Booklets

Research & Development & Innovation

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Canal de Isabel II

The key aspects of residential water consumption in the Comunidad de Madrid

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Presentation

The collection Booklets of Research, Development & Innovation of Canal de Isabel II are part of the vision of the company's knowledge management, the development of its 2017-2020 R&D&I Strategy, and of the 2018- 2030 Strategic Plan of Canal de Isabel II.

The Booklets represent an element for diffusion of projects and initiatives developed and promoted by the company and aim at innovation in areas related to the water services in an urban environment.

They deal with the problems tackled by each project as well as the results obtained. The aim of publishing these Booklets is to share experience and knowledge with the entire water industry sector, with the scientific community and with all those who work in the fields of research and innovation. With these publication, what it is hoped is contribute the improvement and efficiency in water management and, as a result, make it possible to offer a better service to the citizens.

The titles published in the series to date are shown in the following table.

BOOKLETS OF RESEARCH, DEVELOPMENT & INNOVATION PUBLISHED

Collection Number	***Research, Development and Innovation Booklets published***
1	Transferences of Water Rights between Urban and Agrarian Demands. The case of the Community of Madrid
2	Identification of Hydrometeorological Runs and Tendencies within the scope of the Canal de Isabel II system
3	Contribution of Canal de Isabel II to the International Demand Management Project (IDMF)
4	Microcomponents and Explanatory Factors on Domestic Water Consumption in the Comunidad de Madrid
5	Virtual Water and Hydrological footprint in the Comunidad de Madrid
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid
7	Potentials of efficiency in using dishwashers in the Comunidad de Madrid
8	Accuracy in the measurement of individual water consumption in the Madrid Region
9	Research project to define and assess the applicability of a Bioassay Test to determine the toxicity of water using Zebra Fish embryos
10	Water Use Efficiency in Gardening in the Region of Comunidad de Madrid
11	Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid
12	Cyanotoxin Dynamics Study in two of the Canal de Isabel II's supply reservoirs in the autonomous region of the Comunidad de Madrid
13	Development of a validation, estimation and prediction of hourly consumption by sector, for the distribution network of Canal de Isabel II
14	Monitoring of the consolidation urban development in the Comunidad de Madrid using remote sensing techniques
15	Experiences in the recovery of phosphorus from wastewater, in the form of Struvite, at Canal de Isabel II
16	Integration of weather forecasting in the management modules supply system of Canal de Isabel II, via daily contributions models
17	Improvement in forecast capacity of monthly and seasonal runoff in the scope of Canal de Isabel II
18	Inflow of nutrients from the basin to Pinilla reservoir. Effect on the eutrophication process
19	A new criterion for calculating urban sewage flows
20	Idea Management at Canal de Isabel II Gestión: The GENYAL Experience

Collection Number	***Research, Development and Innovation Booklets published***
21	Research on measuring techniques for subsidence related to groundwater exploitation
22	Precipitation patterns in the basins of the Lozoya and adjacent rivers
23	Observability study for hydraulic state estimation of the sectorised supply network
24	Study of failure causes and modes in pipes, service connections, and water meter assemblies in the Comunidad de Madrid
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1. Executive Summary

Technical Data Sheet

Project title	The key aspects of residential water consumption in the Comunidad de Madrid
Research line	Guaranteeing the balance between supply / demand
Areas involved at Canal de Isabel II	Subdirección de Relaciones Comerciales, Área de Imagen y Publicaciones y Subdirección de I+D+i
External participation	Wasser, S.A.E.
Aim and justification of the Project	An in-depth analysis of the information available in the Canal de Isabel II supply system, in relation to the consumption of drinking water in the Comunidad de Madrid, particularly focusing on residential or household uses, considering the use patterns observed and the relation thereof with the socioeconomic variables and the environment, which could explain the variations over time and the dissemination thereof within the various geographical areas.
Contribution to the state of the art	The project represents progress in the characterisation of end uses of residential water consumption and the factors that explain these. It is the most comprehensive experimental study carried out in terms of continuity over time and in terms of the volume of water monitored
Summary of the project development and outstanding milestone	Analysis of the historical progress of the water supplied by Canal de Isabel II. Geographic distribution and by economic sectors. Trends observed in the long-term progress. Detailed analysis of residential consumption, based on the records in the Customer Management System. Usage patterns and explanatory factors. Study of micro-components or end uses of residential consumption taken from a sample of more than 200 homes monitored since 2008.
Summary of the results obtained	Water consumption patterns in residential uses and statistical modelling in relation to the various explanatory factors. Detailed study of consumption and micro-components, including monthly, daily and hourly variations, meteorology, type of household and occupancy thereof and calendar variables. Analysis of usage patterns for each type of household appliance. Consumption characterisation in different flow rate spectrums.
Research Lines open for continuing the work	Research on the application of techniques based on artificial intelligence for the recognition and analysis of residential water use patterns and in other areas. Implementation of precise flow rate metering techniques that enable the water use to be monitored in a broader sample, or in all users.

Keywords

Water demand. Residential water use. Consumption patterns. Demand explanatory factors. Demand forecasting. Water end uses. Microcomponents.

Summary

The aim of this study is the in-depth analysis of the information gathered in recent years on the Canal de Isabel II supply system, in relation to the consumption of drinking water in the Comunidad de Madrid, particularly focusing on residential or household uses, taking into account the usage patterns observed and the relationship thereof with socioeconomic variables and the environment, which could explain the variations over time and the dissemination thereof within the various geographical areas.

Firstly, it presents residential consumption in relation to other uses and with a historic perspective, showing the long-term trends observed and the events of the last 25 years in greater detail. The information analysed in this section comes from the SCADA Remote Monitoring System, with real-time flow rate measurements and from the Customer Management System records (GRECO) from users' individual meters, with bimonthly readings.

A more in-depth analysis of the residential consumption recorded in recent years is then carried out. Residential uses account for around 70% of the total volume supplied to users in the Comunidad de Madrid. Residential consumption is the most homogeneous in terms of its geographic and temporal distribution, despite which, there are significant differences in terms of unitary supplies in the various municipalities within the region. The various factors affecting these differences are analysed, together with seasonal, weekly or daily patterns, and long-term trends that establish the temporal behaviour of water demand for residential uses.

On the one hand, records of invoices issued to customers are analysed (GRECO), for the last 25 years, which enable long-term trends to be observed in residential consumption recorded during that period. Particular attention shall be given to the data for the 2007 - 2016 period, which can be considered relatively stable, after the last drought episode recorded in the Comunidad de Madrid.

Lastly, in order to gain a better insight into the water end use in users' installations, there is a representative sample (*Monitoring Panel*) of around 300 households, continuously monitored over a period of nearly 10 years, which provides much more detailed information about consumption patterns and end uses of water in terms of residential use.

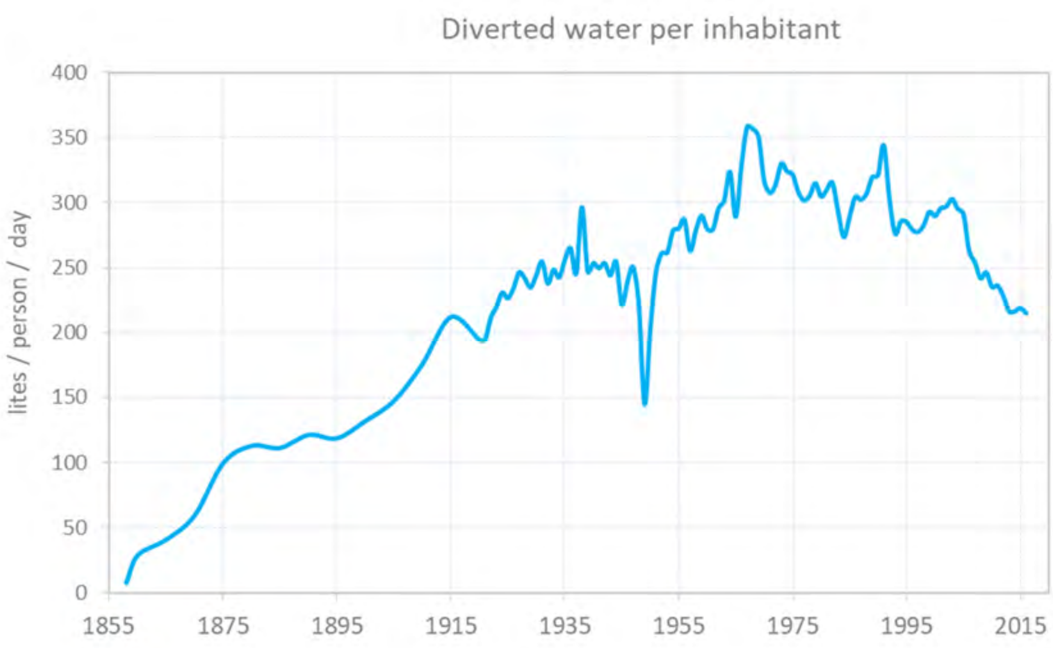
ES.1. DIVERTED WATER

Since the start of Canal de Isabel II, flow rates abstracted from the different sources and reservoirs have been recorded. The volume of diverted water during the initial years barely reached the figure of 1 cubic hectometre per year, with it now standing at 500 cubic hectometres, reaching maximum volumes of 600 cubic hectometres per year (610.10 hm3 in 2005).

The supplied population has grown continuously practically since the start, although it has slowed down in recent years.

The unitary consumption per inhabitant, in terms of abstracted or diverted water, went from 7 litres per person and day in 1858, to around 215 litres per person and day (214.78 in 2016) according to Figure 1. The annual fluctuations indicated on the graph are related to the weather, and particularly, to drought phenomena, particularly those of 1948 – 50, 1983 – 85, 1992 – 95 and 2005 – 06.

FIGURE 1. PROGRESS OF THE PROVISION OF DIVERTED WATER PER INHABITANT



In recent years, there has been a change in trend, which can be pinpointed to around 2003, that is, before the last drought episode and which represents a downward interval in unitary consumption, which has lasted until now.

Apart from the overall annual consumption data and the pattern thereof, which are relevant in terms of managing the resource and forecasting the availability in future scenarios, it has been included an analysis of the seasonality and peak flows, which determine the design of treatment, regulation and transport infrastructures.

ES.2. BILLED WATER

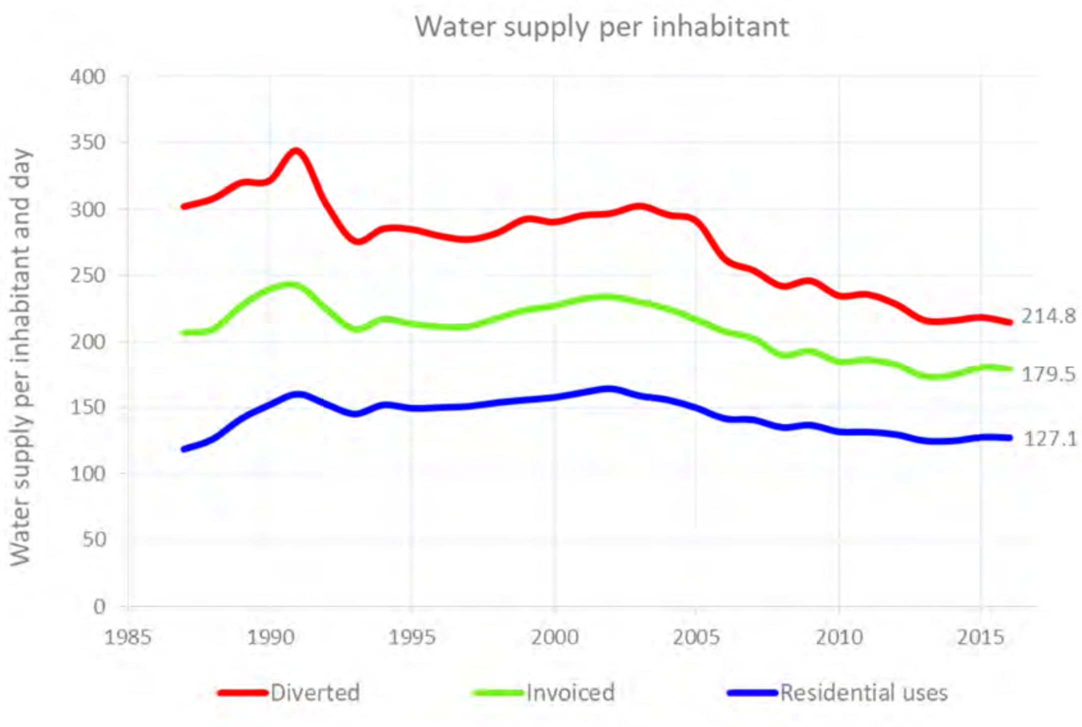
Nowadays, 100% of Canal de Isabel II's customers are equipped with individual meters to record and bill their consumption at. These meters have been read every two months since 2005, while previously they were read every quarter.

