SmartSPIN

# **Smart** energy services to solve the **SP**lit **IN**centive problem in the commercial rented sector

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**Duration:** 36 months

## D4.2 – SMARTSPIN EARLY BUILDING PERFORMANCE DIAGNOSTICS

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| Version | Date (MM/DD/YYYY) | Created/Amended by | Changes |
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| 0.1 | 09/30/2022 | Roberto Garay | Initial draft |
| 0.2 | 11/14/2022 | Antonio Garrido Marijuan | Consolidated draft |
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| 0.5 | 02/27/2023 | Antonio Garrido Marijuan | Revised version |
| 1.0 | 03/14/2023 | Olaia Eguiarte & Antonio Garrido Marijuan | Final Version |
| 2.0 | 03/15/2023 | Ruchi Agrawal & Luciano De Tommasi | Final Review and Submission |

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

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## List of Abbreviations and Acronyms

| Abbreviations | Full Form |
|---|---|
| **AC** | Air Conditioning |
| **AHU** | Air Handling Unit |
| **API** | Application Program Interface |
| **CDD** | Cooling Degree Days |
| **DHW** | Domestic Hot Water |
| **EPC** | Energy Performance Contract |
| **HDD** | Heating Degree Days |
| **REEB** | Real Estate Environmental Benchmark |
| **SRI** | Smart Readiness Indicator |
| **Tout** | Outdoor temperature |
| **WP** | Work Package |

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# EXECUTIVE SUMMARY

This task develops data-driven energy diagnostics algorithms to identify the most significant energy & cost streams in buildings using a minimal dataset of information. It considers general information about the building such as location (i.e., climate), characteristics (i.e., size), usage (opening hours, schedules, etc.), and general HVAC characteristics, as well as overall facility energy consumption.

In line with the overall SmartSPIN concept, the diagnostic will comprise not only overall energy use, but also deliver granular data for its integration with energy tariffs in real practice (i.e., this implies that energy use is divided by energy carrier, and that electricity use is divided by billing schedules).

The early building diagnostic results in the calculation of key performance metrics that allow automatic identifying energy saving measures when cross-referenced against current building performance databases. CommONEnergy Data Mapper, INSPIRE project and BBP Real State Environmental Benchmark are used for the present work.

The development of this module supports Task 5.1 in the calculation of the baseline for pilot buildings of the project. This work, together with the previous work developed in T4.1, will show the potential for energy management in EPC for the pilots, resulting in a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use, operating hours, cost of energy carriers and other factors. The following measures will be considered: optimization of heating & cooling schedules, lighting systems, upgrade/replacement of heating & cooling equipment and building envelope improvement.

A user-friendly web-dashboard that allows users to upload specific building information and datasets to obtain early building energy diagnostics, through an application program interface (API) that accesses the developed algorithms, is produced as an output from the present task.

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# 1 INTRODUCTION

This task develops data-driven energy diagnostics algorithms to identify the most significant energy & cost streams in buildings using a minimal dataset of information. It considers general information about the building, such as location (i.e., climate), characteristics (i.e., size), usage (opening hours, schedules, etc.), and general HVAC characteristics, as well as overall facility energy consumption.

In line with the overall SmartSPIN concept, the diagnostic comprises not only overall energy use but also delivers granular data for its integration with energy tariffs in real practice (i.e., this implies that energy use is divided by energy carrier, and that electricity use is divided by billing schedules). The methodology of the energy use diagnostics is detailed in section 2.

The present report summarises the work performed as well as details the characteristics of the user-friendly web-dashboard and API developed. These outputs allow users to upload specific building information and datasets to obtain early building energy diagnostics, as explained in section 3.

The baseline resulting from the diagnostic is cross-referenced against current building performance databases for benchmarking, specifically, CommONEnergy Data Mapper, INSPIRE project and BBP Real State Environmental Benchmarks. The calculated key performance metrics together with the benchmarking allow to automatically identify energy saving measures.

This work, together with the previous work developed in T4.1 of the project (Assessment of the potential for energy management within performance-based contracts), shows the potential for energy management in EPC, resulting in a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use, operating hours, cost of energy carriers and other factors. The following measures are considered: optimization of heating & cooling schedules, lighting systems, upgrade/replacement of heating & cooling equipment and building envelope improvement.

Pilots' data are used to test the algorithms, providing the pilot baselines that will be later used in WP5. The outputs from the demo-sites building diagnostics are included in sections 4, 5 and 6.

Finally, section 7 includes the main conclusions from the work performed.

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# 2 METHODOLOGY OF ENERGY USE DIAGNOSTICS

## 2.1 PURPOSE

The purpose of energy use diagnostics is the assessment of the energy consumption and associated costs of commercial buildings. The diagnostics shall:

- Be based on already available data from sources such as on-site Building Energy Management Systems and data from utilities/energy suppliers. The processes should be adaptable to high-frequency (i.e., hourly) and low-frequency (i.e., monthly) data.
- Allocate the energy use to specific areas and/or subsystems in the building.
- Benchmark energy use to other buildings with similar size, configuration, usage, and climate conditions.
- Allow for the identification of energy saving measures and size their potential.

These diagnostics are NOT focused on developing tools and methods for any of the following applications:

- Building management applications such as short-term forecasting.
- Fault detection.
- Performance models for specific pieces of equipment (i.e., Chiller #5 in a building).

## 2.2 REFERENCE DOCUMENTS

Frame Protocols:

- ASHRAE (2014) ASHRAE Guideline 14: Measurement of Energy and Demand Savings. American Society of Heating, Refrigerating, and Air-Conditioning Engineers Inc., Atlanta, GA. https://webstore.ansi.org/Standards/ASHRAE/ashraeguideline142014 (accessed: 2022/09/26)
- ASHRAE (2010), Performance Measurement Protocols for Commercial Buildings

Methods for energy baseline assessment:

- Mikel Lumbreras, Roberto Garay-Martinez, Beñat Arregi, Koldobika Martin-Escudero, Gonzalo Diarce, Margus Raud, Indrek Hagu, Data driven model for heat load prediction in buildings connected to District Heating by using smart heat meters, Energy, Volume 239, Part D, 2022, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.122318
- Beñat Arregi, Roberto Garay, Regression analysis of the energy consumption of tertiary buildings, CISBAT 2017, Lausanne, Switzerland. Energy Procedia, Volume 122, 2017, Pages 9-14, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.07.290.

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Methods for clusterization of energy loads by building usage:

- Mikel Lumbreras, Gonzalo Diarce, Koldobika Martin, Roberto Garay Martinez, Beñat Arregi, Unsupervised Recognition and Prediction of Daily Patterns in Heating Loads in Buildings, Publication Pending.
- Sicheng Zhan, Zhaoru Liu, Adrian Chong, Da Yan, Building categorization revisited: A clustering-based approach to using smart meter data for building energy benchmarking, Applied Energy, Volume 269, 2020, https://doi.org/10.1016/j.apenergy.2020.114920

Energy costs:

- Tariff structures shall be defined in agreement with bilateral energy supply agreements. Shall these not be available, nationally available references shall be used.

## 2.3 Input data

The required input data is the following:

- Building characteristics[1]:
    - Building location (city), or, as an alternative, weather file of the location.
    - Building size (sqm).
    - Main building usage (shops/offices/hotels/…).
- Actual building usage[2]:
    - Energy supplies (Electricity, Natural Gas, Other fuels).
    - Opening times (or proxy signal with high resolution. i.e., electric consumption for lifts, water consumption…).

## 2.4 Data management

The assessments carried out in this report are coherent with the Data Management Plan (DMP) agreed among the SmartSPIN partners. In this regard, the DMP identified the main datasets to be used within the project. These are mostly related to public deliverables, energy assessments and energy datasets. As data from demo-sites may be sensitive, but needs to be disclosed to deliver the assessments committed in WP4, the assessment published are based on aggregated data, monthly resolution, which allows for assessing the ratio for different energy sources and the severity of winter/summer months compared to the average.

[1] Consistent with SmartSPIN D4.1: Interactive Web-App Showing The Potential For Energy Management In Energy Performance Contracts

[2] High resolution shall be used as much as possible. Ideally data frequency should be 1 hour

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On the other hand, the hourly resolution is based on statistical values, which allows for the delivery of some typical day profiles and communication of intra-daily energy load profiles, which are relevant for demand-response related activities.

Finally, overall energy consumption is normalized by floor space. By doing so, key business information is not published while reporting the main outcomes of the project.

In all cases, the publication of the datasets has been validated by the project pilot leaders (SMARKIA/LS/EUNICE).

## 2.5 CONTEXT

- Local climate[3]: Temperature, Relative Humidity and Solar Irradiation.
- Bank holidays.

## 2.6 ASSUMPTIONS

Energy patterns in buildings are assumed to resemble one of the following behaviours:

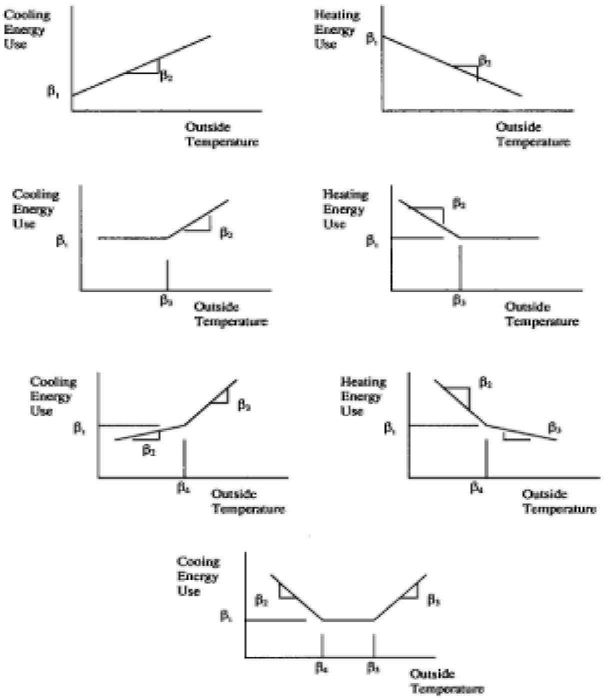


**Figure 1 Overall approach to changepoint models (top-left), 5-parameter (top-right), 3-parameter (heating) & 3-parameter (cooling) changepoint models[4].**

[3] High resolution shall be used as much as possible. Ideally data frequency should be 1 hour
[4] Kissock, J.K., Jeff S Haberl, and David E. Claridge. 2002. "Development of a Toolkit for Calculating Linear, Change-Point Linear, and Multiple-Linear Inverse Building Energy Analysis Models."

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This model is the most general approach to energy loads in buildings. It shall be considered as a true approximation for the cases where heating and cooling are served with the same energy carrier (e.g., electricity), and where heating and cooling loads do not overlap temperature wise.

Particular cases of this model are those for heating-only and cooling-only HVAC systems, sub-metered systems, and/or supplies of these systems with different energy carriers. In these cases, intercepts (parameters in the X-axis) and slopes on one of the two sides of the model can be neglected, delivering a three-parameter changepoint model.

Additionally, there are other systems that should present little-to-no climate dependence such as electricity use for indoor/outdoor lighting. In these cases, the hourly average can be used as a suitable model.

There is a very relevant variance to the data associated with intra-daily patterns as well as the specificities of specific day profiles. Understanding this variance is key to the success of energy management in buildings.

