of street lighting that is turned off in this period.

In 2020, the year was marked by the pandemic which caused several changes in behaviors and actions. Energy consumption is no exception, the change in the operating time of the establishment, the number of employees, among others, influences the existing energy consumption in the building.

Through the **Figure 7** the difference in energy consumption between 2019 and 2020 is obvious. In this case the study focuses more on these years because there had already been a reduction in energy consumption between 2015 and 2019 and when comparing the average energy consumption of these 5 years with the year 2020, differences that would not have to do with COVID-19 would be observed.

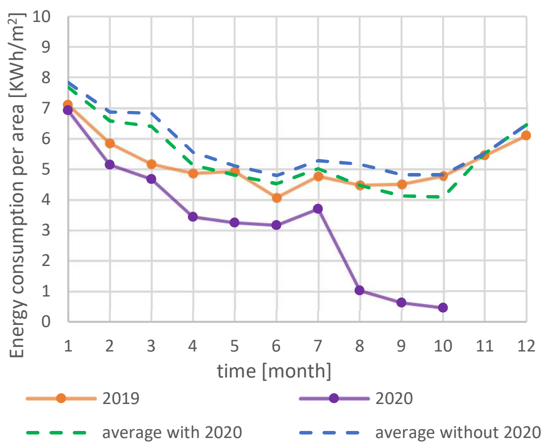


**Figure 7** - Comparison of energy consumption between 2019 and 2020, and between averages (2015 to 2019) and average with 2020. Adapted from Costa [7]

Due to the energy trend explained earlier, this decrease was expected, which occurs from January to March. What was not expected was the significant reduction between April and June and then again, with the largest reduction compared to energy consumption sums of about 90%, in the months between August and October.

The level between April and June is explained by the appearance of COVID-19 in Portugal, which by this time implied movement restrictions (confinement) and telework, consequently influenced the decision of energy needs in the building. That last level was not explained even with the company and can only exclude that it would have to do with the decrease of employees since in June there was some return of workers, within the possible restrictions.

The constructive characteristics of a building is important enough to create good conditions of comfort inside and seen that, as this establishment is old, certain conditions could not be maintained. More comfort promotes greater investment by employees.

It is expected that the variables: external air temperature and solar radiation are possible indicators that affect energy consumption, because these variables are associated with certain energy needs such as lighting, cooling, and heating due to the demand for comfortable working environment.

Solar radiation has implications for the energy needs of lighting, due to the time of natural light, but also on the production of electricity by the photovoltaic panel. It can be seen over the years that when compared to solar radiation in that area and the energy consumption of the building in a dimensionless way (**Figure 8**), the trend is that when there was less solar radiation the energy production was lower. In the months between May and August there is higher solar radiation, which is also at the time where there is a greater use of the energy production of PV and consequently self-consumption.

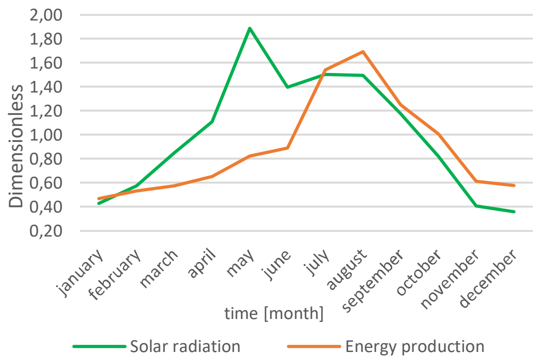


**Figure 8** - Comparison between the average solar radiation and energy consumption between 2015 and 2019. Adapted from Costa [7]

Compared to the temperature in that zone with the energy consumption obtained from 2015 to 2019, there was a direct influence on consumption, when the temperature decreased consumption increases and vice versa and this variation crosses in April and September, among these months there are high temperatures and low energy consumption (**Figure 9**).

The temperature causes effect on consumption, which is directly linked to heating and cooling needs, in this case higher heating needs were found.

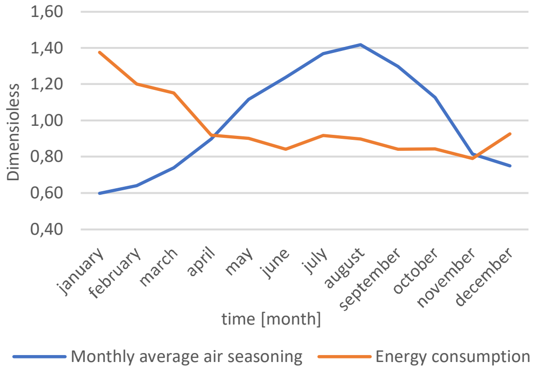


**Figure 9** - Comparison between the average of the external temperature and energy consumption between the years 2017 and 2019. Adapted from Costa [7]

As mentioned, a new correlation analysis was performed between variables for the new consumption indicators (index consumption) and the new parameters.