The tariff structure applied to the different types of customers enables the classification thereof by type of activity, distinguishing household, industrial, commercial uses, etc. Furthermore, as all the customers can be precisely located in geographic terms, the analysis of these data enables the geographic distribution of consumption to be known, grouped together by municipalities, districts or neighbourhoods in the case of the capital, by statistical areas or other geographic entities and also, by sectors of the distribution network.

The difference between diverted water and water recorded on users' meters (invoiced or not) is called "unmetered water", which mainly refers to operation uses, pipes breaks and losses on networks, fraudulent or unauthorised uses and undermetering by the measurement devices. The volume of unmetered water has dropped continuously, thanks to policies designed to improve the efficiency of the water supply system and in 2016, it represented 16.4% of the total diverted water.

Figure 2 illustrates the progress since 1987 of the amounts of water diverted from reservoirs and catchments per inhabitant and recorded for invoicing and, in this section, residential uses.

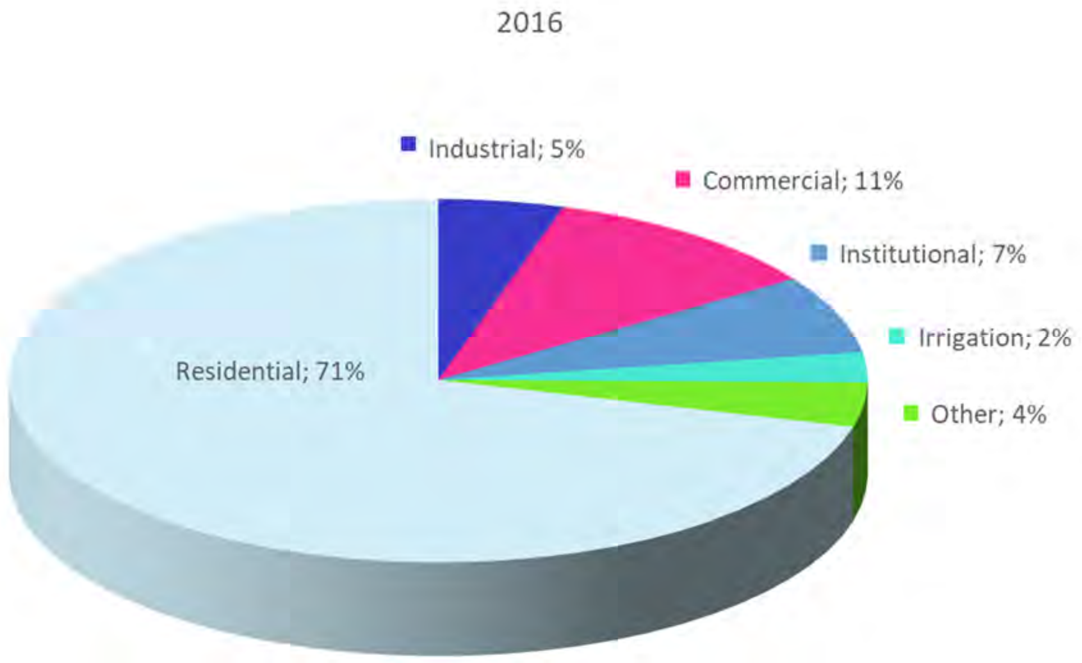
FIGURE 2. UNITARY CONSUMPTION PER INHABITANT OF DIVERTED AND BILLED WATER 1987-2016



The aforementioned change of pattern can be seen previously (2002 - 2003) in invoiced water unitary consumption, which indicates a change in user habits, which took place before the 2005 – 2006 drought began. At this point (2005), there is a greater drop in the difference between diverted and billed water, that is, the way in which this episode of lack of water was managed, had a clear impact on improved efficiency, reducing unmetered water.

Figure 3 shows the current annual consumption distribution (2016) by types of use.

FIGURE 3. CONSUMPTION BILLED BY ECONOMIC SECTORS IN 2016



Residential uses currently account for 70.8% of the total water recorded for billing and these are followed by commercial uses, with 10.8%. This percentage has varied throughout the years as a result of various circumstances. Of particular note is industrial use, which, in 1992, represented 10.5% of the total and now only 4.7%

There is a notable dispersion in unitary consumption per household in the various geographical areas, a dispersion which could be attributed to socioeconomic differences, characteristics of the household and climate conditions, among others. The overall consumption and the various economic sectors have been analysed by household, over the last 25 years in the 11 statistical areas of the Comunidad de Madrid. In all the areas and uses, there is a general drop from the initial years of this century.

The greatest dispersion can be seen in industrial uses, geographic and temporal dispersion, which is related to changes in industrial processes, the geographic mobility of industries with higher levels of water consumption.

The more stable behaviour can be seen in residential uses, also following the general downward trend and with inter-annual fluctuations related to the weather. In 2016, distribution per household ranged between 263 litres per day in the municipality of Madrid and 437 litres per day in the western metropolitan area.

If these data are separated in terms of municipality, the dispersion is much greater, as reflected in Table 1.

Although the purpose of this work does not include delving into the management of unaccounted for water, for information purposes, we have included a summary of the pattern of real and apparent losses in recent years in the Canal de Isabel II water supply system.

Another section describes outdoor water usage, outlining the methodology used for the assessment thereof and the results of recent inventories of green areas and swimming pools, carried out with satellite images from 2014.

TABLE 1. **ANNUAL UNITARY CONSUMPTION 2007–2016 BY MUNICIPALITIES LITRES/HOUSEHOLD/DAY)**

Use	Average (L/property/day)	Standard deviation (L/property/day)	Coefficient of Variation
Residential	316.78	167.13	0.528
Industrial	5,229.37	19,502.05	3.729
Commercial	1,054.83	2,058.73	1.952
Institutional	4,226.75	9,483.85	2.244
Irrigation	3,706.50	14,795.29	3.992
Other	919.99	4,504.04	4.896

ES.3. RESIDENTIAL CONSUMPTION

The analysis of the variables affecting residential water consumption firstly reflects the type of household. There is a clear difference between single-family homes (detached houses, freestanding houses, semi-detached or attached houses) and multi-family homes (blocks of houses), see Figure 4.

The difference between the two types of households is mainly that single-family homes generally have more outdoor use (gardens, swimming pools), therefore consumption levels are higher and consumption patterns are notably different. Currently, around 14% of the households supplied by Canal de Isabel II are single-family homes.

After this initial classification of single-family and multi-family homes, there is still a clear dispersion in unitary consumption data.

Frequency distribution in multi-family homes is roughly normal. For the 2016 data (2,426,000 households) an average normal distribution of 227.93 litres/household per day and a standard deviation of 92.71 has been adjusted, as illustrated in Figure 5. The tails show 3.3% of households with a consumption below 25 litres per day, and 2.3% with a consumption exceeding 5,000 litres per day.

FIGURE 4. **DISTRIBUTION PATTERN PER HOUSEHOLD (MULTI-FAMILY AND SINGLE-FAMILY HOMES) 1991-2016**

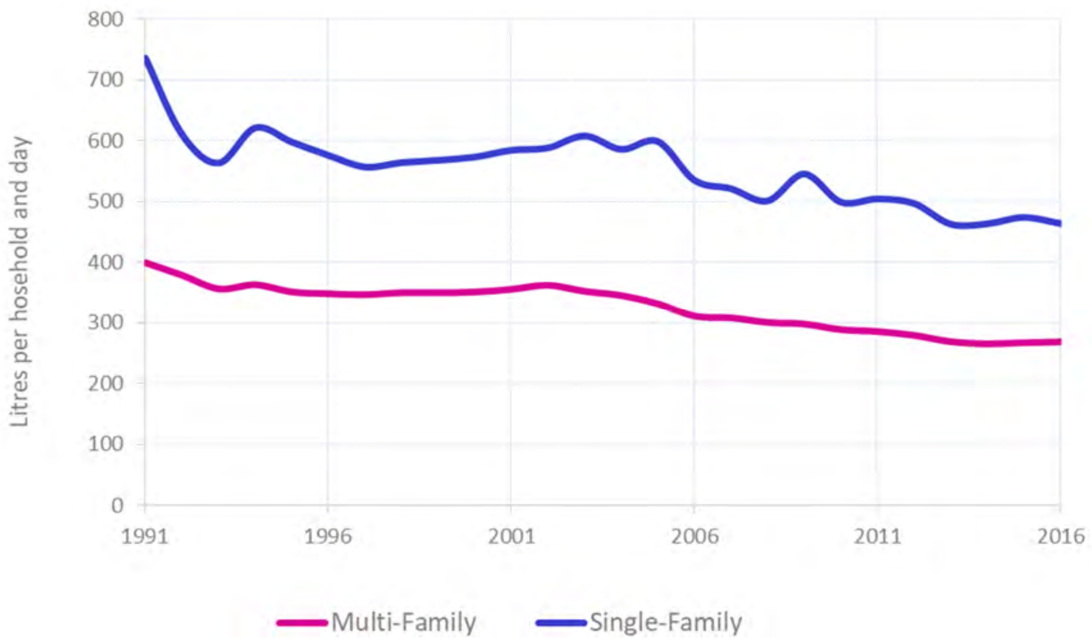
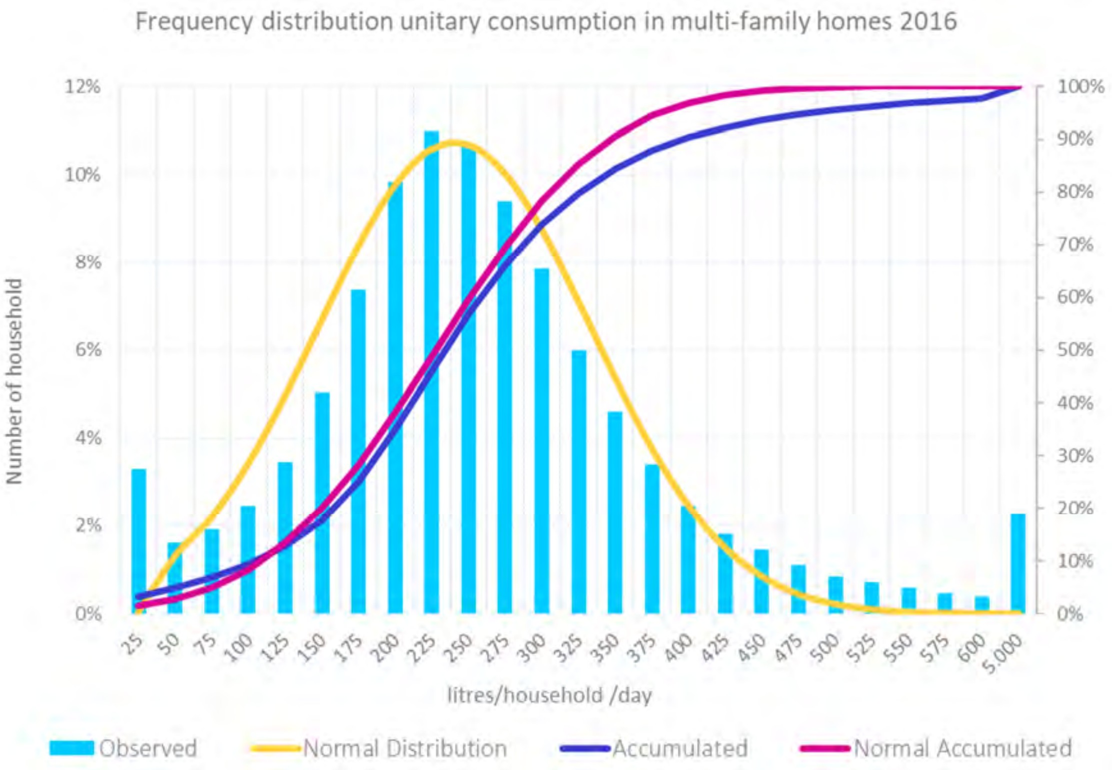


FIGURE 5. **FREQUENCY DISTRIBUTION UNITARY CONSUMPTION IN MULTI-FAMILY HOMES 2016**



In the case of single-family homes, the frequency distribution is quite different to what is considered normal. There is a significant number of *outliers,* in both cases (Figure 6). 12% of the households have a consumption below 50 litres per day, which is probably related to holiday homes. In the other hand, 9.1% of the households recorded an average consumption exceeding 5,000 litres per day in 2016. The normal adjusted distribution has an average of 369.36 litres/household per day and a standard deviation of 207.0. If households that are considered second homes and those with unusual consumptions, exceeding 10,000 cubic metres per year are eliminated, the distribution normalises somewhat, although there is a clear skew to the left.