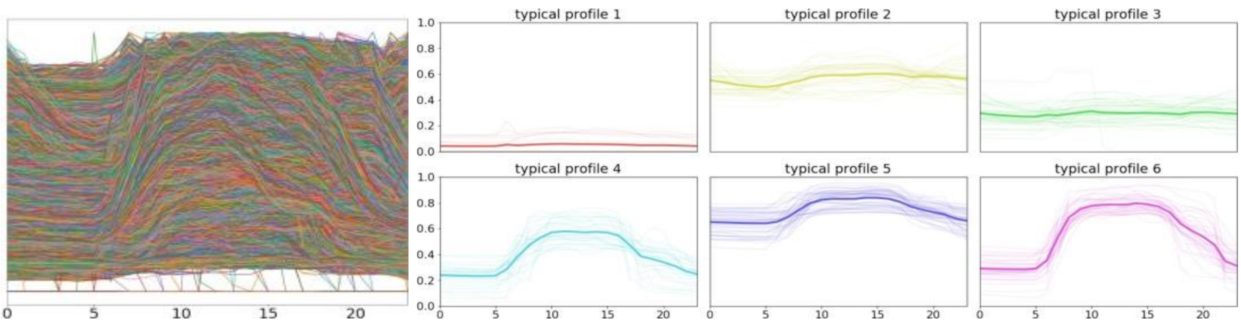


**Figure 2. Normalized daily electric load patterns in a set of buildings (left) and selected typical profiles for the same buildings after a clustering process (right)[5]**

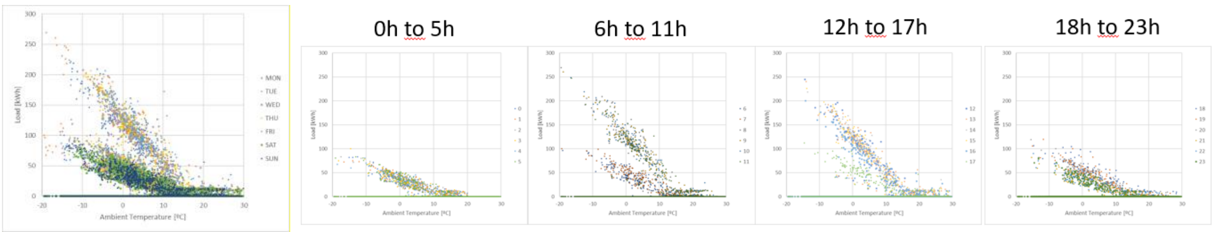


**Figure 3. Q-T scatterplot of hourly heat loads in buildings. Left: full data, coloured by day of the week. Right: Weekdays, separated into 6-h ranges[6]**

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[5] Sicheng Zhan, Zhaoru Liu, Adrian Chong, Da Yan, Building categorization revisited: A clustering-based approach to using smart meter data for building energy benchmarking, Applied Energy, Volume 269, 2020, https://doi.org/10.1016/j.apenergy.2020.114920, available at https://ideaslab.io/publication/zhan-2020-building/

[6] Roberto Garay, UPV/EHU, Erasmus Mundus Master in Smart Cities and Communities (SMACCs), "Building Heat Load Analysis", 2022. https://github.com/robgaray/SMACCS_Building_Heat_Load_Analysis

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The hourly variance is dealt-with by calibrating changepoint models for each hour of the day or relevant sets (i.e., 0-5h), and for each relevant daily pattern. Potentially patterns are the following:

- Based on a-priori knowledge on usage patterns and calendar data: i.e., Monday to Friday, Saturday and Sunday, bank holiday.
- Based on clusterization processes such as those listed in section 2.2.

## 2.7 PROCESS

I. Identification of system boundaries & Relevant Energy Loads

1. The system boundaries are identified as those corresponding with the metered energy supplies (i.e., full building).
2. Subsystems out of control of the facility manager (i.e., Ikea/Carrefour in La Gavia in Spain), with independent energy supply and/or submetered/billed energy are excluded from the system boundary.
3. Energy loads are categorized by types (i.e., lighting, lifts, heating, cooling…) and building areas (i.e., first floor, west wing, management offices, restaurants…).
4. Relevant energy loads are defined as those exceeding a relevant share (~5%) of the total energy consumption/energy costs. This allows to avoid complex & non-relevant analysis to be performed in small areas (i.e., ~10m$^2$ served with a locally deployed split AC system) or during low-consumption periods.

II. Data analysis

1. Data curation: pre-process data, eliminate outliers, etc.
2. Definition of typical operational days. This step can be performed based on a-priori data, and/or clusterization processes such as those stated in section 2.2.
    a. Weekdays vs weekends.
    b. Closing time vs opening hours.
3. Assessment of correlation of energy loads with boundary conditions
    a. Outdoor temperature; Heating Degree Days (HDD); Cooling Degree Days (CDD); solar irradiation; other weather parameters.
4. Calibration of changepoints.

IV. Identification of potential energy misuse

The following conditions can be considered as indicative of energy misuse.

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1. No/incorrect indexation of lighting loads with opening hours (indoor) or daylight (outdoor).
2. No indexation of constant heating/cooling energy loads with opening hours.
3. Sharp changes in energy loads, with peak values in peak unit cost periods.
4. High heating changepoint / low cooling changepoint temperatures.
5. High ratio between constant load & variable loads.
6. High energy use intensity levels when compared with benchmarks.

## 2.8 OUTPUT

The output of the diagnostics shall be the following:

- List of relevant energy flows & associated costs.
- Energy use intensity (i.e., per $m^2$ & type of energy use).
- Models and parameters for energy flows in relation with boundary conditions.
- Intuitions on potential energy misuse.
- Cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use, operating hours, cost of energy carriers and other factors.

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# 3 INTERACTION THROUGH APIS AND WEB-DASHBOARDS

The algorithms that allow for early building performance diagnostics are made available through a web-dashboard. For the sake of user-friendliness, the communication with the algorithms is made via an API, which simplifies the underlying calculations, only exposing objects the stakeholders need without requiring the knowledge of the operations occurring behind the scenes. Therefore, this web-dashboard allows users to upload specific building information and datasets to obtain early building energy diagnostics, through the API that access the developed algorithms.

## 3.1 ACCESS TO API

The API and web-dashboard is accessible via: http://digicon.tecnalia.com/smartspin/datavis/

## 3.2 FUNCTIONALITIES

The web-dashboard looks as follows:

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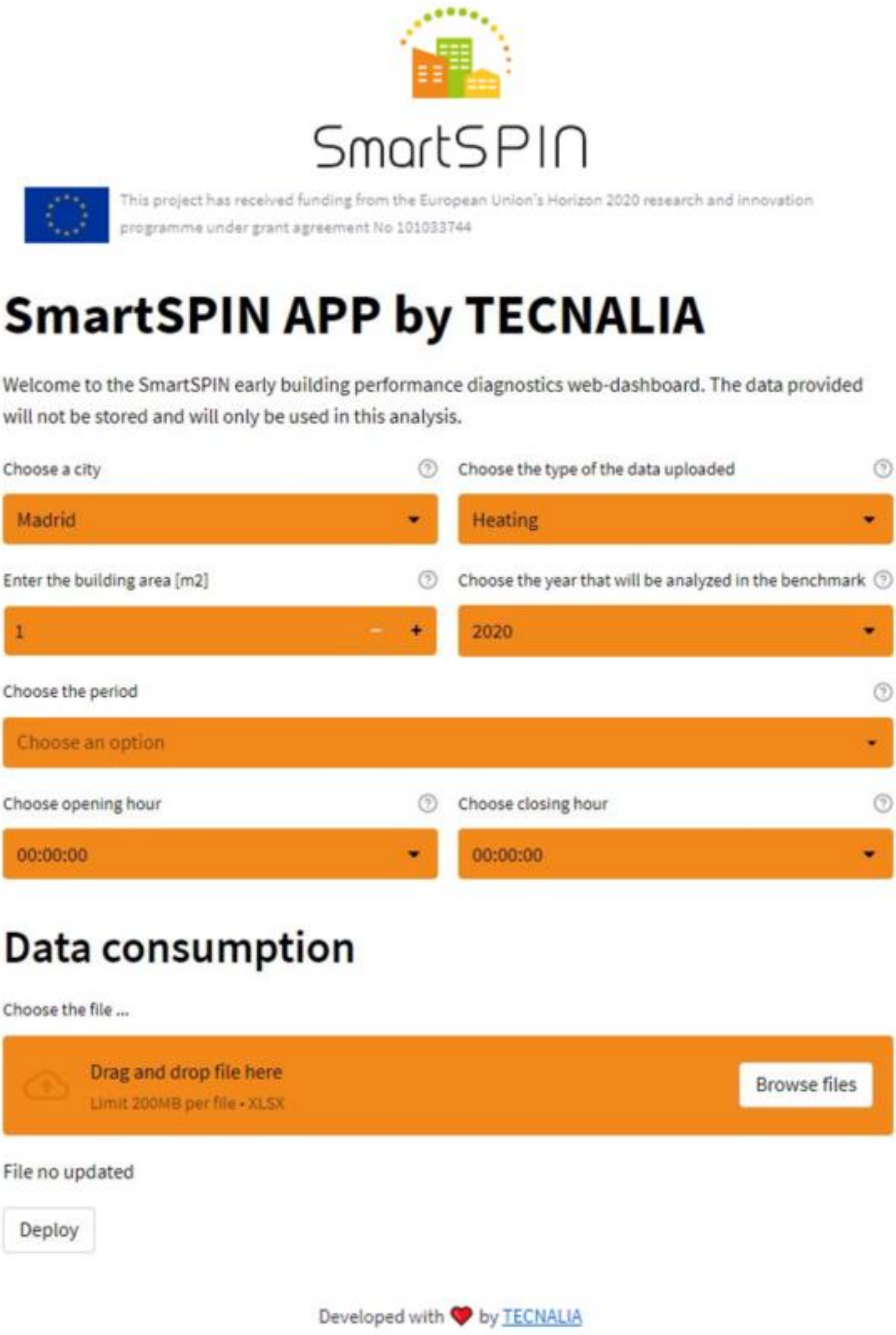


Figure 4 **Web-dashboard, serving as interface between users and algorithms.**

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The user enters the building characteristics through the different options available. The weather information for the available locations is pre-uploaded to the API for the later calculations. Additionally, the datasets must be uploaded. For this purpose:

- an exemplary excel file must be downloaded.
- data must be copied to this excel sheet.
- excel sheet must be uploaded.

The user interface (web-dashboard) is connected to the developed algorithms via API. Once the run button is clicked, the calculations are performed, and a list of energy saving recommendations is displayed to the user.

## 3.3 INPUT DATA

The required input data has been simplified to increase user-friendliness. More functionalities and analysis could be performed with more data (i.e., bank holidays, HVAC characteristics), but simplicity has been preferred to increase the interest of potential users of the application. The minimal dataset of information required is the following:

- Building characteristics:
    - Building location (city). A dropdown menu with below three options are available:
        - Thessaloniki.
        - Dublin.
        - Madrid.
    - Building size (sqm).
- Energy data with hourly granularity:
    - Electricity.
    - Natural Gas.
    - Other fuels.
- Services provided.
    - Heating.
    - Cooling.
    - Heating and cooling.
- Opening times.
    - Opening and closing hours.
    - Working days (i.e., Monday-Friday).

To provide an example of the use of the tool, the Irish demo site is used.

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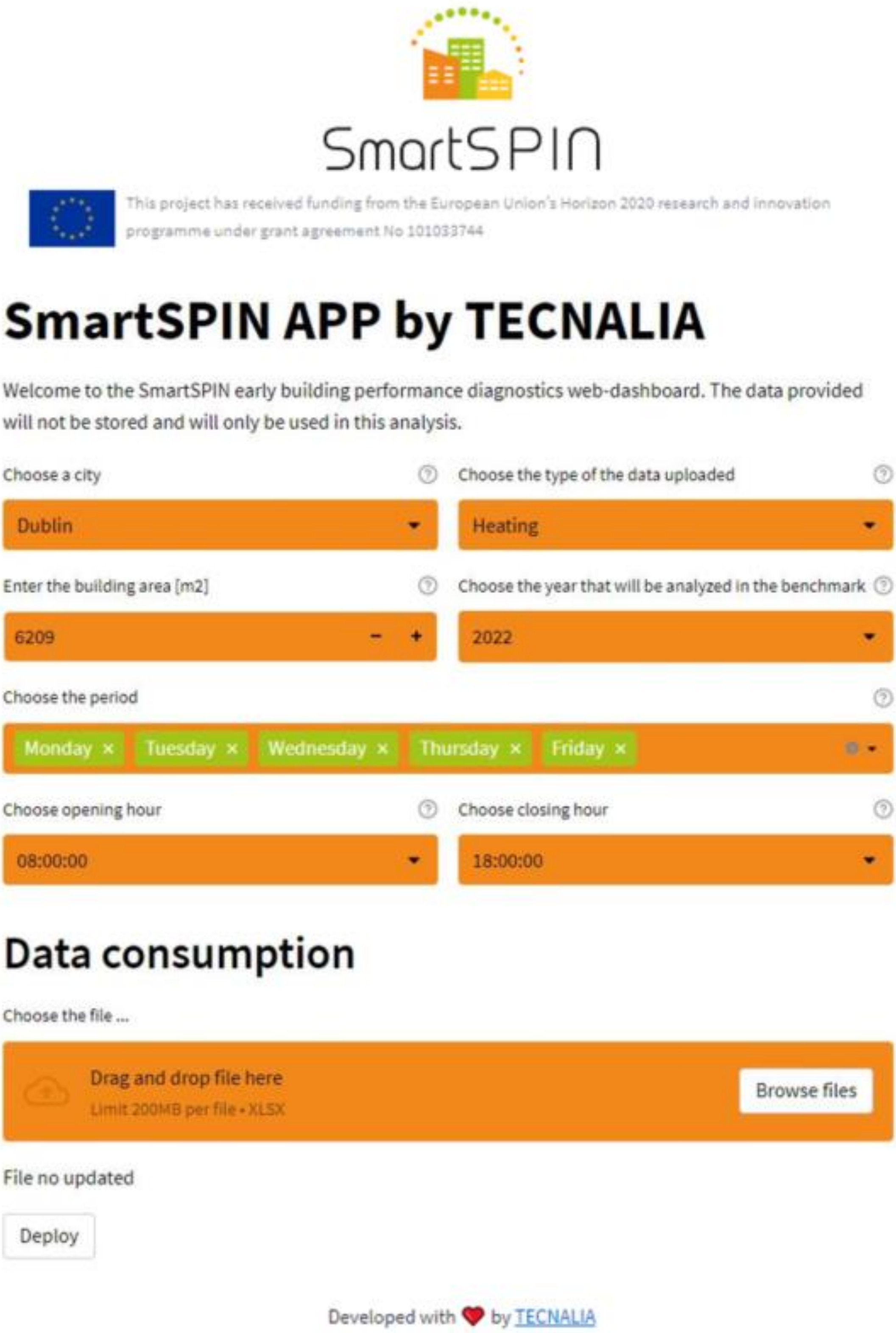