The unidimensional analysis consisted in testing the energy consumption and production distribution differences between the groups of the categorical variables (year, month, and weekday) and the correlation between the energy consumption / production and the continuous variables (temperature, rainfall, solar radiation, and the existence of COVID-19). The distributions comparison results confirm that the variables year, months, weekdays, and COVID-19 period are all statistically significant.

**Table 7** is an extract sample from all correlation study that was done. This table just present values from Spearman test since it was the one with the highest correlations.

There are also statistically significant correlations between the several energy consumption indicators and the weather data (in bold there are the correlation values who are not statistically significant). Most of them have negative correlations. The negative sign of the energy consumption correlations values related with the radiation and temperature can be explained by the location of the building in the

North of Portugal and the predominance of the worker's vacations in the summer months.

**Table 7** - Extract from the table of non-parametric correlation results

| Spearman | | Rainfall | Radiation | Temperature |
|---|---|---|---|---|
| Consumption | r | **0.006** | -0.388** | -0.428** |
| | Sig. | **0.852** | 0.000 | 0.000 |
| Monthly Consumption Index | r | -.145** | **-0.043** | **0.003** |
| | Sig. | 0.000 | **0.165** | **0.929** |
| Annual Consumption Index | r | 0.057 | -0.305** | -0.414** |
| | Sig. | 0.067 | 0.000 | 0.000 |
| Production | r | -.314** | 0.249** | 0.284** |
| | Sig. | 0.000 | 0.994 | 0.000 |

**Correlation is significant at the 0.01 level (2-tailed)
r - Correlation coefficient. Adapted from Costa [7]

In the multidimensional analysis, it is confirmed once again by the **Table 8**, that the variation of the distributions of independent variables is better explained by the ANN model, and the one with the highest coefficient is the energy consumption, with 88.9%.

**Table 8** - GLM and ANN models performance (specific building case)

| Coefficient of determination ($R^2$) | Models | |
|---|---|---|
| **Independent variable** | GLM | ANN |
| Consumption | 0.765 | 0.889 |
| Annual Consumption Index | 0.617 | 0.788 |
| Monthly Consumption Index | 0.621 | 0.727 |
| Production | 0.453 | 0.579 |
| Annual Production Index | 0.400 | 0.557 |
| Monthly Production Index | 0.394 | 0.525 |

**Source:** [7]

According to the GLM model, for daily energy consumption and for daily production, the variable with the greatest relative importance is the day of the week (**Figure 10**).

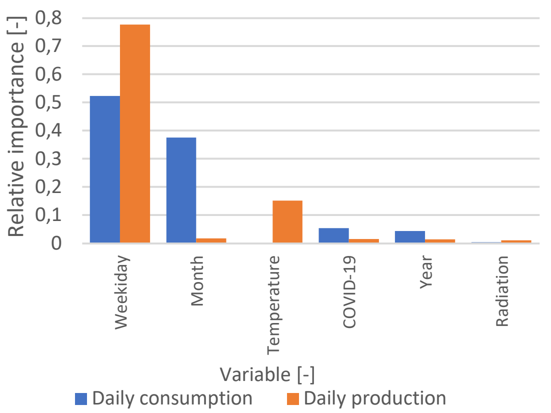


**Figure 10** - Relative importance of independent variables in the GLM models (specific building case). Adapted from Costa [7].

Comparing the predicted and observed consumption of the GLM and ANN models it is concluded that the independent variables have an approximately linear relationship with the variables that are in the model. As can be seen from the example of the annual consumption index in the **Figure 11**.

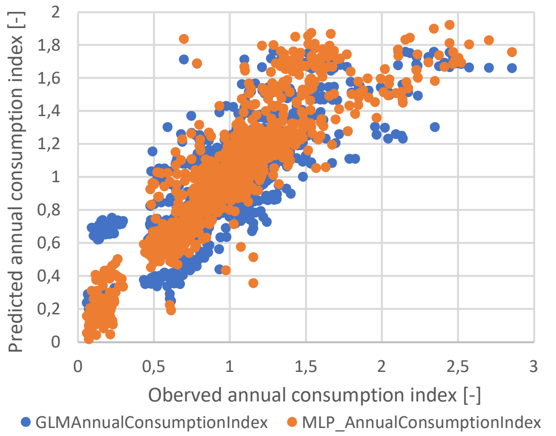


**Figure 11** - Performance comparison of the GLM and ANN models for the consumption. [7]

## 4. Conclusion

The main objective of this dissertation was to analyze energy consumption in office buildings. In the exploratory process of the theme, it was noticed that there is a lack of investigations and databases that support this type of object of study. This thesis is a scientific contribution in increasing knowledge on this subject. The growth of energy consumption is an irrefutable fact in today's society representing the commercial sector, which has grown the most in recent times.