Taking the average values of unitary consumption per municipality, there is still a considerable variance as observed in the individual values. The extreme values during the 2007-2016 period are outlined in Table 2. The unitary consumption for the municipality of Madrid, can be considered the modal value.

Seasonal consumption patterns are also notably different between both types of households. For multi-family homes, consumption is at its highest during June and drops in July and particularly during August, which is the holiday month par excellence, in which there is a reduction of around 10% compared with June. On the other hand, in single-family homes, the highest consumption takes place during the summer months: June, July and August, in which consumption doubles with regard to winter, following a pattern clearly related to outdoor uses.

FIGURE 6. FREQUENCY DISTRIBUTION UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES 2016

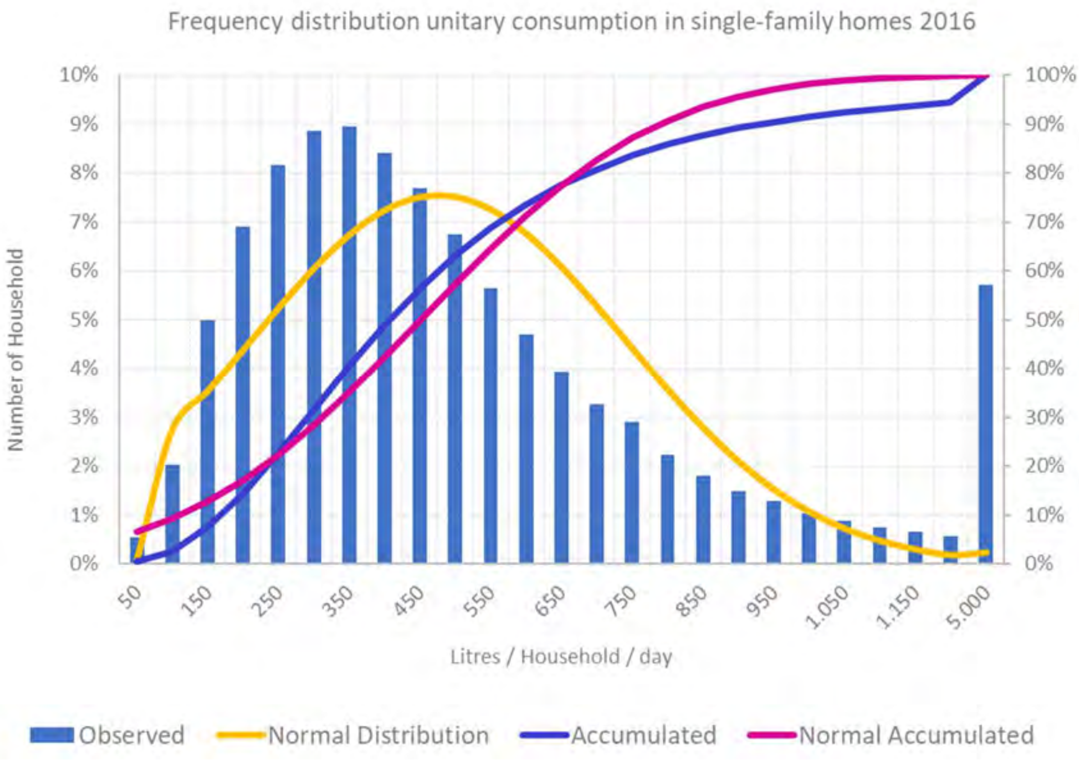


TABLE 2. UNITARY CONSUMPTION IN SINGLE-FAMILY AND MULTI-FAMILY HOMES, 2007 TO 2016 PERIOD (LITRES/HOUSEHOLD AND DAY)

	Multi-family homes		Single-family homes	
Minimum	Canencia	37.5	Hiruela (La)	75.4
Mode	Madrid	260.7	Madrid	613.4
Maximum	Guadarrama	757.7	Alcobendas	1,264.6

ES.3.1. EXPLANATORY FACTORS AFFECTING RESIDENTIAL WATER CONSUMPTION

Climate and meteorological variables have been indicated as affecting residential water consumption variables.

There are other economic and social factors regarding the population and structural factors, in terms of the typology of the households and their installations, which could explain the geographic and temporal dispersion observed in residential consumption. Apart from these factors, there is a personal component relating to usage habits, which is much harder to assess and contrast.

All the variables obtained from objective information and which could affect water consumption have been studied.

ES.3.1.1. Disposable income in households

The economic level of families, represented by the disposable income indicator, undoubtedly has an effect on residential water consumption.

Each year, the Instituto de Estadística of the Comunidad de Madrid publishes an indicator of disposable income in households, for all the municipalities in the region and the 11 statistical areas, together with the overall value. On the date of drawing up this report, details are available for the period comprising 2000-2014 (advance), and provisional data for 2012 and 2013.

Although the temporal progress of the income is not clearly related to that of residential water consumption, the difference between the economic levels in the different areas or municipalities in the region, does appear to partly explain the disparity in the figures. At a municipal level, the dispersion of disposable income is notable, with values in 2014 ranging between Euros 9,618 per year in Somosierra and, Euros 30,426 per year in Pozuelo de Alarcón.

For single-family homes, there is a correlation coefficient between the figures and the level of income of 0.75, which indicates that 56% of the variance observed in consumption at a municipal level can be explained by the difference in income levels. For multi-family homes, this correlation is considerably lower, with the r^2 coefficient being 0.32, i.e. 32% of the variance attributable to income differences.

ES.3.1.2. Size of the household

It is clear that the number of people living in the household affects water consumption. In order to assess this indicator, municipal population patterns published annually have been used, together with details regarding the number of households supplied, from customer records.

The size of the household in the Comunidad de Madrid has not varied greatly in recent years, reaching a maximum in 2009 (2.56 people) and dropping slightly later. In the municipality of Madrid, the behaviour was similar, with values ranging between 2.18 in 2016, and a maximum of 2.30 in 2009.

By municipalities, the range of values is considerable, varying between lower figures than the unit in small populations and values exceeding 4 in some places. In this case, there is a greater correlation between the figures in multi-family households, where a correlation coefficient of 0.66 is obtained. For single-family homes, this coefficient is 0.62.

ES.3.1.3. Primary and second households

In some areas of the Comunidad de Madrid, particularly in the sierra areas, a significant number of households are used as second homes, and these are not occupied all year round. The national statistics institute (INE, Instituto Nacional de Estadística) household census distinguishes between "Primary homes" and "Total households". It is understood that the difference between the two are second residences or second homes and unoccupied households. According to the 2011 census, 14.7% of the households in the Comunidad de Madrid are not considered primary homes, reaching values more than 50% in areas such as Sierra Norte and Sierra Sur. In the municipality of Madrid, 13.7% of the households are second homes or they are empty.

Using billing records, households with a consumption below 5 cubic metres during January and February are classed as "second homes" or "not primary homes".

The percentage value of second or unoccupied homes may be an explanatory factor for the average figures. By municipalities, with the 2016 figures, there is a clear correlation for both multi-family homes (r = 0.73) as for single-family homes (r = 0.71).

ES.3.1.4. Physical characteristics of the households

The physical characteristics of the households and the installations thereof, are another parameter to be considered, affecting water consumption. In order to classify the households, the usable floor area according to the cadastral registry for 2015 has been used as an indicator.

By municipalities, as with the indicator for disposable income in households, there is also a significant correlation between single-family home water consumption and average floor area, but that is not the case in multi-family homes. In fact, both indicators, income and surface area of the household, are not completely independent, since there is also an important correlation between the two.

ES.3.1.5. Outdoor uses

Outdoor uses represent an important component in urban water consumption, and in terms of residential usage, they are mainly related to single-family homes, which normally have gardens and, in many cases, swimming pools.

With the inventory of the aforementioned outdoor uses, the location, with the cadastral plot, green areas and swimming pools in the entire Comunidad de Madrid can be identified. This enables irrigated areas and water surface areas to be related with single-family homes and therefore the average surface area applicable to each household can be calculated. The differences observed per area or municipality are another factor to be taken into account, in terms of being related to the unitary consumption for single-family homes.

There is a greater correlation between the figures for single-family homes with average swimming pool areas (r=0.64) than with the surface area of green areas (0.35), which is probably because of the various irrigation practices and garden typology.

ES.3.1.6. The price of water

The pattern of tariffs for residential uses have also been analysed and the block structure thereof since 2001, concluding that the effect of the tariff on residential consumption is considerably limited and almost exclusively affects users with higher consumption levels and it is observed with some delay.

ES.3.1.7. Statistical modelling

Using the various explanatory factors outlined above: disposable income in households, size of home (number of people per household), percentage of second homes, surface area of the households and the scope of outdoor uses, statistical models have been adjusted for the different statistical areas in the region and the types of single and multi-family homes.

By applying these models to each of the municipalities with the figures from 2011-2015, and comparing the figures calculated by the model with the real recorded results, an adjustment has been obtained, for single-family homes with a coefficient of determination $r^2 = 0.796$.

For multi-family homes, the adjustment is considerably poorer, pursuant to the foregoing regarding the effect of different factors on consumption in these types of households.

ES.4. END USES IN RESIDENTIAL CONSUMPTION

The aim of this part of the work is to address specific issues regarding the manner in which families in Madrid use water supplied to them and the factors that determine such use. The study focused on consumption and residential end use or micro-components.

The details outlined herein were collected between January 2008, and June 2017, from a relatively stable sample of 200-300 households distributed throughout the Comunidad de Madrid. During this period, around 15.8 million consumption hours were monitored and around 208 million litres of water were recorded and analysed.

The selected sample was considered sufficiently representative of all the households in the Comunidad de Madrid, stratified in terms of type of household, occupancy, etc., and with a geographic distribution covering, insofar as possible, the entire region with all its diversity. The percentage of single-family homes in the sample is currently 13%, similar to the average of the Comunidad de Madrid (13.7%), although this has not always been the case (in 2011 it was only 9%) and has normally barely been represented, due to the difficulty in installing metering devices in these types of households.

ES.4.1. INSTRUMENTS USED

For monitoring the consumption of the sample, rotary piston flow meters with meteorological **class C** and **D** were used, equipped with a pulse transmitter generating an impulse each time one litre or decilitre of water passes through. For recording and transmitting data to the control centre, remote control stations with integrated GSM were used.

ES.4.2. DATA PROCESSING

The complete data processing procedure followed these phases:

- Data acquisition: recording consumption data of each user and transmitting these to a server with storage and processing capacity.
- Transformation in events: conversion of pulse/time data collected by flow meters and from those flows, creation of consumption events.
- Assignment of uses: correlation of consumption events and each of the possible uses in each household. This is carried out according to characteristic data of the event (duration, volume, maximum flow peak).
- Data analysis: the data obtained about events/uses are analysed and presented in way that enables conclusions to be reached regarding the effect of certain variables on residential consumption.