Figure 5 **Building characteristics for the demo site in Dublin are introduced.**

## 3.4 Outputs

- Energy use intensity (i.e., per m$^2$ & type of energy use).
- Models and parameters for energy flows in relation with outdoor temperature (The regression model is performed using the function "*piecewise_regression*"[7] in Python).
- Intuitions on potential energy misuse.

From the above example, the outputs are as follows:

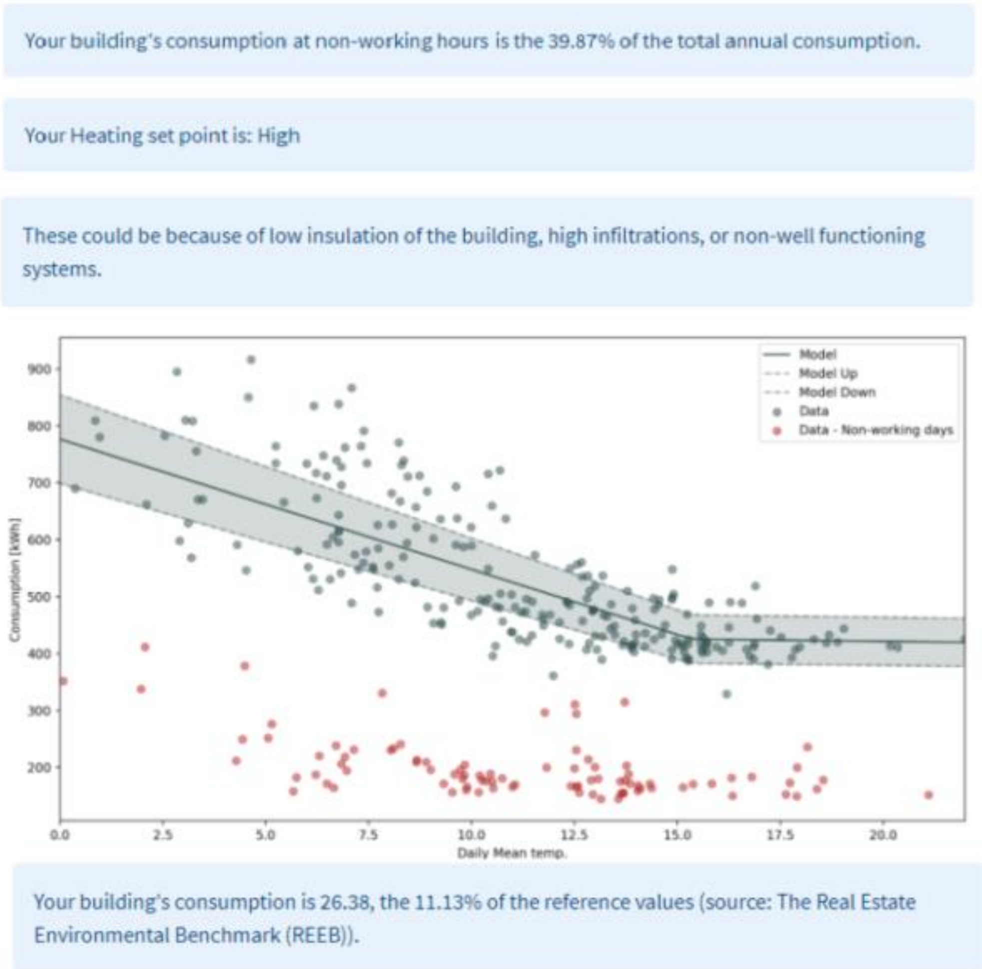


Figure 6 **Analysis provided by the API.**

[7] Pilgrim, C., (2021). piecewise-regression (aka segmented regression) in Python. Journal of Open Source Software, 6(68), 3859, https://doi.org/10.21105/joss.03859

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# 4 EARLY BUILDING DIAGNOSTICS - IRISH DEMONSTRATION SITE

The present section includes the early building diagnostics for the Irish demo site. This analysis is more detailed than the one offered in the web-dashboard with the purpose to be used as input in task 4.4 and WP5.

## 4.1 DEMO SITE DATA

The data provided is from **Jan 2022** when the smart meter started operating, in an hourly report basis. The data available is composed of:

- Building characteristics:
    - Dublin.
    - Building size: 6,209m$^2$.
    - Main building usage: offices.
- Opening times:
    - Mon-Fri.
    - 8-18h.
- There are no energy intensive processes (i.e., laundries) associated to the normal operation of the building.
- Energy supplies
    - Electricity
        - Hourly data for consumption from mid-January to November.
    - Gas
        - From end January to November.
- Weather data: The weather for Dublin has been retrieved from Met Éireann (Copyright statement: Copyright Met Éireann; source www.met.ie).
- Bank holidays:
    - 1 January.
    - 15 March (some closed).
    - 17-18 March.
    - 18 April.
    - 2 May.
    - 6 June.
    - 1 August.
    - 31 October.
    - 25-26 December.

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From this data, descriptive parameters have been statistically calculated to identify potential correlations with the above-mentioned parameters (outdoor conditions, schedule, …).

The data can be considered of quality, as hourly data is continuously collected and few outliers are encountered, as observed in the next figures.

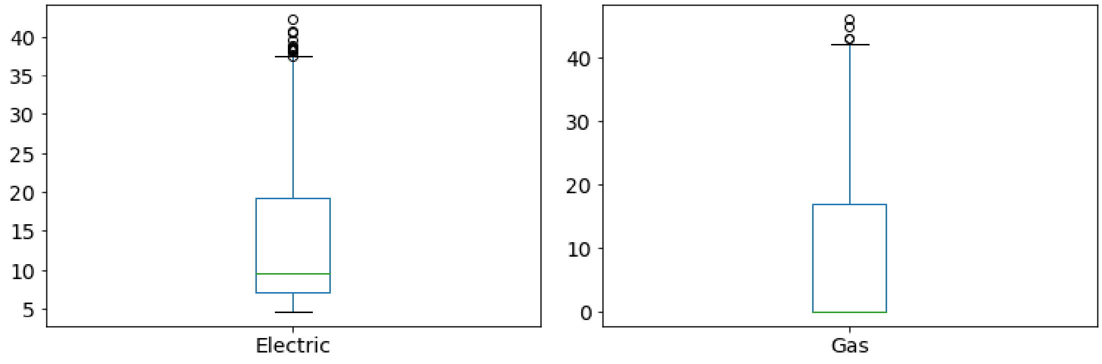


Figure 7. **Boxplot graphs show the statistical distribution of the hourly energy consumption [kWh], with few outliers.**

The following sections explain in detail the analysis performed.

### 4.1.1 Identification of subsystems & submetering

There is no submetering. Only available data is from gas and electricity meters. As observed in Figure 7, both energy streams are relevant, and therefore the analysis is performed for both.

The demand covered by both energy streams is as follows:

- Gas
  - Heating, which is provided by a radiator system.
  - DHW

Therefore, it is expected that gas consumption has a strong correlation with outdoor temperature, with a base consumption due to DHW needs.

- Electricity
  - Lighting.
  - Equipment and appliances such as computers, etc.
  - Ventilation is achieved through mechanical means substantially from roof mounted Air Handling Unit (AHU).
  - Air Conditioning (AC), which can deliver both heating and cooling.

Therefore, it is expected that electric consumption has a strong correlation with outdoor temperature for both warm and hot days.

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## 4.2 Definition of typical operational days

A clusterization process has been conducted for both energy carriers as stated in section 2.2 based on the known schedule to understand the time dependency of the consumption. To identify those energy consumption patterns that differ for different hours, days of the week or months, independently from climatic variables, a time dependency has been introduced into the consumption analysis. In this context, two kind of visual data representations are used:

- Descriptive analysis to observe only the time dependency: a boxplot of the quartiles of hourly consumption is included to show if consumption varies in function of the time (month, day of the week, hour of the day).
- Scattered plot to observe both time and outdoor temperature dependency of the hourly consumption.

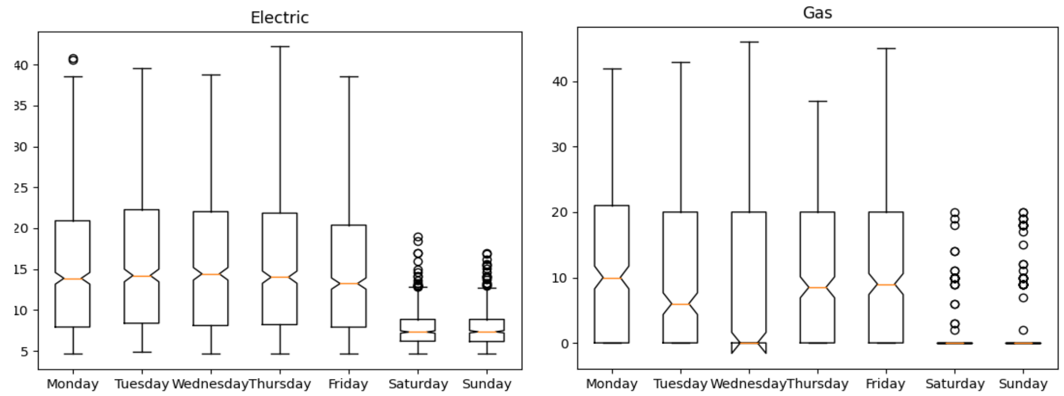


**Figure 8. Hourly consumption [kWh] versus time dependency, where boxplot graphs show the statistical distribution of the energy consumption for each day of the week.**

Next sections show the time dependency of the electric and gas consumptions with the type of day (weekdays, weekends, and bank holidays), day of the week and month of the year.

### 4.2.1 Type of day

The bank holidays have been further included to compare office days versus vacations.

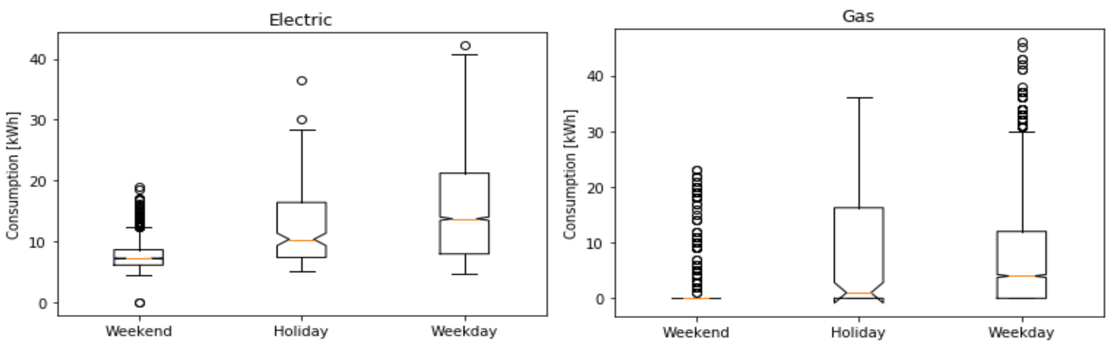


**Figure 9. Type-of-day dependency of the total hourly consumption.**

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As it can be seen in the pictures, in both gas and electric data the consumption on weekends is at its minimum during off days-time, being the variability low with a relative high number of outliers. Working days show higher variability but low outliers. This strong correlation with the type of day is normal for an infrastructure that operates only from Monday to Friday.