The partnership with EDP Distribution enabled data collection and, thus, to know and evaluate the variables that interfere with energy consumption in offices buildings, as well as to perceive the evolution of energy consumption in this type of buildings.

It is concluded that when analysing the sample of 104 buildings at district level, on average, the sample in 2019, reveals an annual consumption of 94.4KWh/m$^2$ and 2500 KWh/employee, and the districts that contribute the most to a higher energy consumption per area are Lisbon, Porto, and Coimbra. However, if the analysis is per employee, it is located in the districts of Lisbon, Braga, and Faro.

It was the monthly analysis that made the greatest contribution to this study on this sample, making it possible to determine consumption patterns, by area and by number of employees, to know the months with the highest rates of energy consumption, which corresponds between the months of November and April, and it also showed that in Portugal there is a tendency for greater energy needs for heating and lighting, in this type of buildings. As for the temporal analysis of energy consumption, the annual one is less reliable due to an inconsistent database with omissions, which could skew the study.

In the study carried out at a specific establishment (Building073) of the sample, it was possible to conclude that the contribution of renewable sources (PV) is not very significant, noting that from 2017 to 2020 the maximum values reached was of 4%.

In Building073, the monthly consumption pattern is very identical to that of the sample. In the average daily consumption index, the variability is notorious depending on whether it is a working day or a weekend/holiday, and on business days the consumption indexes have higher values.

It is concluded that the higher the solar radiation, the greater the capacity of the photovoltaic panel to produce energy, thus reducing the need for a contribution of network consumption, the external temperature and energy consumption are inversely proportional to an increase in temperature corresponds to a decrease in energy consumption and vice versa. The COVID-19 pandemic regulated a few labor measures, including teleworking and staying at home, which consequently had a drastic impact on energy consumption.

As final remark, the analysis of the correlation between the variables makes it possible to point a set of explanations in the sustained management of energy consumption. Through unidimensional analysis, it was found that most of the variables studied are statistically significant and that a large part of the correlation between consumption/production indicators and the continuous variables (temperature, radiation, and precipitation) are negatively related. In the multidimensional analysis it was revealed that some variables that appear to be correlated and significant are not, whereas in the other analysis when comparing only two variables it is assumed that everything else is the same and this is false.

## 5. References

[1] U.S. Energy Information (2020) Use of energy in explained - U.S. Energy Information Administration (EIA). https://www.eia.gov/energyexplained/use-of-energy/ (Accessed in Nov. 15, 2020).

[2] Eurostat (2020) Eurostat - Data Explorer. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en (Accessed in Nov. 15, 2020).

[3] Guerra, M. D., Ribeiro, R. and Rodrigues, S. (2019) Produção e consumo de energia: Relatório do Estado do Ambiente. https://rea.apambiente.pt/content/produção-e-consumo-de-energia (Accessed in Dec. 10, 2020) (in Portuguese).

[4] APREN (2019) APREN - Produção. https://www.apren.pt/pt/energias-renovaveis/producao (Accessed in Nov. 15, 2020) (in Portuguese).

[5] Naspi, F., Arnesano, M., Zampetti, L., Stazi, F., Revel, G. M. and D'Orazio, M., (2018). Experimental study on occupants' interaction with windows and lights in Mediterranean offices during the non-heating season. *Building and Environment*, vol. 127, pp. 221–238, doi: 10.1016/j.buildenv.2017.11.009.

[6] Antoniadou, P., Kyriaki, E., Manoloudis, A. and Agis, M. (2017). Evaluation of Thermal Sensation in Office Buildings: A Case Study in the Mediterranean. *Procedia Environ. Sci.*, vol. 38, pp. 28–35, doi: 10.1016/j.proenv.2017.03.071.

[7] Costa, C. (2020). Análise do desempenho do consumo energético em edificios. Caso de estudo edificios de escritório. Master Thesis. Instituto Superior Técnico, University of Lisbon, (in Portuguese).