Before the data analysis, activities have been carried out to obtain information regarding the characteristics of the households and the occupants thereof, via surveys, tests on the households to characterise the different water uses, by calibrating devices, and also climate data downloaded from official agencies.

One of the challenges of the project was relating the type of water usage to the different identified events. Trained technicians manually assigned the uses to each event, in at least two months of data for each meter. The manual assignment of uses provides great quality in the assignments, but a trained technician uses around two hours for 15 days of data, which makes it unfeasible to process vast amounts of data from a wide sample of households over various years, therefore, at the beginning of the project, a method was developed to automatically assign the water use.

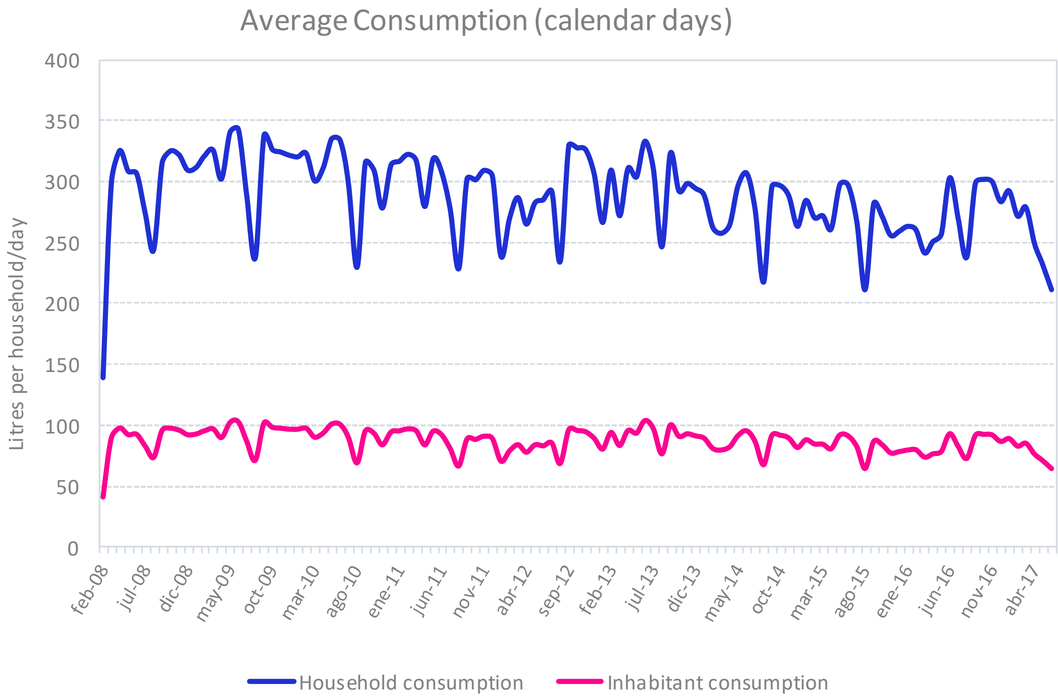
The data for these months of training assigned by operator, have been statistically studied using three parameters for each event: volume, peak or maximum flow rate of the signal and event duration. Considering the possible dependencies between the three variables, a very simple Bayesian network has been built (three nodes), which enables a calculation of the probability of a specific event, given its volume, duration and maximum flow rate characteristics, belonging to each of the different water usage categories and finally assigning the most probable of these.

Later, (2016), a new methodology was developed for identifying events, using advanced artificial intelligence techniques: artificial neuronal networks with deep learning, and support vector machines. This methodology is presented in RDI Booklet 25, entitled "**A pattern recognition system for the identification of residential end uses of water".**

ES.4.3. STUDY RESULTS

Average consumption during the entire study period was **327.7** litres per household and day and **99.8** litres per inhabitant and day, for days with actual consumption, together with **286** litres per household and day, and **87.2** litres per inhabitant and day for calendar days (Figure 7).

FIGURE 7. PATTERN OF MONTHLY CONSUMPTION BY CALENDAR DAYS



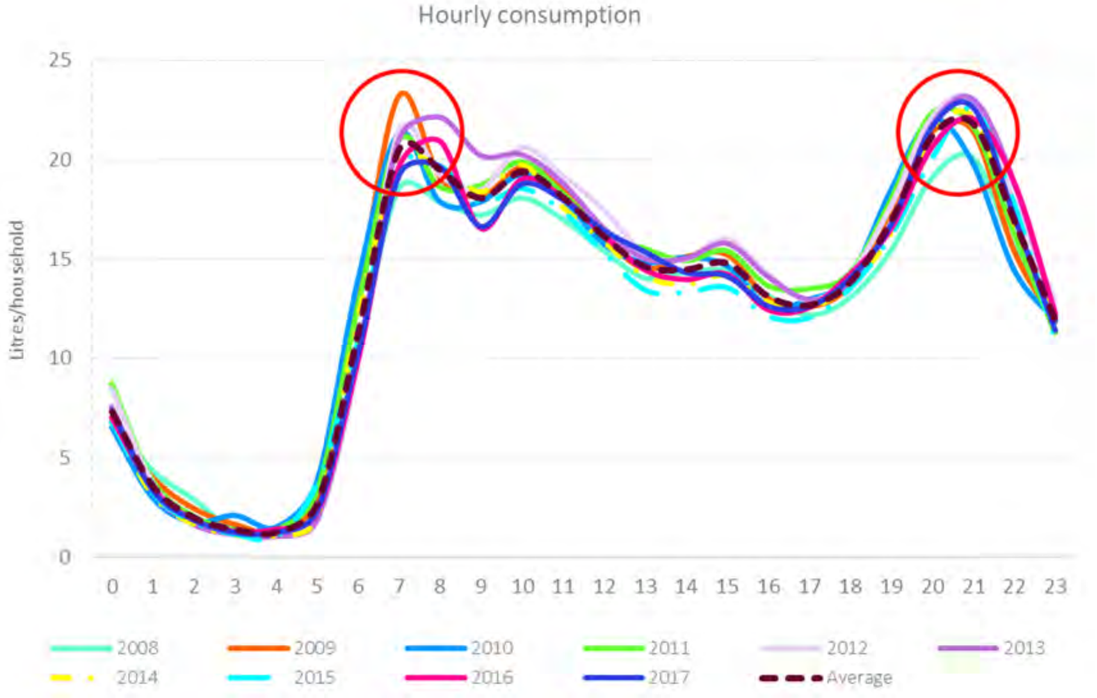
Since the start of the study, there has been a downward trend in consumption, with an annual average rate of 1.7% with regard to consumption per household, taking into account both, calendar days, and real days with consumption. The average for the last three years is 12% lower than that of the first three years of the study. The unitary consumption per inhabitant also dropped, by around 1.3% per year.

Residential consumption showed annual alterations related to high population movements, during holiday seasons and bank holidays. Basically, during the latter, weather had a noticeable effect on consumption variations.

If hourly compared consumption patterns for the last ten years are analysed, the data show similar patterns throughout the entire study, with two maximum consumption figures between 7 a.m. and 8 a.m. and between 8 p.m. and 9 p.m.

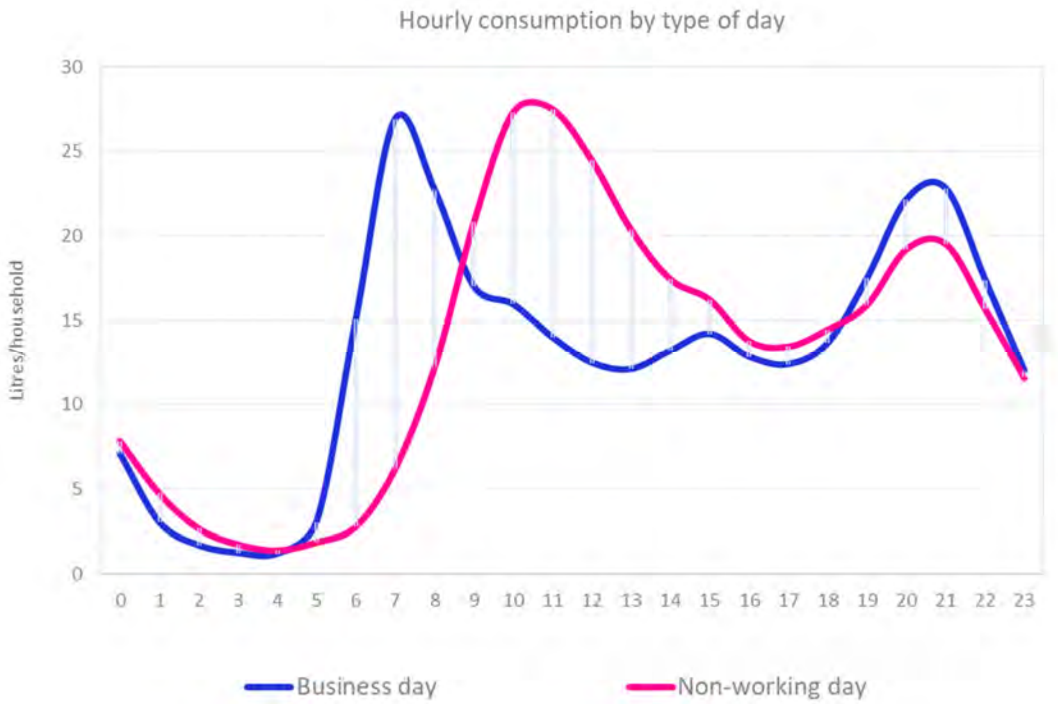
Minimum night consumption occurs between 2 a.m. and 5 a.m. During this period, hourly consumption is below 1% of average daily consumption, (see Figure 8).

FIGURE 8. **HOURLY CONSUMPTION**



By type of day, average consumption on business days was 321.0 litres per household and day and 97.6 litres per inhabitant and day. On non-working days, average consumption was slightly higher, with 330.2 litres per household and day (2.9%), and 100.4 litres per inhabitant and day (2.9%). On a monthly basis, significant variations were recorded, ranging between the 283.4 litres per household and day in August 2015, and 368.4 litres per household and day in June 2009 on business days, or those that were not public holidays. Greater variations were recorded on non-working days, between 277.4 litres per household and day in August 2015, and 370.7 litres per household and day in June 2008, (see Figure 9).

FIGURE 9. **HOURLY DISTRIBUTION OF CONSUMPTION BY TYPE OF DAY**



By type of household, average consumption in multi-family homes was 271.2 litres per household and day, and 83.2 litres per inhabitant and day. Single-family homes recorded a much higher average consumption than multi-family homes, standing at 449.1 litres per household and day (65.6%), and 127.5 litres per inhabitant and day (53.2%).

Significant variations were recorded monthly, namely the 176.1 litres per household and day in August 2015, to the 325.5 litres per household and day in October 2012, in multi-family homes. Greater variations were recorded in single-family homes between 262.3 litres per household and day in January 2016, and 993.3 litres per household and day in July 2015.