In the case of electricity, further analysis is done to find if the consumption is due to appliances in stand-by. In the case of holidays, the consumption in both cases remains similar to the non-holidays; further analysis is also performed in these cases to figure out what is the reason of this consumption. As a result, the three of them are separately analysed, and consumption pattern of each of them is later identified.

### 4.2.2 Day of the week

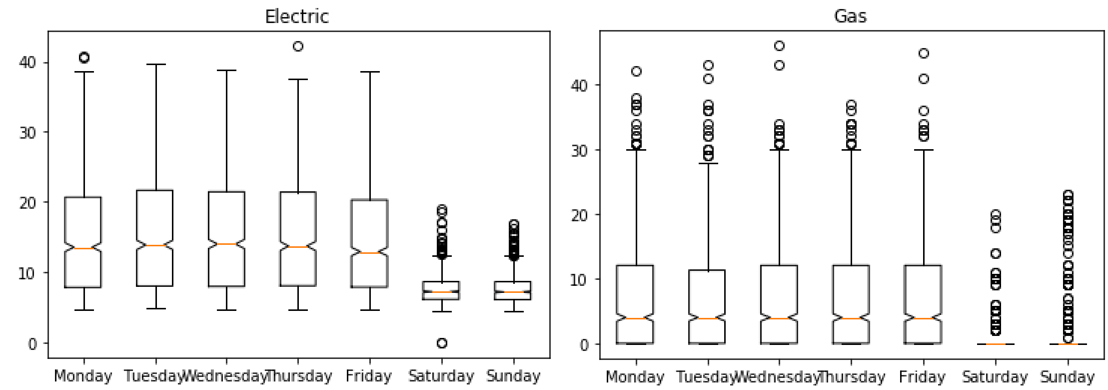


Figure 10. **Daily dependency of the total hourly consumption [kWh].**

Similar consumption is found during weekdays in both cases. Thus, no discrimination between the days of the week is done from this point. Moreover, weekends also show a similar minor consumption for both days.

### 4.2.3 Month

In order to analyse the monthly consumption, weekdays have been only considered.

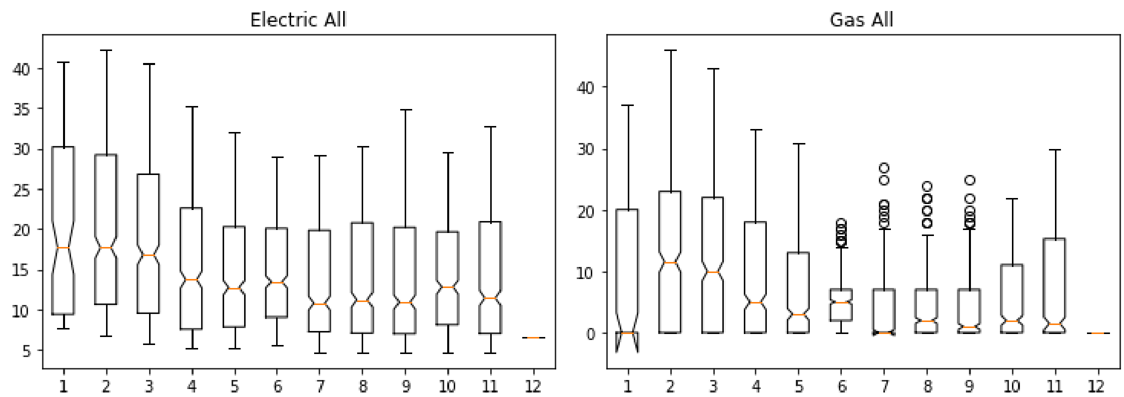


Figure 11. **Monthly dependency of the total hourly consumption [kWh].**

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At the point of the analysis, data was missing for half January and December. However, the conclusions can be drawn as the behaviour for these months can be considered similar to the rest of the heating season.

It is found that during cold months, the gas and electric consumption seems to be weather dependent, as predicted; therefore, from January to May, and from October to December data is jointly considered as, from now on, Cold period. From May onwards, the consumption is pretty constant and, consequently, data from May to September are grouped, and a common pattern is identified

So, the electric weekly data is clustered in two main groups:

- Cold period, or heating season.
- Warm, or non-heating season.

### 4.2.4 Hour of the day for heating season

**Weekdays**

The consumption dependency with the hour of the day is analysed for weekdays, for the months from January to May.

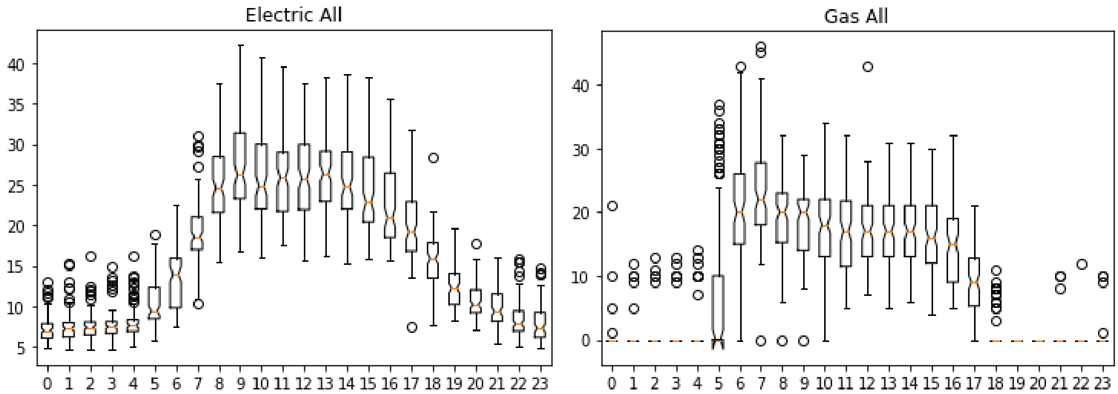


Figure 12. **Hourly dependency of the consumption [kWh].**

Regarding the hourly dependency, it can be observed that the consumption is at its minimum during night-time, also with the lowest variability (and highest number of outliers). At the beginning of the working schedule (6-8h), the electricity consumption starts to increase, showing its maximum between 8 and 14h. At the end of the working schedule (16-18h), the electricity starts to decrease. For the gas case, the situation is similar, although the increase starts 2 hours before the working schedule and decreases greatly at 16h.

A closer look to the data for every different working day versus hour show very similar patterns, as predicted:

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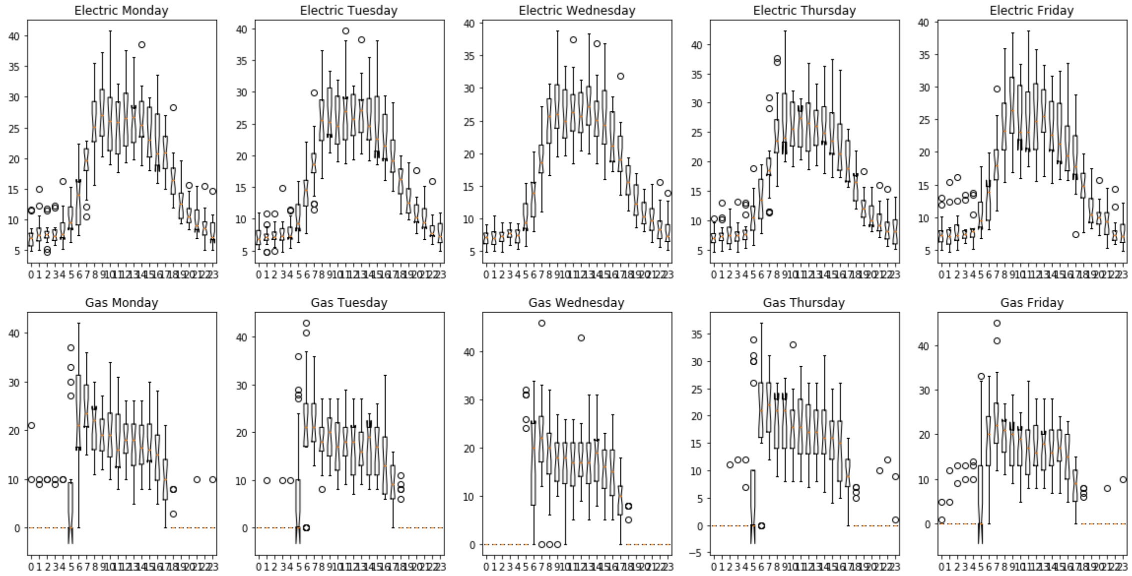


Figure 13. **Hourly dependency of the consumption for the different working days [kWh].**

## Weekends

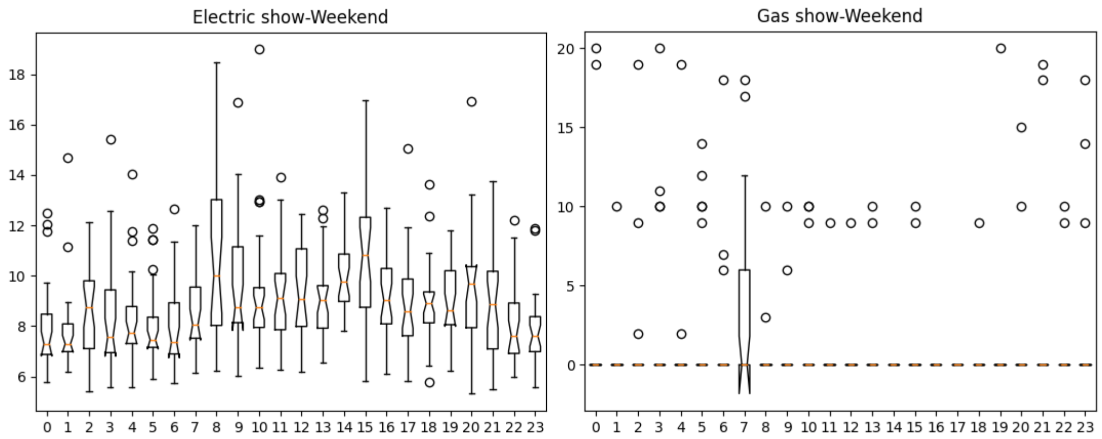


Figure 14. **Hourly dependency of the consumption [kWh] for weekends.**

Low consumption, with low hourly dependency, is found for both energy carriers. The gas consumption of 7[th]h is caused by reading errors and missing data.

## Holidays

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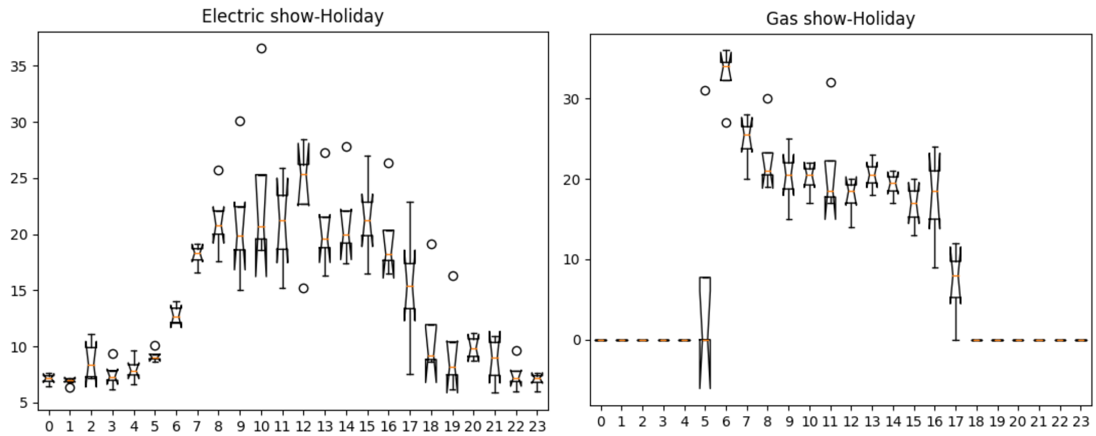


**Figure 15. Hourly dependency of the consumption [kWh] for the holidays.**

Holidays show a behaviour more similar to weekdays than weekends, which shows a suboptimal behaviour, as bank holidays should have lower consumption. This indicates energy misuse during the holiday period and calls for an action to efficiently use the energy.