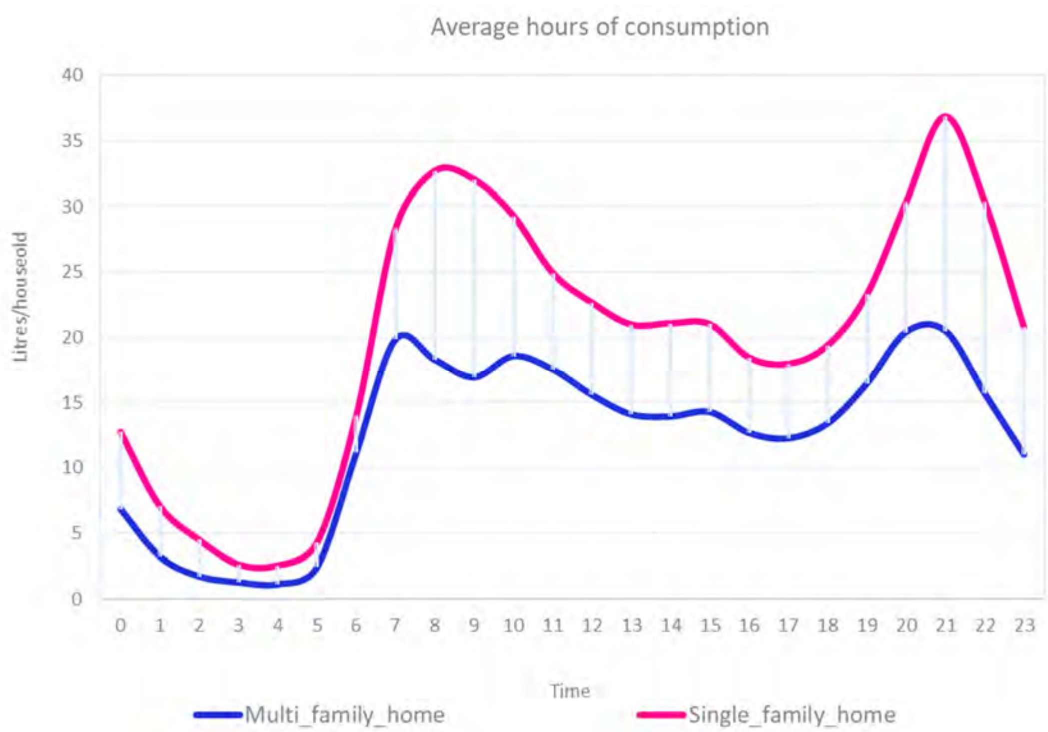
The study also illustrated that the differences between the hourly distribution of consumption based on the type of day and type of household are notable. Essentially, at the maximum consumption time, in the case of type of day and consumption intensity, in the case of type of household (see Figure 10).

The analysis of consumption by occupancy, shows quite stable trends throughout the year. The sole difference is in the drop in own consumption during the summer period, where, the higher the occupancy figure, the greater the drop-in consumption, while those with lower occupancy figures, are hardly affected by the summer.

With the data collected, a **consumption model per household** has been obtained, based on occupancy (see Figure 11).

Consumption per household = -12,957 inhabitants^2 + 139,219 inhabitants

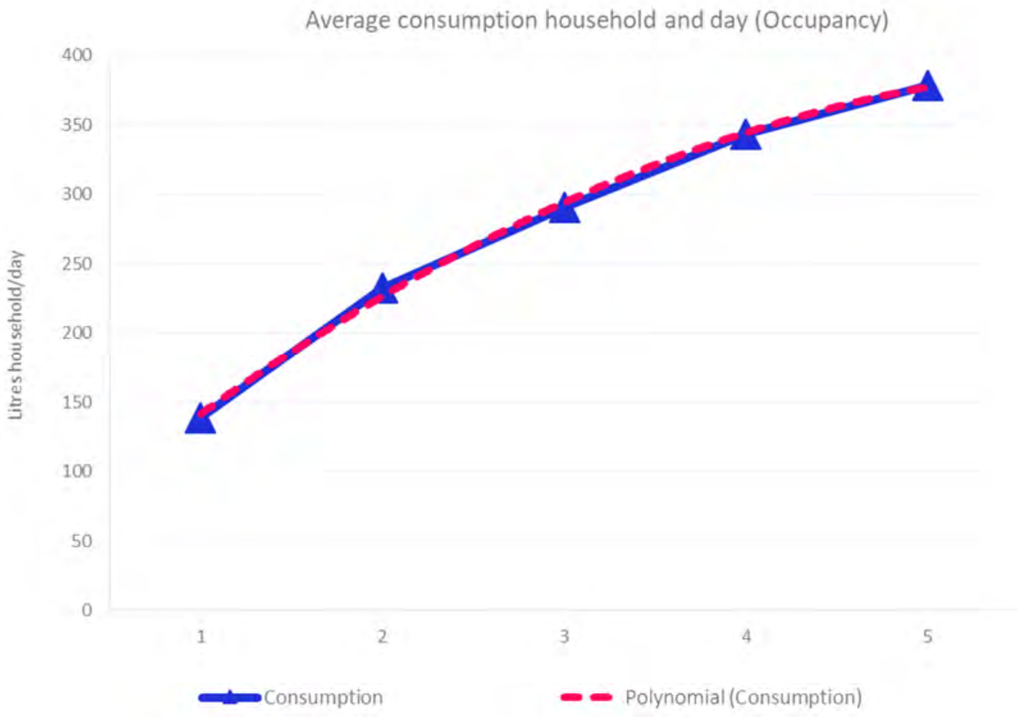
FIGURE 10. HOURLY DISTRIBUTION OF CONSUMPTION BY TYPE OF HOUSEHOLD



In relation to meteorological variables, numerical adjustments have been obtained that model the consumption differential between single-family and multi-family homes and consumption in irrigation.

Single-multi-family difference	0.546 - 0.063 x days of rain + 0.002 x hours of sunshine
Single-multi-family difference	0.0025 x temperature^2 - 0.0352 x temperature + 0.4587
Irrigation (litres/day/household)	0.0025 x temperature^2 - 0.0352 x temperature + 0.4587

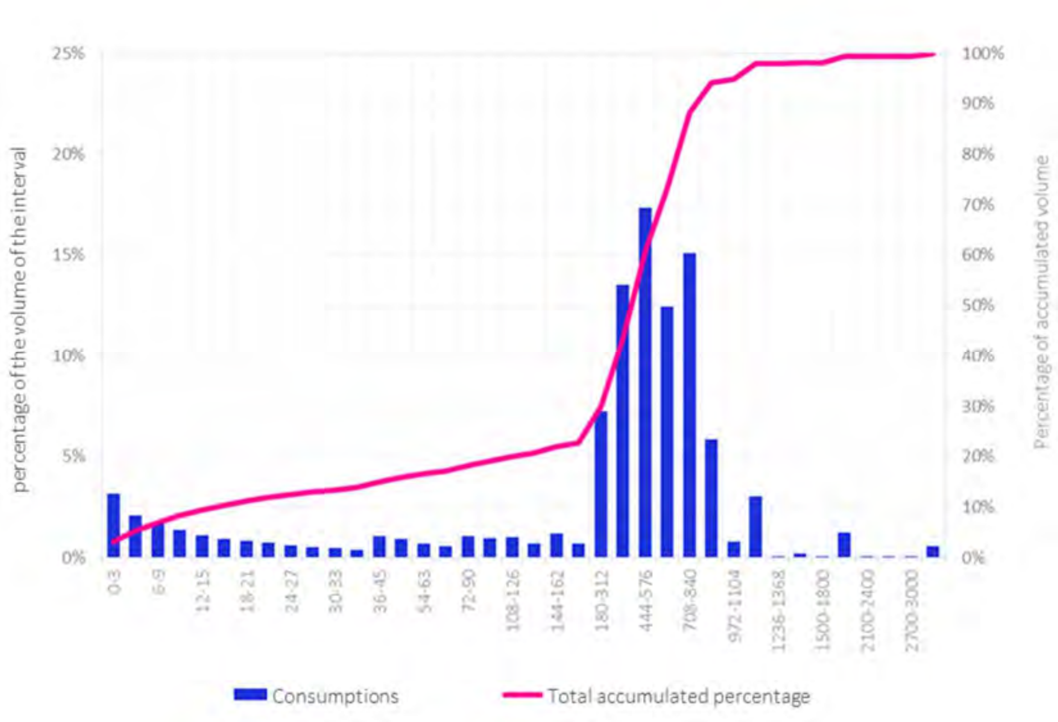
FIGURE 11. **CONSUMPTION MODELLING BASED ON HOUSEHOLD OCCUPANCY**



With regard to the flow rate frequencies in which consumption is recorded, this mainly takes place during the flow interval that goes from 321 to 840 litres per hour, with 59% of the total consumption, which is illustrated in the chart in Figure 12.

The use of meters with a start flow rate equivalent to or below 1 litre per hour, has enabled 22.8% of the volume below 180 litres per hour of flow to be recorded.

FIGURE 12. **GENERAL FLOW RATE HISTOGRAM**



ES.4.4. CONSUMPTION MICROCOMPONENTS

The analysis of the uses in the study sample has determined that **bath tubes or showers** and **taps** are the uses more significant and account for 69% of consumption in a household, with 35% and 34%, 107 and 105 per household and day respectively.

After the foregoing, the most important uses, according to users in the sample, are **toilets** (11.7%, 36 litres per household and day) and **washing machines** (9.5%, 29 litres per household and day). The use of **dishwashers** (7.2 litres per household and day), and **irrigation** (7.7 litres per household and day) each account for 2.5% of consumption. In terms of **leaks**, the average is 4% (13 litres per household and day).

On an annual basis, the drop in uses during the summer months can be observed, due to the movement of the resident population to second residences and holiday homes. The sole use that increases, is irrigation, of course. The type of single-family or multi-family homes, determines the distribution of uses due to the relevance of the irrigation in single-family homes and the greater number of leaks, since they tend to have longer and partly external pipes, with more probability of breaks and small leaks (see Figure13).

In terms of hourly distribution of uses, it shows the different patterns that exist, associated with actual uses.

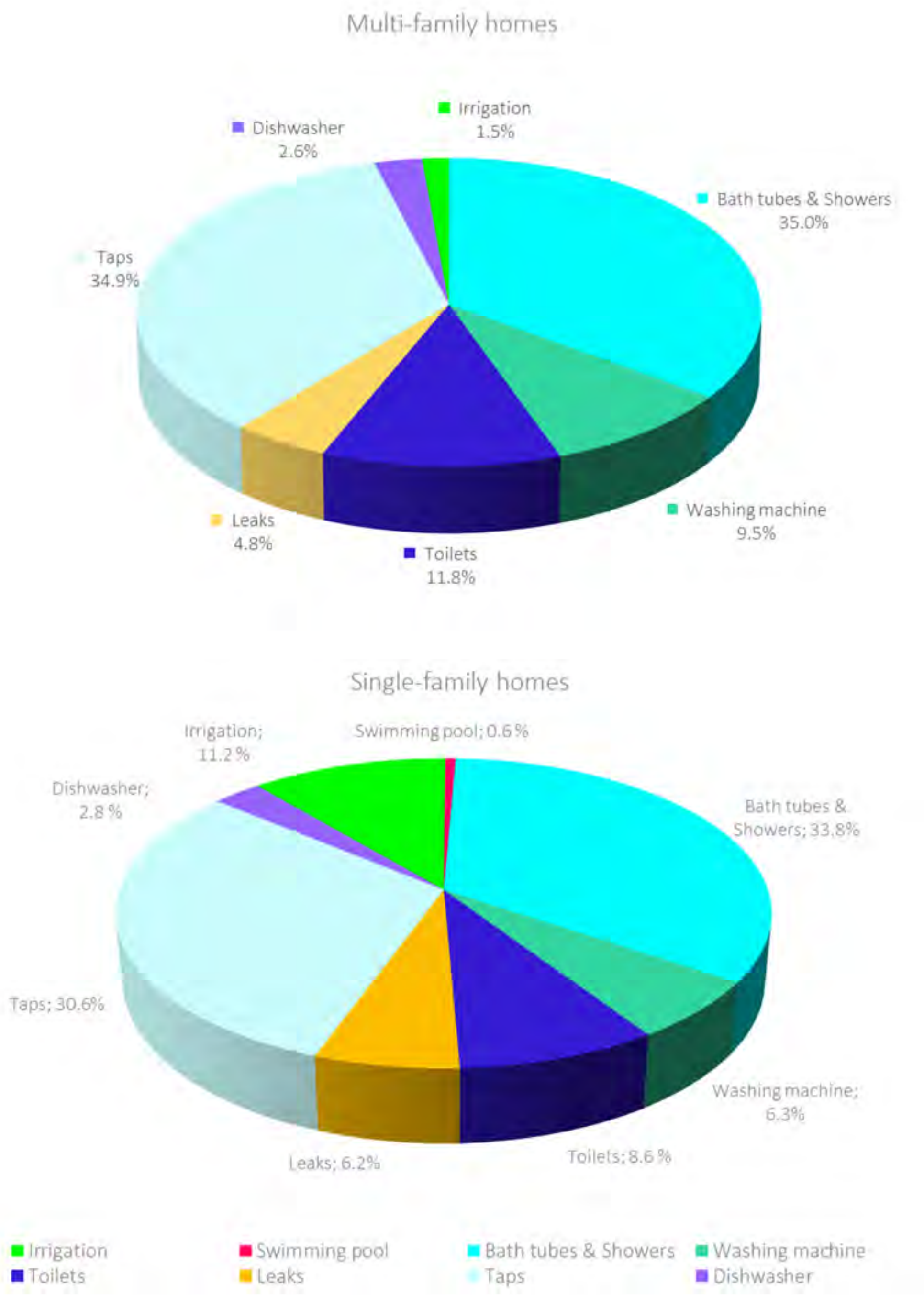
Showers and bath tubes: consumption concentrates on the early and late hours of the day, associated with hygiene habits. Therefore, traditionally, consumption is at a high between 6 a.m. and 8 a.m. and between 7 p.m. and 9 p.m.