### 4.2.5 Hour of the day for the non-heating season

The same analysis is performed for the non-heating season.

**Weekdays**

In the case of the non-heating season, the data shows lower variability.

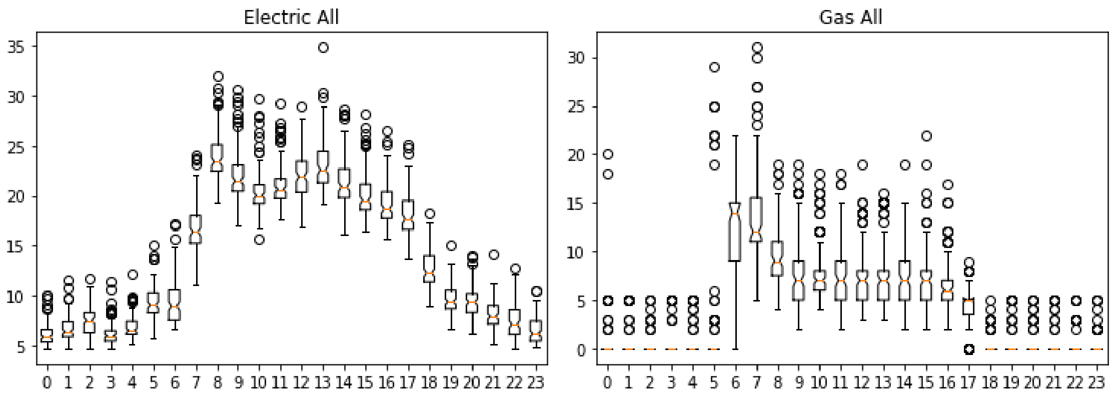


**Figure 16. Hourly dependency of the consumption [kWh].**

The hourly dependency follows the pattern found for the heating season, when the consumption is at its minimum during night-time. At the beginning of the working schedule (6-8h), the electricity consumption starts to increase, showing its maximum between 8 and 14h. At the end of the working schedule (16-18h), the electricity starts to decrease. For the gas case, the situation is similar, although the increase starts 2 hours before the working schedule and decreases greatly after 16h.

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A closer look to the data for every different working day versus hour show very similar patterns, as predicted:

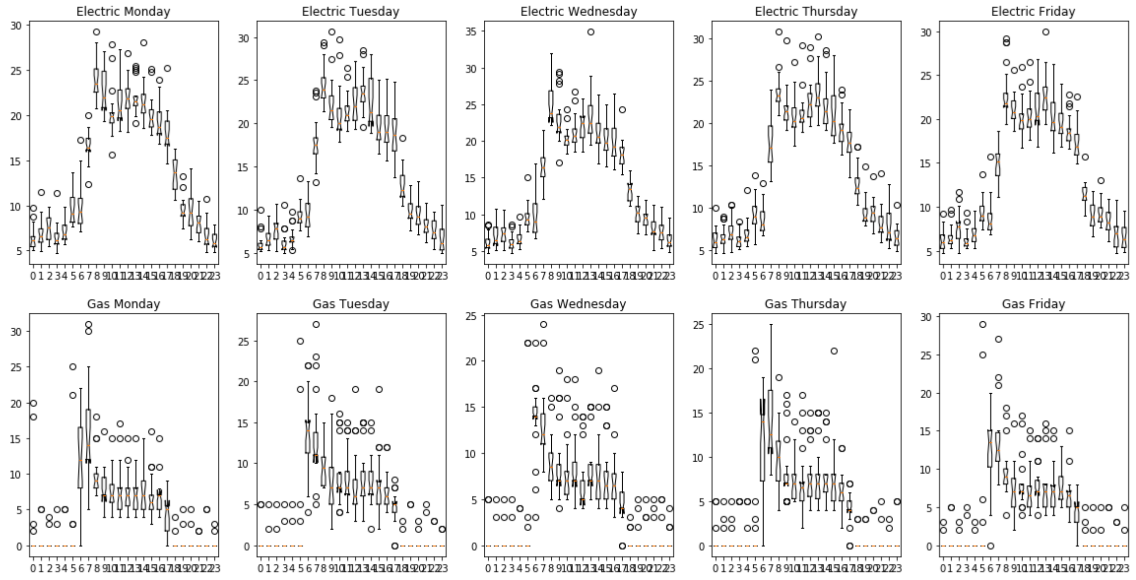


Figure 17. **Hourly dependency of the consumption [kWh] for the different working days.**

## Weekends

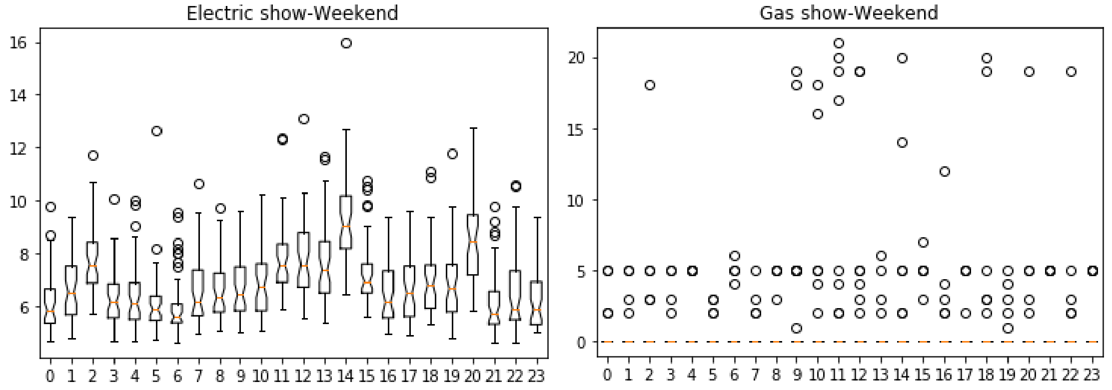


Figure 18. **Hourly dependency of the consumption [kWh] for weekends.**

Low consumption, with low hourly dependency, is found for both energy carriers.

## Holidays

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

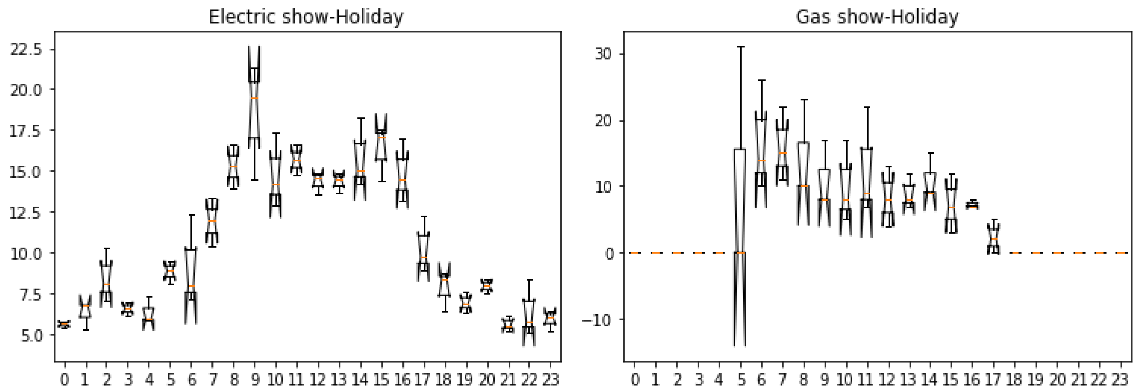


Figure 19. **Hourly dependency of the consumption [kWh] for the holidays.**

Holidays show a behaviour more similar to weekdays than weekends, which shows a suboptimal behaviour, as bank holidays should have lower consumption

### 4.2.6 Summary of the definition of typical operational days

After analysing the plots shown above, the following assumptions are made:

1. The hourly distribution demonstrates that during bank-holidays the building works as a normal weekday. This is not coherent with a normal operation and indicates energy misuse within business premises.
2. During weekends, it can be considered that the electricity is not hourly-dependent neither in the cold period nor warm period. This is coherent with a normal operation.
3. If hourly electric consumption is compared between cold and warm period, the hourly distribution in both cases can be considered to be the same.
4. The assumption of the consumption is not different depending on the weekday is concluded to be correct.
5. The gas consumption is evenly distributed during working-hours (8h-16h). Also, a different pattern is seen at 6h-7h due to starting of the system. Energy consumption in $5^{th}$h and $17^{th}$h are neglected from the study since data show a wide distribution suggesting that the consumption pattern is shifted along those hours (e.g. 5:30).

## 4.3 INDEXATION OF ENERGY LOADS FOR BUILDING USAGE

The present section assessed the correlation of the energy loads with the boundary conditions, specifically weather parameters (outdoor temperature, HDD, etc.). As identified previously, it can be anticipated that when outdoor temperature is low, the demand for space heating consumption will be higher. Electricity has also indicated this behaviour, mainly due to the ventilation system.

**GAS**

The energy signature for gas consumption versus average outdoor temperature is as follows:

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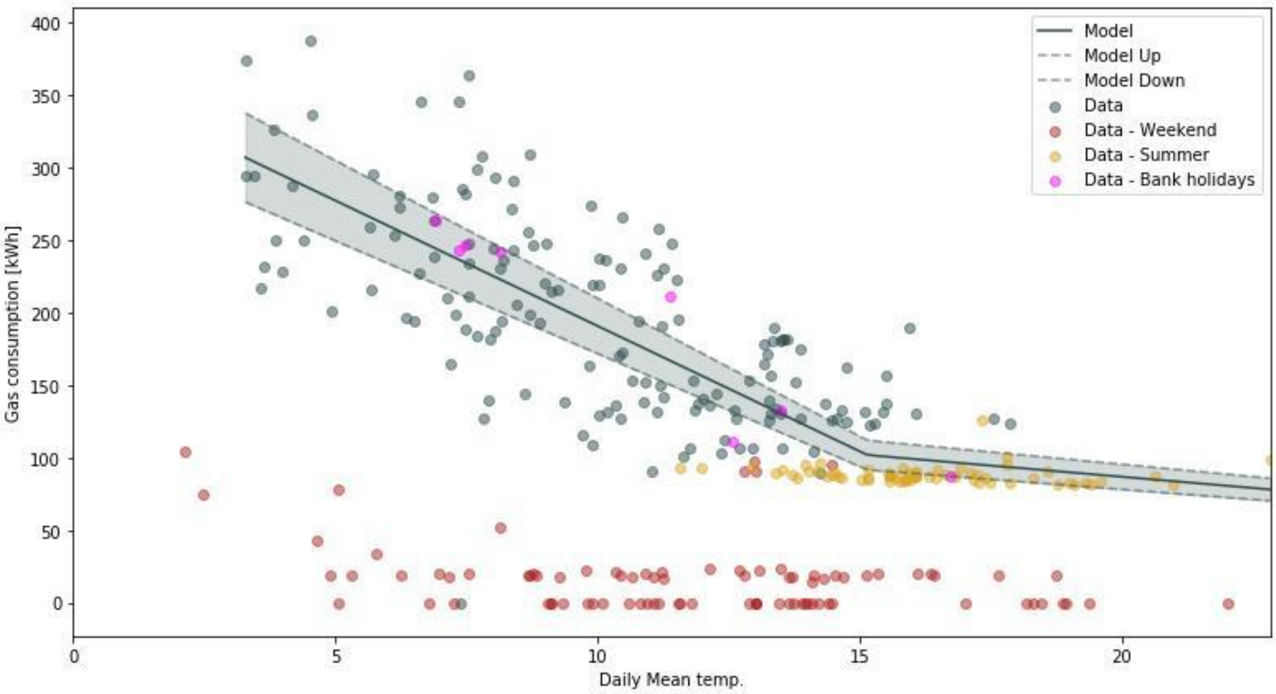


Figure 20. **Daily aggregated values of gas consumption [kWh] versus daily average outdoor temperature. Red dots belong to weekend. Values for daily mean temperature >15ºC are linked to DHW preparation (yellow dots). Grey dots are gas consumption devoted to heating and DHW preparation during working days.**

A regression model has been added to represent the average behaviour of the offices during working days. Since other aspects may affect the consumption of the building apart from the outdoor temperature (e.g., Solar radiation, occupancy, ventilation…), a 10% upper and lower boundaries are added to account those other aspects not considered in the regression. Data out of those boundaries represent values of energy misuse.