Washing machine: consumption is at a high between 10 a.m. and 11 a.m., dropping later until 5 p.m. and experiencing an upturn, with a maximum (much lower than daytime hours) between 8 p.m. and 9 p.m.

Dishwasher: use associated with main meals of the day. Consumption is at a peak after lunch, at 3 p.m., representing 7.8%, then after dinner, between 9 p.m. and 10 p.m., representing 7.4% of the total daily use, with the increase being much lower after breakfast, between 9 a.m. and 10 a.m., representing 5.6%.

In *irrigation,* habits adapted to recommended practices can be seen, since, generally, the central hours of the day (from 10 a.m. to 6 p.m.) are avoided and consumption is at a high during the early and late hours of the day (with daily maximums between 7 a.m. and 8 a.m. and between 8 p.m. and 10 p.m., respectively) Likewise, usage is quite considerable during nocturnal hours.

FIGURE 13. DISTRIBUTION OF USES BASED ON TYPE, SINGLE-FAMILY OR MULTI-FAMILY HOMES



ES.4.5. COMPARISONS WITH OTHER SIMILAR STUDIES

This study was carried out over a period of almost ten years (from 2008 to 2017), and collected data from around 211 households, with over 200 million litres of water monitored and an exact record of the time at which each litre or decilitre of water was consumed. There are no records of any other studies with such a large amount of data analysed with such accuracy.

This study offers a summary of some of the documented works on the analysis of micro-components of residential water consumption in various parts of the world, mainly in Australia and the United States.

The main conclusion is that it is very difficult to compare the results obtained in similar studies carried out in other countries with those carried out in the Comunidad de Madrid. The initial findings indicate that consumption, in both the American and Australian studies, is much higher than that recorded in Madrid, in this study. These vast differences may be due to:

- Differences in the type of buildings (in this study, around 87% of the households are flats, while in other countries they refer mainly to single-family homes with gardens or terraces).
- Differences in the volumes of water per use in devices such as toilets (they have a greater discharge volume) or washing machines (which consume more water per wash cycle).
- Differences in the habits and awareness among users regarding efficiency in terms of water usage.

Different annual periods of the studies. In the studies conducted in the United States and Australia, households were monitored over a short period of time, with a maximum of 4 weeks, therefore the time of the year, weather conditions and even the modification of consumption habits, as a result of being monitored, could have a significant impact on the results.

2. Introduction

Any economic, industrial or business activity requires knowledge of the requirements, expectations preferences or habits of its existing or potential customers. Market studies are necessary for defining expansion strategies, developing new products or price policies, in order to make a business competitive.

The urban water supply sector is no exception, although it does have its peculiarities. The main aim of a responsible public services company is to supply the required volume of water at all times and on a continuous basis, at each consumption point, with the appropriate quality and pressure conditions.

Unlike most economic sectors, in the urban supply of water, as it is a basic and essential commodity, without any economic alternatives and practically without competition, demand for the product, is barely related to price, and it is essentially related to satisfying the individual or social requirements of a community, related to vital, economic and well-being functions.

Furthermore, one of the greatest challenges to which the water supply service is currently subjected to, is in the sustainability of the system, in terms of the balance between available resources, which are always scarce, and increasing demand, related to urban development and the improvement of the quality of life in cities.

Maintaining this balance can be achieved by incorporating new resource supplies, which inevitably will be increasingly more expensive, they will be of a lower quality and will have a greater impact on the environment. The alternative is to act on demand, improving efficiency in the use of available resources, by both the supplier company and users.

The design and implementation of an efficient water demand management policy should be based on realistic estimates of the quantity of water than can be saved in each sector of the economy, in savings that can actually be achieved by implementing various efficiency improvement measures, such as awareness campaigns, replacing plumbing components with other more efficient ones or modifying rates.

The strategic planning of a water supply system, the necessary development or extension of infrastructures in accordance with planning horizons, to meet the population’s future requirements, is based on taking into account the most possible accurate future water demands Likewise, daily or short term management of the system requires knowledge of the expected behaviour of demand in these horizons.

The information for the analysis and characterisation of the demand is obtained from the direct measurement of the flow rates (or volumes) of water supplied in various locations within the supply system and with different spatial or temporal scales and levels.

The Canal de Isabel II supply system has a wide network of metering points to control volumes of water circulating through the strategic network, which provide real-time information regarding the supply of water.

These metering points are integrated within the SCADA remote control system and are mainly located in the installations outlined below.

- Outlets in reservoirs and catchments of surface or ground water
- Drinking Water Treatment Plants (ETAP)
- Regulation tanks
- Inflows into the supply network sectors

For billing users, all customers have individual meters, which take bi-monthly readings. Lastly, for greater knowledge regarding the end water use in users' installations, there is a sample (*Monitoring Panel)* of households where consumption is monitored constantly, which enables consumption patterns and habits of users to be determined regarding the use of different household appliances.

All this information is analysed on a regular basis, in order to observe and monitor the behaviour of demand and the explanatory factors thereof, which are used systematically for a forecast of the future progress with various levels of detail in spatial and temporal resolution. The results are included in internal reports to be applied in planning and infrastructure projects and in the management of the supply system.

The titles that appear in Table 3 in relation to the studies on water demand in the Comunidad de Madrid have been published in the collection of Canal de Isabel II R+D+I Booklets.

TABLE 3. R+D+I BOOKLETS ON WATER DEMAND IN THE COMUNIDAD DE MADRID

Number	*Title*	*Year*
4	Microcomponents and explanatory factors on domestic water consumption in the Comunidad de Madrid	2008
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid	2009
7	Potentials of efficiency in using dishwashers in the Comunidad de Madrid	2009
10	Water use efficiency in gardening in the region of Comunidad de Madrid	2010
11	Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid	2010
13	Development of a validation, estimation and prediction of hourly consumption by sector, for the distribution network of Canal de Isabel II	2011
14	Monitoring of the consolidation urban development in the Comunidad de Madrid using remote sensing techniques	2011
19	A new criterion for calculating the volume of urban sewage flows	2013

This document focuses on residential consumption, which represents around 70% of the entire supply to users within the scope of the Comunidad de Madrid, and the main source of information used are the records from customer billing meters and data collected from the Panel of household users, monitored since 2008.

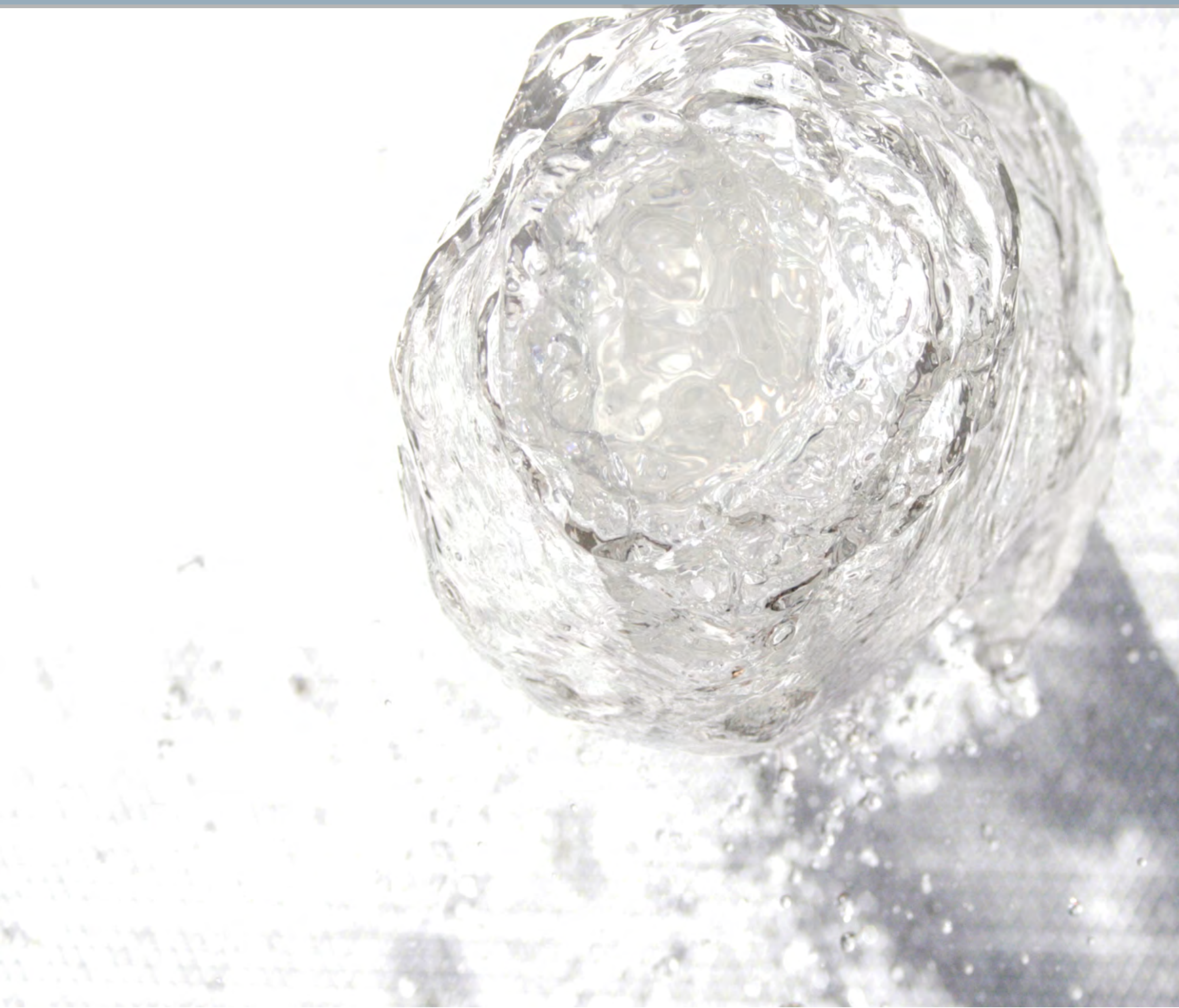
3. Objective

The aim of this paper is to conduct an in-depth analysis of the information collected in recent years through the Canal de Isabel II supply system, in relation to the consumption of drinking water in the Comunidad de Madrid, particularly focusing on residential or household uses, taking into account the usage patterns observed and the relation thereof with socioeconomic variables and the environment, which could explain the variations over time and the dispersion thereof within the various geographical areas.

The aim is to disseminate this information among stakeholders interested in knowing about water demand patterns in an urban environment: supplier companies, corporations, researchers, professionals or citizens in general.

The data used to draw up this paper refer exclusively to the Comunidad de Madrid and cannot be extrapolated to any other areas; however, the methodology may be of use to collect data, and to analyse and research the causes and explanatory factors affecting water demand.