From Figure 20, it can be observed that gas consumption is weather dependent with low outdoor temperatures. There is an exception to this behaviour: summer days with low daily mean temperature. It is assumed that the heating system is switched off during summer period (this is, from 21st June to 21st September).

A constant consumption of 88.4 kWh/day is observed during summer (yellow dots of Figure 20). This constant consumption is because there is only DHW demand during this period of time. Although certain consumption during weekends is observed, it is assumed is due to failures on the recording and can be neglected.

Changepoint for the heating pattern is = 15.5ºC of the daily mean outdoor temperature. The daily heating consumption increases 17.3 kWh/day for every 1ºC decrease on the daily mean temperature.

As predicted above, there is gas consumption for heating preparation during bank holidays, being a clear sign of energy misuse.

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**ELECTRICITY**

Regarding electricity, the energy signature of electric consumption versus daily mean outdoor temperature is as follows:

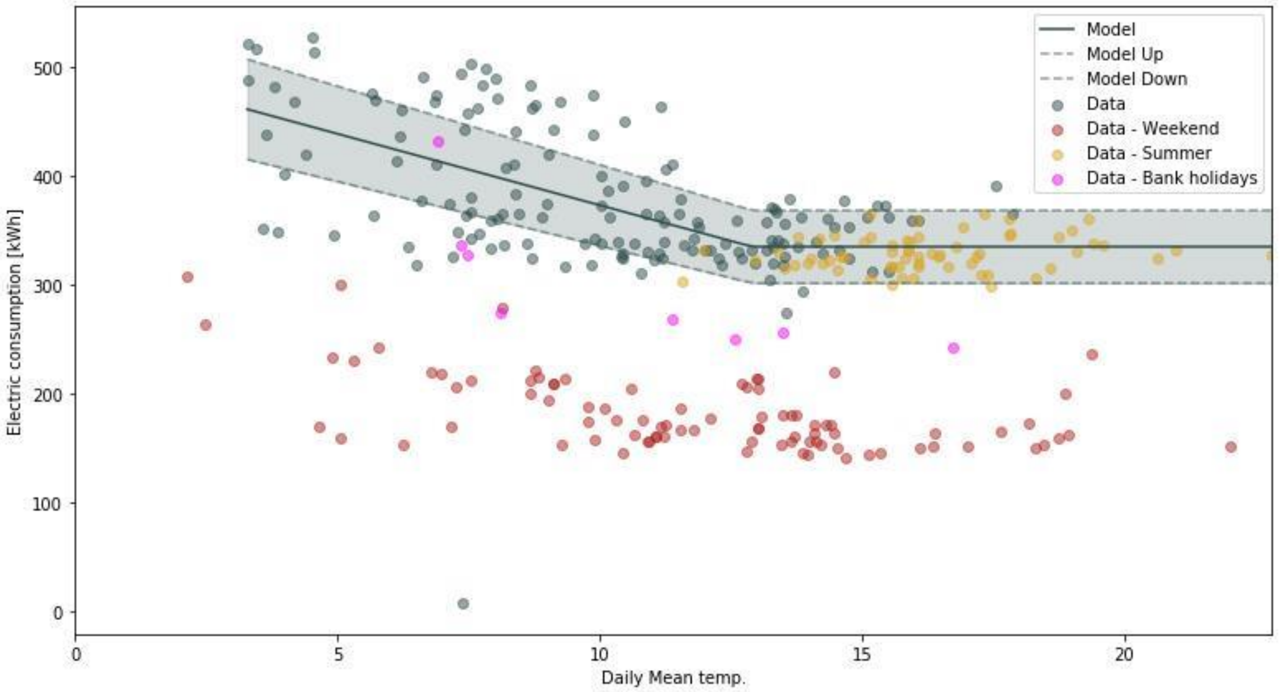


Figure 21. **Daily aggregated values of electricity consumption [kWh] versus daily average outdoor temperature. Red dots belong to weekend, which consumption is linked to stand-by modes and other residual process. Yellow dots belong to summer period, being linked to overall electric consumption except heating.**

As in the case of the gas consumption, a regression model has been added to represent the average behaviour of the offices for working days. Again, 10% upper and lower boundaries are added to account those other aspects not considered in the regression. Data out of those boundaries represent values of energy misuse.

From the Figure 21, it can be observed that electricity consumption is weather dependent with low outdoor temperatures, without any correlation with warmer periods. Therefore, it can be stated that cooling is not consumed in the building.

A constant consumption of 328.85 kWh/day is observed during summer, being assigned to ventilation, lighting and plug loads (equipment and other appliances). The load associated to stand-by modes and other residual process that still operate during weekends has an average value of 181.83 kWh/day, which is more than 40% of the electricity consumption during working days.

Changepoint for the heating pattern is at 13ºC (daily mean outdoor temperature). The daily heating consumption increases 13 kWh for every 1ºC drop on the daily mean temperature.

## 4.4 MOST SIGNIFICANT ENERGY & COST STREAMS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

The previous analysis together with cost of energy carriers allow to identify the most significant energy and cost streams.

Table 1. **Prices of the different energy carriers for Ireland. Source: Eurostat.**

| Country | Electricity [€/kWh] | Gas [€/kWh] |
|---|---|---|
| **Ireland** | 0.18 | 0.055 |

### 4.4.1 Heating

As previously analysed, both electricity and gas are partially devoted to heating consumption, with the following values.

- Electricity: [0-130] kWh/day*0.18€/kWh= [0-23.4] €/day.
- Gas: [0-200] kWh/day*0.055€/kWh= [0-11] €/day.

### 4.4.2 DHW

Gas is partially devoted to DHW preparation, with the following values.

- Gas: [80-100] kWh/day*0.055€/kWh= [4.4-5.5] €/day.

### 4.4.3 Ventilation, lighting and plug loads

As previously analysed, electricity has a baseline consumption, this is, non-devoted to heating or cooling, of ≈350kWh/day for working days. In economic terms, this equals:

- Electricity: 328.85kWh/day*0.18€/kWh= 59 €/day.

### 4.4.4 Stand-by and other residual processes

The load associated to stand-by modes and other residual process that still operate during weekends is ≈180kWh/day. In economic terms, this equals:

- Electricity: 181.83kWh/day*0.18€/kWh= 32.73 €/day.

## 4.5 Benchmark

The present section cross-references the demo site baseline against current building performance databases for benchmarking. The Real Estate Environmental Benchmark (REEB) database, a publicly available operational benchmark of environmental performance for commercial property in the United Kingdom (UK), has been selected. The REEB database is based on a 3-year rolling average and updated each year. The results are as follows:

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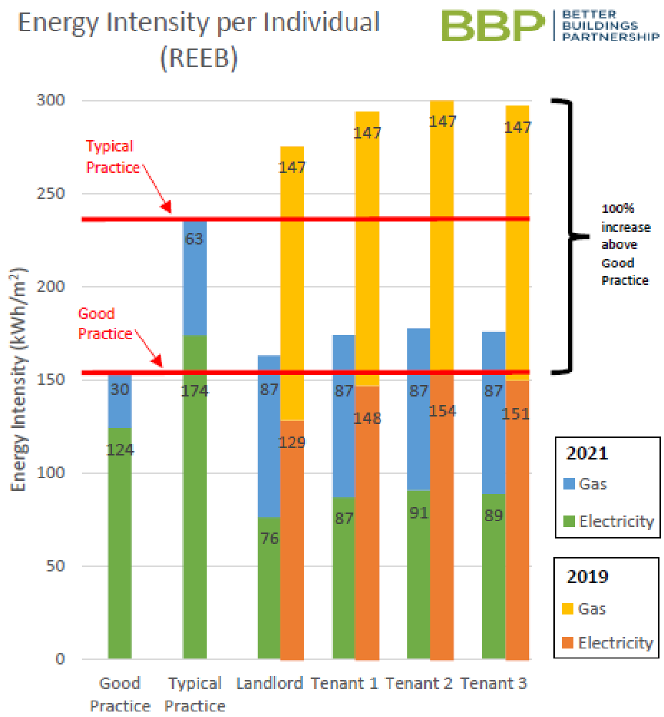


Figure 22. **Benchmark of the Irish baseline for 2021 and 2019 against REEB. 2019 must be considered as 2021 was largely influenced by COVID-19 restrictions and home-office.**

When compared to the data presented in SmartSPIN D4.1 - Interactive web-app[8], the baseline consumption for the Irish demo site can be considered as high (>200 kWh/m$^2$ and <400 kWh/m$^2$).

## 4.6 Energy saving measures - Cost-benefit analysis

Based on the above analysis, a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use are performed

### 4.6.1 Optimization of heating & cooling schedules

- The gas boiler operates during bank holidays like working days, providing heating and DHW to empty spaces. This means a consumption on the range of [80-300] kWh/day, [4.4-16.5] €/day.
- Regarding the setpoint for heating for the radiator system, it is activated when Tout=15ºC. Every decrease of 1ºC on the setpoint would bring around 17kWh/day of savings. In the case of the electric consumption associated to heating, it is activated when Tout=12ºC, not being suitable to reduce this number.
- The hourly consumption for heating is around 5kWh for gas. Switching off the heating at 17h would result in daily savings.

[8] For further reference, see D4.1-Interactive-web-app-showing-the-potential-for-energy-management-in-energy-performance-contracts.pdf (smartspin.eu)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

As seen in D4.1, the cost-benefit on the improvement of the Smart Readiness Indicator (SRI) of the typical office in Ireland would have an estimated payback between 4 months and 3.6 years.

### 4.6.2 Lighting systems and other electric consumers

The analysis of the electric equipment does not allow to estimate the energy consumption share of lighting. Therefore, it is not possible to propose energy savings measures directly linked to lighting systems. However, the following can be proposed from the analysis of the electric consumption:

- The electric consumption during weekends is >40% of the electricity consumption during working days. This consumption is linked to stand-by modes and other residual loads. It is recommended to analyse what consumptions could be reduced, with a saving potential of ≈180kWh/day, 32€/day.
- In any case, the benchmark of the electric consumption shown in **Figure 22**, shows that the demo site electric consumption can be considered close to good practice and below the consumption for typical practice.

### 4.6.3 Upgrade/replacement of heating & cooling equipment and building envelope improvement

Regarding the improvement on the building fabric and HVAC systems, the following can be extracted from the analysis:

- The benchmark of the gas consumption shown in **Figure 22**, shows that the demo site gas consumption more than doubles the gas consumption for typical practice. This indicates that the building envelope has important thermal losses and should be improved.
- The ratio between the unit price of electricity and gas is 3.27. This means that the replacement of heating and DHW preparation from gas to electricity (both available within the demo site), should ensure the COP of the heat pump is above 3.27 the performance of the gas boiler if economic terms are only considered. In other words, since the electricity is currently 3.27 times higher compared to gas, the electricity consumption need to be, at least, 3.27 times less than the gas consumption. However, as we move to a more carbon conscious world, selecting the less carbon intensive form of heat will become important.

As seen in D4.1, the cost-benefit on the improvement of the energy efficiency of the typical office in Ireland would have an estimated payback of 5.3 years.

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# 5 EARLY BUILDING DIAGNOSTIC - SPANISH DEMONSTRATION SITES

This section includes the early building diagnostic for the Spanish demo site La GAVIA. The mall, that hosts 139 tenants over 85,328m$^2$, has two floors, and is divided between common areas and shops, each of them with independent HVAC systems. This analysis is more detailed than the one offered in the web-dashboard with the purpose to be used as input in task 4.4 and WP5.

## 5.1 DEMO SITE DATA

The data provided is from **2016-2023**, in an hourly report basis. The data available is composed of a large set of energy streams separated in two groups north/south, so the focus have been put in two of this set of group 1. These two were selected because they show the HVAC consumption with a high dependency with the outdoor temperature, and their quality was good for the analysis.

The summary of

- Building characteristics:
  - Madrid.
  - Building size: 85,328m$^2$.
  - Main building usage: mall – shops and restaurants.
- Opening times:
  - Monday-Sunday.
  - 10-22h.
- There are no energy intensive processes (i.e., dryers) associated to the normal operation of the analysed energy streams.
- Energy supplies considered:
  - Overall electricity consumption of the HVAC system in group 1.
  - Overall electricity consumption of the rooftops in group 1.
- Weather data: The weather data for Madrid has been retrieved from https://www.degreedays.net/, and the SMARKIA data platform from where the daily mean temperature and the monthly HDD and CDD have been obtained.
- La GAVIA is also opened in bank holidays.