4. Context



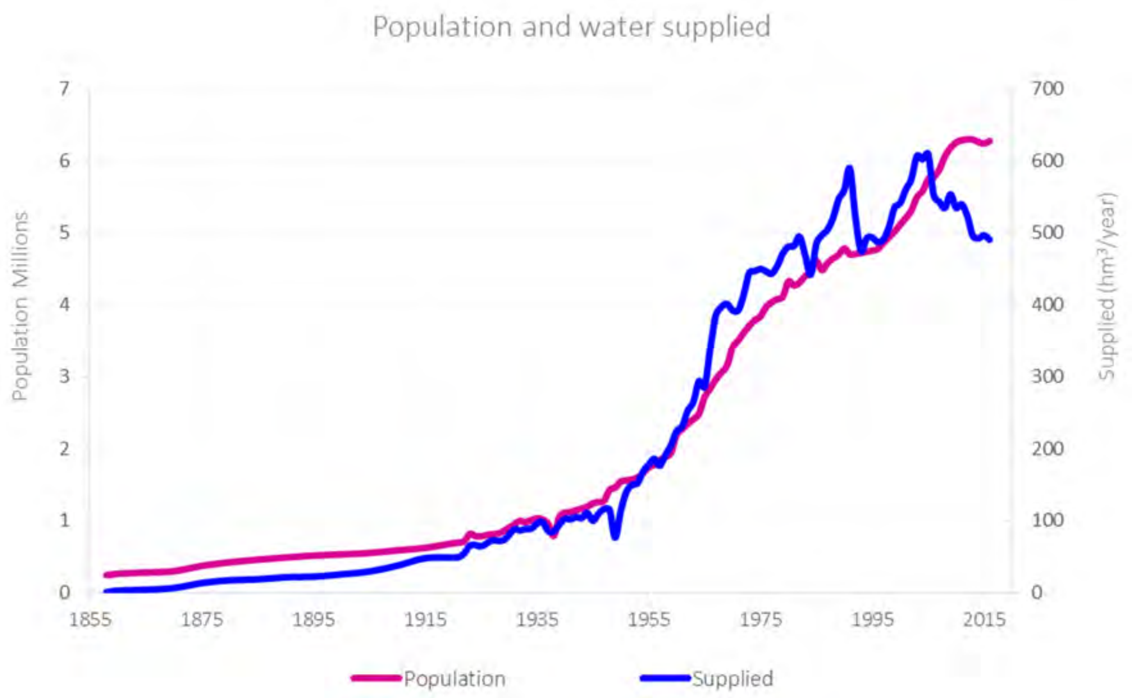
This chapter initially presents residential consumption in relation to other uses and with a historic perspective, showing the long-term trends observed and the events of the last 25 years in greater detail.

4.1. DIVERTED WATER

Since the start of Canal de Isabel II history, records have been taken of the volumes of water diverted from the various catchments and reservoirs.

The total annual supply progress, since records began, is illustrated in Figure 14. The volume diverted during the initial years barely reached the figure of 1 hm^3 per year, while it now stands at around 500 hm^3, having reached maximum levels of around 600 hm^3 per year (610.10 hm^3 in 2005).

FIGURE 14. HISTORIC PATTERN OF WATER SUPPLIED AND SUPPLIED POPULATION



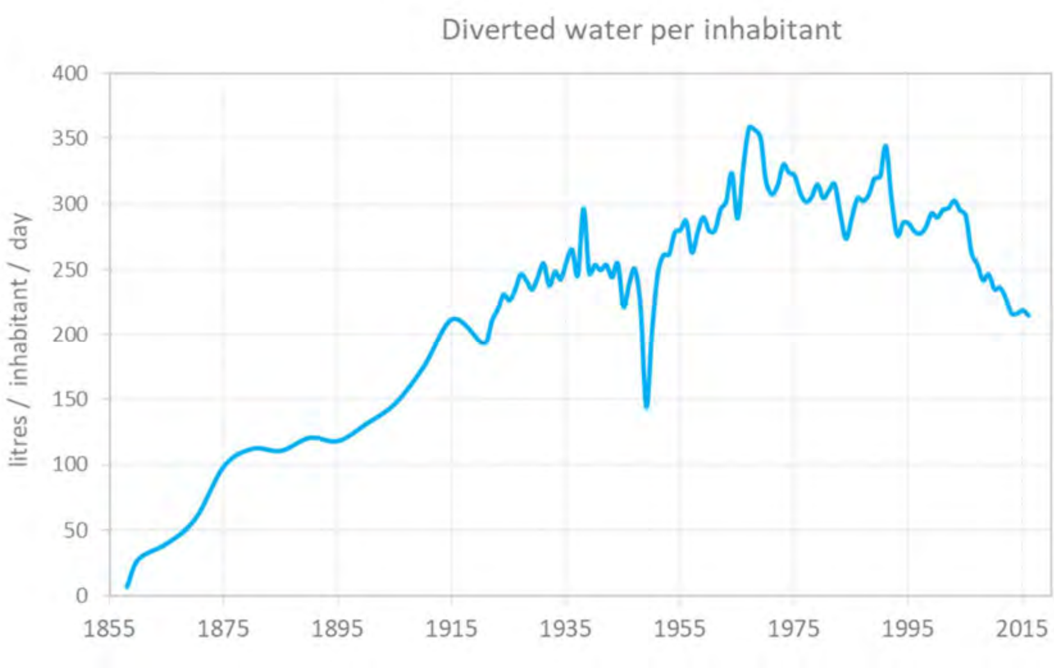
The trend curve for water supplied, almost followed the same pattern until the last decade as that of the supplied population, which, in 1858, was 240,000 inhabitants (just in the municipality of Madrid), and which currently (2016) stands at 6,269,112 inhabitants in 175 municipalities of the Comunidad de Madrid and other neighbouring provinces of Avila and Guadalajara.

4.1.1. Unitary consumption per inhabitant

The supplied population, experienced a continuous growth practically since the start, although it slowed down in recent years. However, the curve that marks the volume of diverted water is more irregular, dropping during some periods and subsequently recovering, in relation to weather circumstances, particularly prolonged drought periods. In recent years, from 2005 onwards, there is a clear downward trend.

Figure 15 illustrates the supply per inhabitant, in terms of abstracted or diverted water, going from 7 litres per person and day in 1858, to around 215 litres per person and day (214.78) in 2016.

FIGURE 15. HISTORIC EVOLUTION OF THE DIVERTED WATER SUPPLY PER INHABITANT

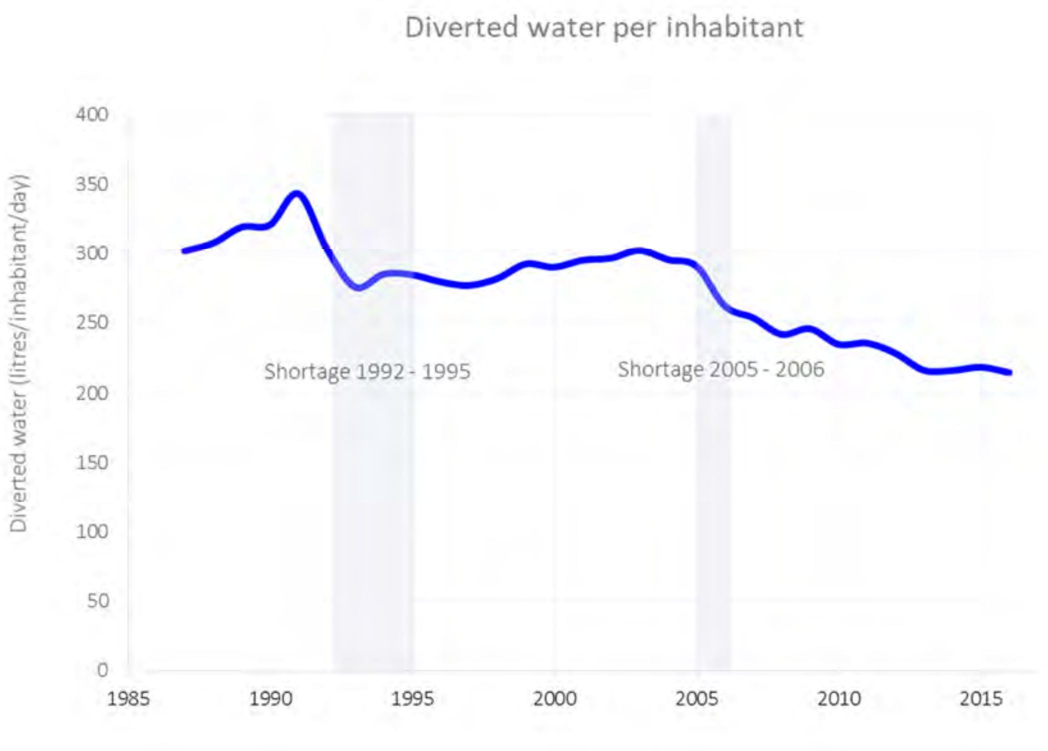


Graphs in figures 15 and 16 regardless of the supplied population, provides a clearer view of the annual fluctuations related to the weather and particularly, to drought phenomena, particularly those of 1948 – 50, 1983 – 85, 1992 – 95 and, 2005 – 06.

By taking a closer look at the pattern over the last 30 years, as reflected in this graph, the effect of the last two episodes of severe drought recorded in the Comunidad de Madrid can be seen, and the effect thereof on water demand, related to awareness-raising campaigns among the population and other measures adopted by Canal de Isabel II and the relevant authorities. In both cases, there is a notable drop in supply per inhabitant, without the values recorded before the drought being recovered afterwards.

A change in trend had already been observed before the drought episode of 2005 - 2006, which can be pinpointed to around 2003, and which represents a downward interval in unitary consumption, which has lasted until now. The possible causes and consequences of this change in trend will be analysed in later chapters.

FIGURE 16. **DIVERTED WATER SUPPLY PER INHABITANT 1987-2016**



4.1.2. Seasonality and peak volumes

The overall annual consumption data and the progress thereof are relevant in terms of managing the resource and forecasting the availability thereof in future scenarios. Short or medium-term management of the supply system and planning and designing water facilities for the treatment, regulation, transportation and distribution, require more in-depth knowledge of the behaviour of demand in relation to time, seasonal, weekly, daily and hourly patterns, with the peak volumes normally recorded at the start of summer, being the ones to dictate the design of the infrastructures. Overall consumption in the Comunidad de Madrid has a clear annual periodicity, with maximum values being recorded during June and July and minimum values in the winter months, with local drops during holiday periods, mainly Easter Week and the month of August, as shown in the graphs in Figure 17.

In order to design treatment and regulation infrastructures, the average daily expected maximum volumes are used as a reference (24-hour regulation). Transport or distribution pipelines will be designed for maximum instant flow rates (normally an average of one hour). The progress of these values for the entire supply system is illustrated in Figure 18.

Average flow rates show a descending trend from 2003 -2004, as outlined previously, while peak values show significant fluctuations related mainly to meteorological variables. These peak values normally refer to the initial days of summer, before holiday movements begin and they may be boosted by high temperatures, together with the lack of rain. Accordingly, Figure 19 illustrates a certain parallelism between peak daily flow rates and the maximum temperatures recorded during June and July.