From this data, descriptive parameters have been statistically calculated to identify potential correlations with the above-mentioned parameters (outdoor conditions, schedule, etc.).

The data can be considered of quality, as hourly data is continuously collected and few outliers are encountered, as observed in the next figures.

The following sections explain in detail the analysis performed.

### 5.1.1 Identification of subsystems & submetering

As explained above, from the set of smart meters available at La GAVIA, two submeters have been selected. The demand covered by the analysed energy streams is as follows:

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- Overall electricity consumption of the HVAC system in group 1.
    - Cooling to common areas, through a set of cooling towers that provide water at mild temperatures (18ºC) for the locals through a dedicated circuit.
    - Cooling to common areas, through a set of heat pumps.
    - Ventilation, being fan consumption associated to both heating and cooling.
    - Water circulation, being pump consumption associated to both heating and cooling.

Therefore, it is expected that this electric consumption has a strong correlation with outdoor temperature, with a base consumption due to fans and pumps needs.

- Overall electricity consumption of the rooftops in group 1.
    - Cooling, through a set of heat pumps.
    - Ventilation, being fan consumption associated to both heating and cooling.

Therefore, it is expected that this electric consumption has a strong correlation with outdoor temperature, with a base consumption due to ventilation needs.

## 5.2 Indexation of energy loads for building usage

The present section assessed the correlation of the energy loads with the boundary conditions, specifically outdoor temperature. As identified previously, it can be anticipated that when outdoor temperature is high, the demand for space cooling (electricity) will be higher, whereas the consumption for space heating (gas) will raise at lower outdoor temperatures. Electricity would also show a dependent behaviour with lower outdoor temperatures due to the consumption of the pumps and fans.

**<u>Overall electricity consumption of the HVAC system in group 1</u>**

The energy signature for HVAC system electric consumption versus average outdoor temperature is as follows:

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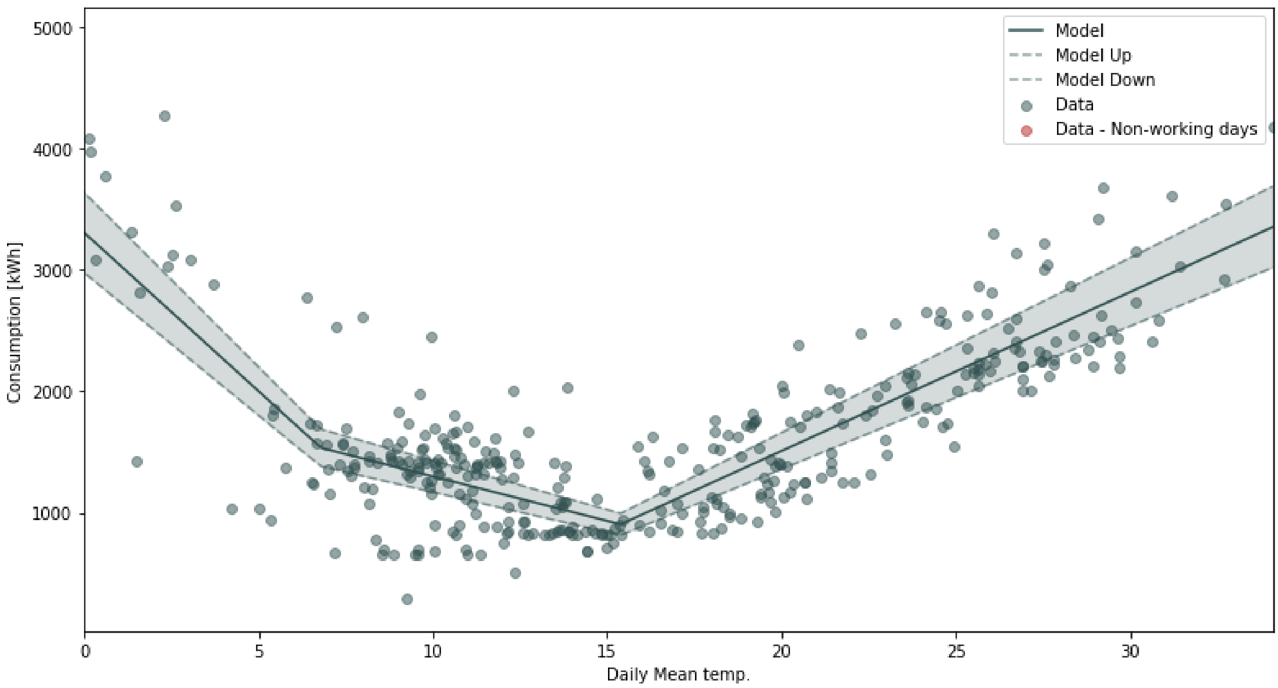


Figure 23. **Daily aggregated values of electric consumption of the HVAC system in group 1 [kWh] versus daily average outdoor temperature.**

A regression model has been added to represent the average behaviour of the offices during working hours. Since other aspects may affect the consumption of the building apart from the outdoor temperature (e.g., solar radiation, occupancy, ventilation…), a 10% upper and lower boundaries are added to account those other aspects not considered in the regression. Data out of those boundaries represent values of energy misuse.

From the Figure 23, it can be observed that consumption is weather dependent with low and high outdoor temperatures, with a change point at 15.5ºC of the daily mean outdoor temperature. It is observed two tendencies on the heating consumption, with the daily heating consumption presenting an overall variance of ≈160 kWh/day for every 1ºC decrease in the daily mean temperature, and ≈136kWh/day consumption for every 1ºC increase in the daily mean temperature.

Furthermore, a baseline consumption of 900kWh/day is observed for mild days where heating or cooling are at their lowest, being associated to ventilation and similar loads such as the operation of the DHW's pumps.

**Overall electricity consumption of the rooftops in group 1**

The energy signature for the group 1 rooftops' electric consumption versus average outdoor temperature is as follows:

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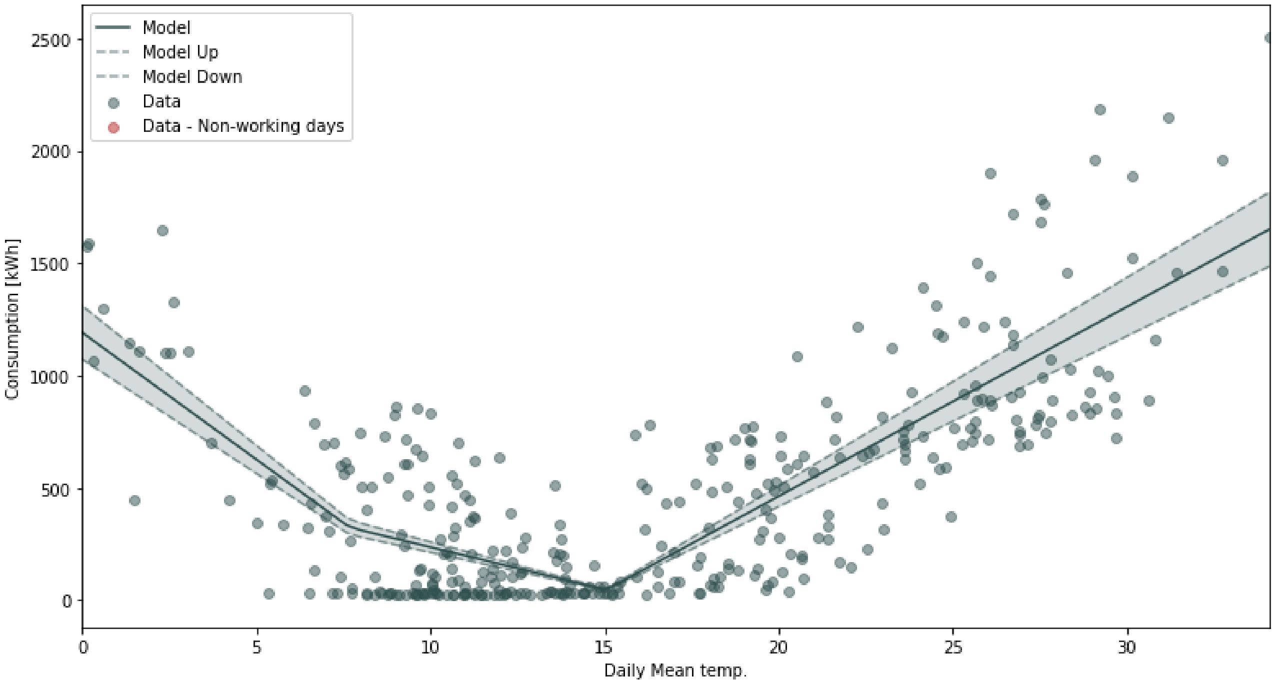


Figure 24. **Daily aggregated values of electric consumption of the rooftops in group 1 [kWh] versus daily average outdoor temperature.**

A regression model has been added to represent the average behaviour of the offices during working hours. Since other aspects may affect the consumption of the building apart from the outdoor temperature (e.g., solar radiation, occupancy, ventilation…), 10% upper and lower boundaries are added to account those other aspects not considered in the regression. Data out of those boundaries represent values of energy misuse.

From the Figure 24, it can be observed that consumption is weather dependent with low and high outdoor temperatures, with a change point at 15ºC of the daily mean outdoor temperature. It is observed two tendencies on the heating consumption, with the daily heating consumption presenting an overall variance of ≈93 kWh/day for every 1ºC decrease in the daily mean temperature, and ≈72kWh/day consumption for every 1ºC increase in the daily mean temperature.

## 5.3 MOST SIGNIFICANT ENERGY & COST STREAMS

The previous analysis together with cost of energy carriers allow to identify the most significant energy and cost streams.

Table 2. **Prices of the different energy carriers for Spain. Source: Eurostat.**

| Country | Electricity [€/kWh] | Gas [€/kWh] |
|---|---|---|
| **Spain** | 0.15 | 0.035 |

### 5.3.1 Heating

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

As previously analysed, electricity is devoted to cooling consumption, and gas is devoted to heating consumption. However, the operation of the pumps and fans also involved the use of electricity. The overall consumption is within the following ranges.

- Electricity: [1,000-3,200] kWh/day*0.15€/kWh= [150-480] €/day.

### 5.3.2 Ventilation, and plug loads

As previously analysed, electricity of the HVAC system in group 1 has a baseline consumption, this is, not directly linked to heating or cooling, of ≈900kWh/day. In economic terms, this equals:

- Electricity: 900kWh/day*0.15€/kWh= 1,450 €/day.

## 5.4 BENCHMARK

This section cross-references the demo site baseline against current building performance databases for benchmarking. For the Spanish case, national references[9] and the INSPIRE project[10] indicate that this kind of commercial buildings have an energy consumption in the range [118-333] kWh/m$^2$, being the energy devoted to lighting around 41.5% of the total (i.e., [118-333] kWh/m$^2$) and 49% for climatization (i.e., [58-163] kWh/m$^2$). Based on these references, the benchmark is as follows:

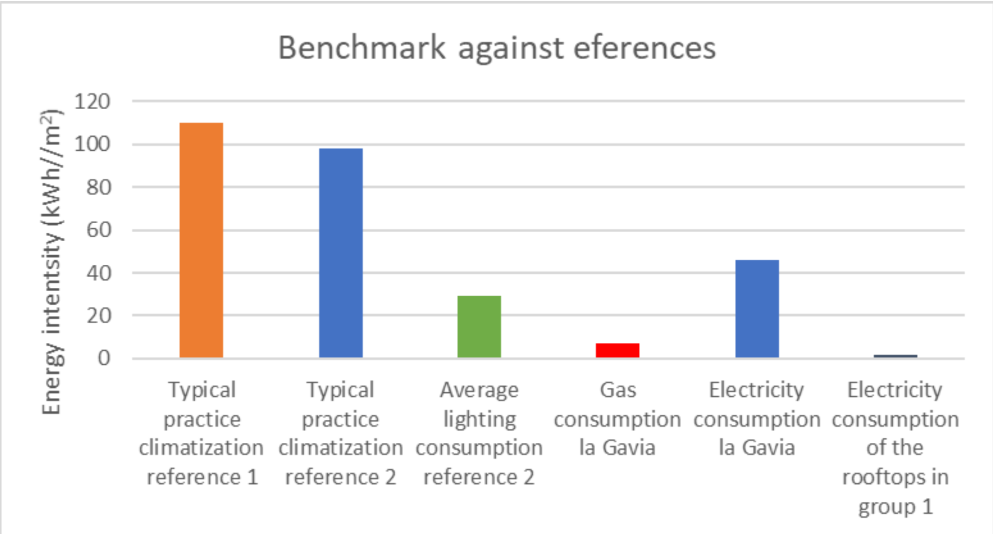


Figure 25. **Benchmark of the Spanish baseline for different energy carriers, being reference 1 national databases and reference 2 the INSPIRE project.**

When compared to the data presented in SmartSPIN D4.1 - Interactive web-app, the baseline consumption for the Spanish demo site can be considered as low (< 100 kWh/m$^2$).

## 5.5 ENERGY SAVING MEASURES - COST-BENEFIT ANALYSIS

[9] Guía de auditorías energéticas en centros comerciales. Juan A. de Isabel et. Al. http://www.madrid.org/bvirtual/BVCM015242.pdf
[10] https://www.rispostaserramenti.com/wp-content/uploads/2015/02/REPORT_EURAC0.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

Based on the above analysis, a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use are performed.

### 5.5.1 Optimization of heating & cooling schedules

- Regarding the setpoint for heating, it is activated when Tout=15ºC; every decrease of 1ºC on the setpoint would bring around 160 kWh/day of savings. In the case of the electric consumption associated to cooling, it is activated when Tout=15ºC; every increase of 1ºC on the setpoint would bring around 136 kWh/day of savings.

As seen in D4.1, the cost-benefit on the improvement of the SRI of the typical mall in Spain would have an estimated payback between 1-2 years. In any case, the benchmark of the electric consumption shown in **Figure 25**, shows that the demo site consumption for climatization can be considered close to good practice and below the consumption for typical practice.

### 5.5.2 Upgrade/replacement of heating & cooling equipment and building envelope improvement

Regarding the improvement on the building fabric and HVAC systems, the analysis of the benchmarking suggests little room for improvement.
As seen in D4.1, the cost-benefit on the improvement of the energy efficiency of the typical mall in Spain would have an estimated payback of 11 years.

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# 6 EARLY BUILDING DIAGNOSTIC - GREEK DEMOSITE

The present section includes the early building diagnostic for the Greek demo site, a large office building complex located in the suburbs of Thessaloniki, comprised of two interconnected buildings.

## 6.1 DEMO SITE DATA

The data provided is from January 2020 to September 2022, in a monthly report basis. The data available is from the two buildings included in the demo site. Building characteristics:

  - Thessaloniki.
  - Building sizes: 1,600m$^2$ and 1,800m$^2$.
  - Main building usage: offices.
- Opening times:
  - Monday-Friday.
  - 8-20h.
- There are no energy intensive processes (i.e., laundries) associated to the normal operation of the building.
- Energy supplies
  - Electricity
    - Hourly data for consumption from mid-January to November.
  - Gas
    - From end January to November.
- Weather data: The weather for Thessaloniki has been retrieved from https://www.degreedays.net/, from where the monthly HDD and CDD have been obtained.

From this data, descriptive parameters have been statistically calculated to identify potential correlations with the outdoor conditions (HDD and CDD). Due to the low data granularity, detailed analysis is not possible; in this regard, the definition of typical operation days and further clustering cannot be performed, and only the indexation of energy loads for building usage (i.e., energy signature) based on monthly values can be calculated.

## 6.2 INDEXATION OF ENERGY LOADS FOR BUILDING USAGE

The present section assessed the correlation of the energy loads with the boundary conditions, specifically the weather parameters HDD and CDD. For the Greek study case, only electricity has been reported. The lack of submetering and the fact that data is monthly aggregated does not allow to differentiate among the different energy loads (i.e., heating, DHW, lighting).

The energy signature for energy consumption versus HDD is as follows:

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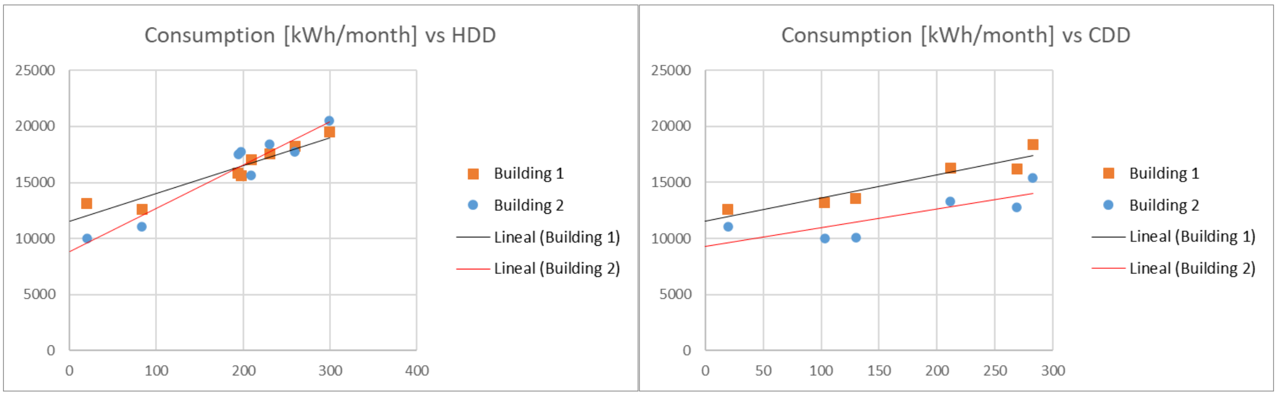


Figure 26. **Monthly aggregated values of electricity consumption [kWh] versus monthly HDD (left) and CDD (right). Orange squares represent values for building 1, while blue circles belong to building 2. The linear regression is included for both buildings.**

A regression model has been calculated to estimate the dependency of the heating consumption with outdoor temperature. From the figure and the calculations, it can be observed that consumption is weather dependent with outdoor temperatures for both low and high outdoor temperatures. This means that both heating and cooling services are delivered to the demo site.

**HEATING**

The heating consumption represents around 16.6kWh/(month·HDD) for building 1 and 20.6kWh/(month·HDD) for building 2.

**COOLING**

The cooling consumption represents around 24.9kWh/(month·CDD) for building 1 and 36.6kWh/(month·CDD) for building 2.

These results suggest a constant base load of ≈11.5MWh/month and ≈9MWh/month respectively, independent of outdoor conditions. This base load could be assigned to ventilation, lighting and plug loads (equipment and other appliances). The load associated to stand-by modes and other residual process cannot be assessed due to lack of data.

## 6.3 Most significant energy & cost streams

The previous analysis together with cost of energy carriers allow to identify the most significant energy and cost streams.

Table 3. **Prices of the different energy carriers for Greece. Source: Eurostat.**

| Country | Electricity [€/kWh] |
|---|---|
| **Greece** | 0.22 |

### 6.3.1 Heating

As analysed previously, electricity is partially devoted to heating consumption, with the following values per building:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101033744.

- Building 1: [0-7,000] kWh/month*0.22€/kWh= [0-1,540] €/month.
- Building 2: [0-10,000] kWh/month*0.22€/kWh= [0-2,200] €/month.

### 6.3.2 Cooling

As analysed previously, electricity is partially devoted to heating consumption, with the following values per building:

- Building 1: [0-5,800] kWh/month*0.22€/kWh= [0-1,276] €/month.
- Building 2: [0-5,440] kWh/month*0.22€/kWh= [0-1,197] €/month.

### 6.3.3 Baseload: Ventilation, lighting and plug loads

- Building 1: [11,500] kWh/month*0.22€/kWh= [2,530] €/month.
- Building 2: [9,000] kWh/month*0.22€/kWh= [1,980] €/month.

## 6.4 BENCHMARK

The present section cross-references the demo site baseline against current building performance databases for benchmarking. commONEnergy has been selected as it has data for Greece, while the Real Estate Environmental Benchmark (REEB) database refers only to UK. In any case, REEB database has also been included for reference. commONEnergy values are in line with the reference "EU Energy in Figures" [11], and therefore considered as valid.

The results are as follows:

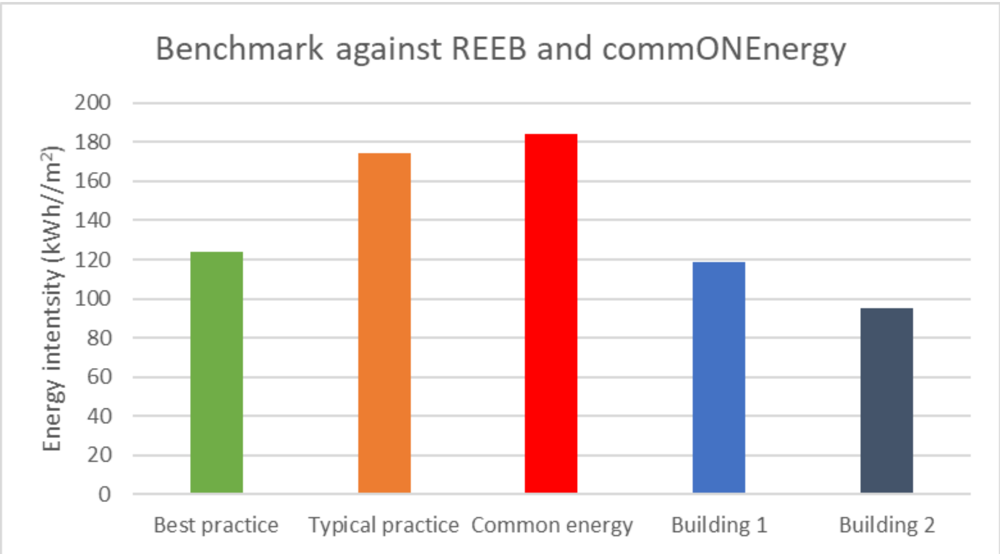


Figure 27. **Benchmark of the Greek baseline for 2022 against REEB and commONEnergy.**

[11] Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/pocketbook_energy-2016_web-final_final.pdf

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When compared to the data presented in SmartSPIN D4.1 - Interactive web-app, the baseline consumption for the Greek demo site can be considered as medium (> 100 kWh/ $m^2$ and <200 kWh/$m^2$) for building 1 and low (<100 kWh/$m^2$) for building 2.

## 6.5 Energy saving measures - Cost-benefit analysis

Based on the above analysis, a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use are performed.

### 6.5.1 Optimization of heating & cooling schedules

The lack of information does not allow to properly analyse this energy saving measure. D4.1, the cost-benefit on the improvement of the SRI of a similar office to the Greek demo site would have an estimated payback of 3.5 years.

### 6.5.2 Lighting systems and other electric consumers

The analysis of the electricity consumption and the benchmark suggest little room for improvement.

### 6.5.3 Upgrade/replacement of heating & cooling equipment and building envelope improvement

The lack of data does not allow to assess the performance of the HVAC equipment, but the analysis of the benchmarking suggest little room for improvement.

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# 7 CONCLUSIONS

The work carried out in task 4.2 has been presented. This includes the development of a web-dashboard that allows for early building performance diagnostics which are made available through a web-dashboard. The web-dashboard allows users to upload specific building information and datasets to obtain early building energy diagnostics, through the API that access the developed algorithms.

The development of the API and the trials performed until its final version show the great importance of the availability and synchronization of data. The proposed diagnostic process is largely based on utility meters (whose data is now increasingly delivered still with great challenges) and climate data (available from public sources). But there is still a need/interest to get data from energy sub-meters, building usage and indoor comfort conditions, which would significantly improve the performance assessment. There is a high likelihood that data from all these sources is not synchronous (i.e., gathered from the same time period).

The algorithms developed to be used in the API have been used to assess the data provided by the three pilot buildings of the SmartSPIN project. The assessment of this data has been extensively presented and analysed in this deliverable.  This analysis will be used as input for Task 5.1 of the project (Site preparation and setting the baseline). Thanks to the methodology developed, most significant energy & cost streams in buildings can be identified using a minimal set of information. In line with the overall SmartSPIN concept, the diagnostics comprises not only overall energy use, but also economic value.

The early building diagnostic results in the calculation of key performance metrics that allow to automatically identify energy saving measures when cross-referenced against current building performance databases. CommONEnergy Data Mapper, INSPIRE project and BBP Real State Environmental Benchmark are used for the purpose of the present work.

The work here presented, together with the previous work developed in Task 4.1 (Assessment of the potential for energy management within performance based contracts), show the potential for energy management in EPC for the pilots, resulting in a cost-benefit analysis of the identified energy saving measures and a sensitivity assessment against variations in building use, operating hours, cost of energy carriers and other factors.

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