FIGURE 17. **MONTHLY DIVERTED WATER 1991-2016 AND 2012-2016**

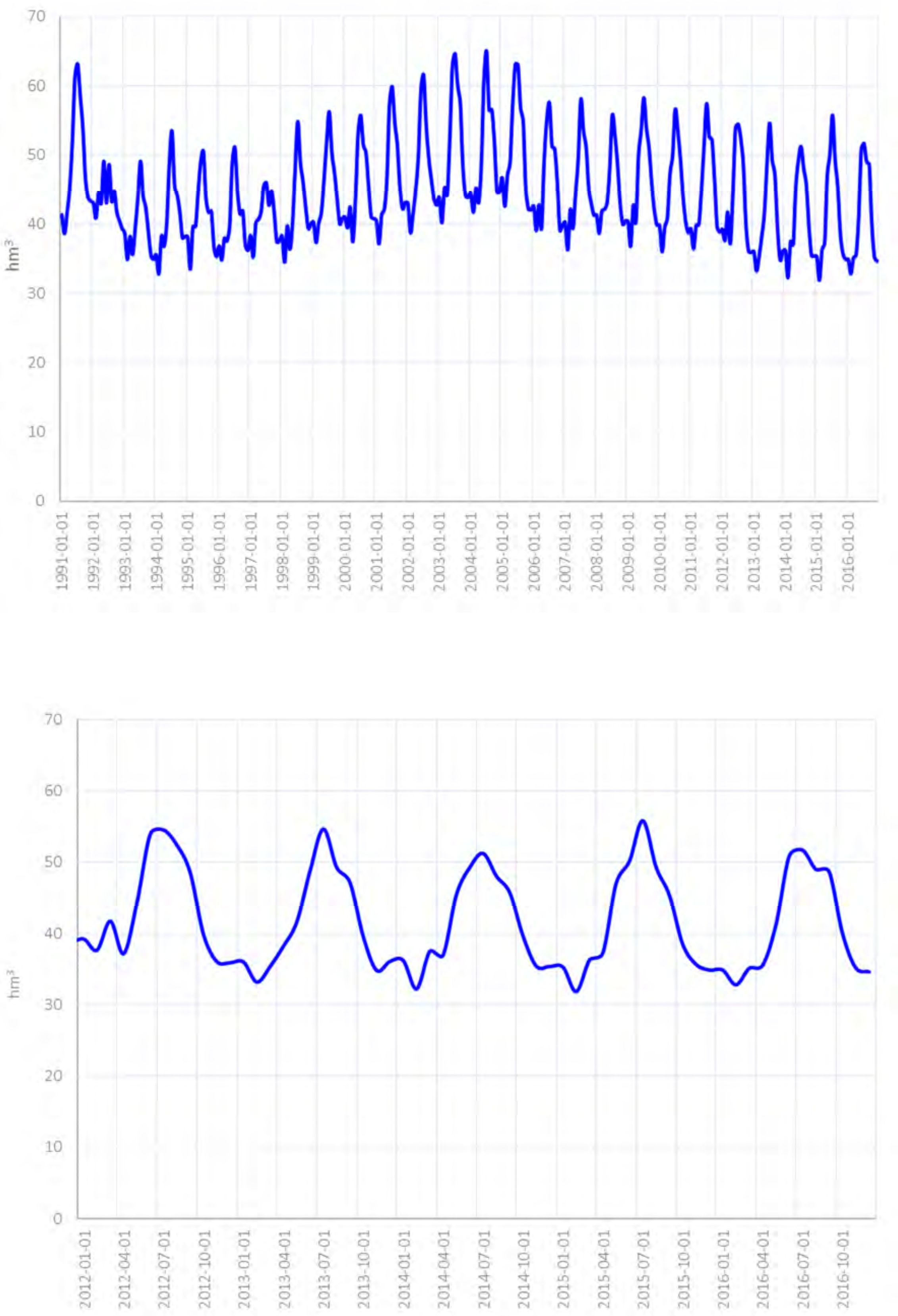


FIGURE 18. **AVERAGE FLOW RATES AND PEAK FLOW RATES FOR THE TOTAL SUPPLY 1995 - 2017**

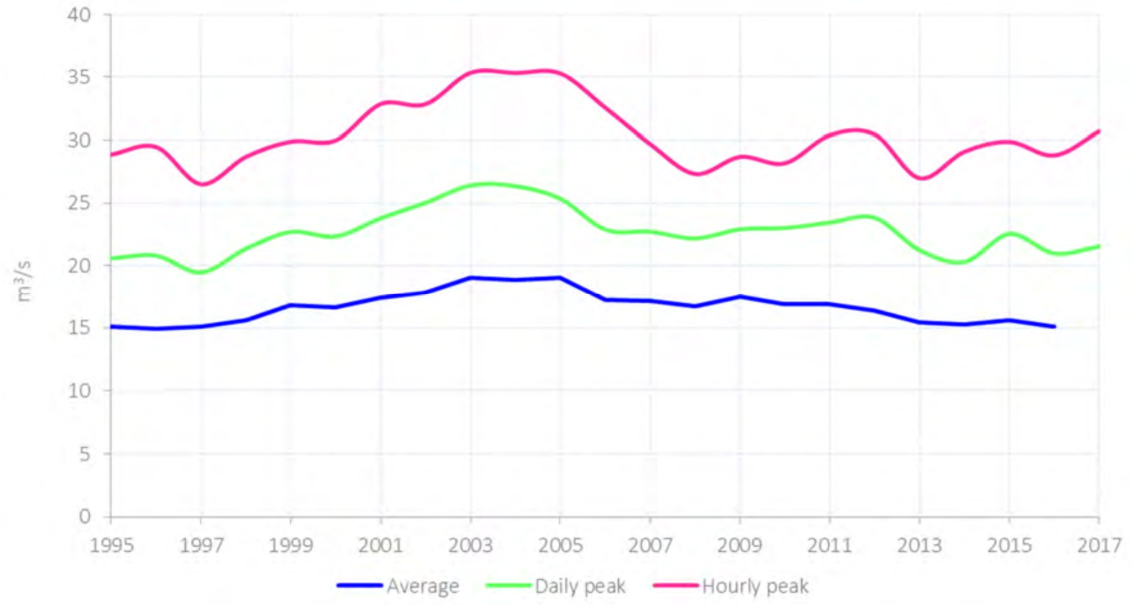
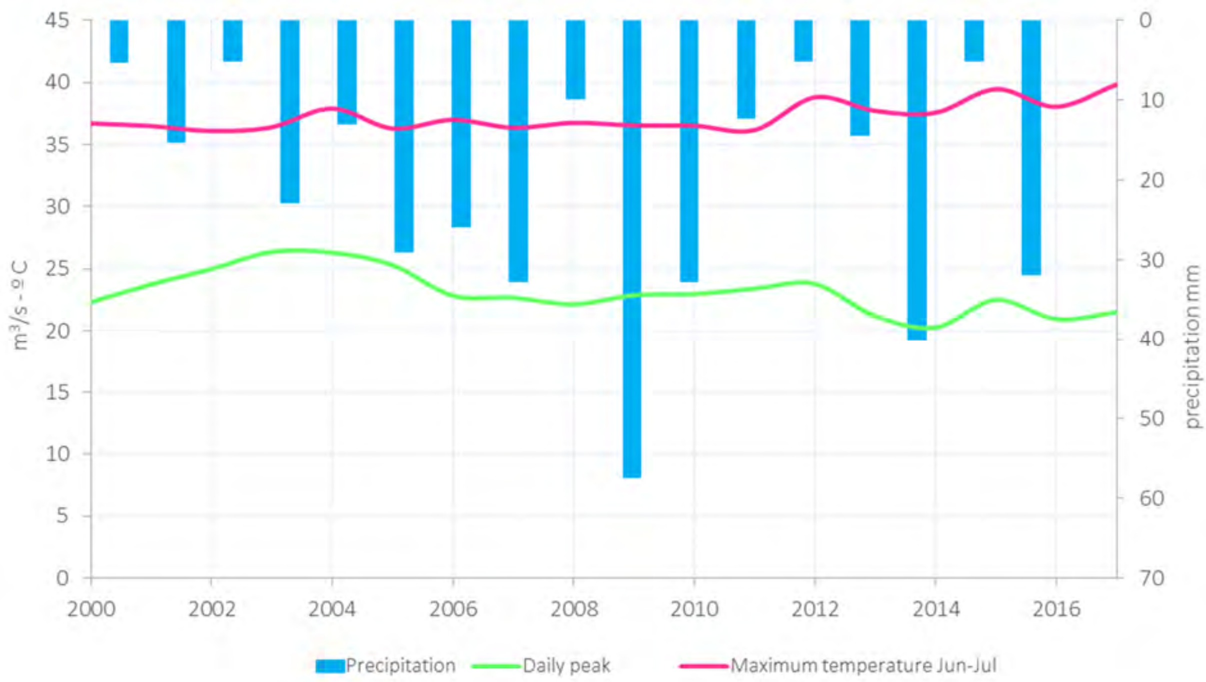


FIGURE 19. **PEAK FLOW RATES IN RELATION TO METEOROLOGICAL VARIABLES**



Peak flow per sectors

The sectorisation of the Distribution Network (Figure 20) has divided it into 580 sectors, with all their inputs controlled in real time by means of flow measurement devices integrated into the Canal de Isabel II remote control system, providing much more information regarding the behaviour of peak flow rates in various circumstances. Observations in various sectors or combinations thereof show that, with the same meteorological conditions, the peak coefficient (relationship between the peak flow rate and the average flow rate) is exponentially related to the number of households supplied from the measurement point. This is due to the concurrency factor, so, the greater the number of households supplied, the lower the probability of the maximum consumption of them all, or a large number of customers, coinciding in time.

FIGURE 20. SECTORISATION OF THE DISTRIBUTION NETWORK. CLASSIFICATION BY NUMBER OF HOUSEHOLDS

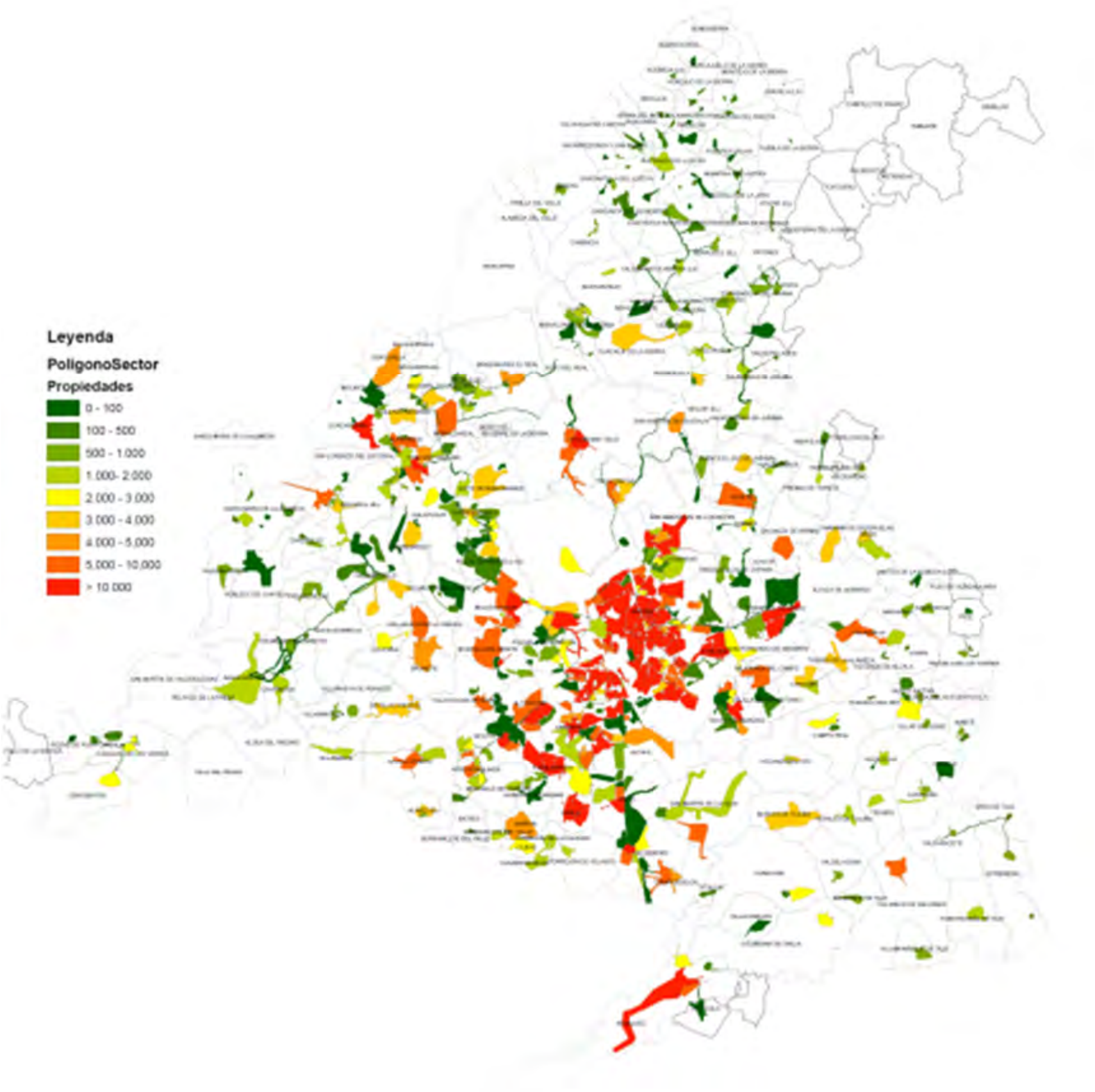
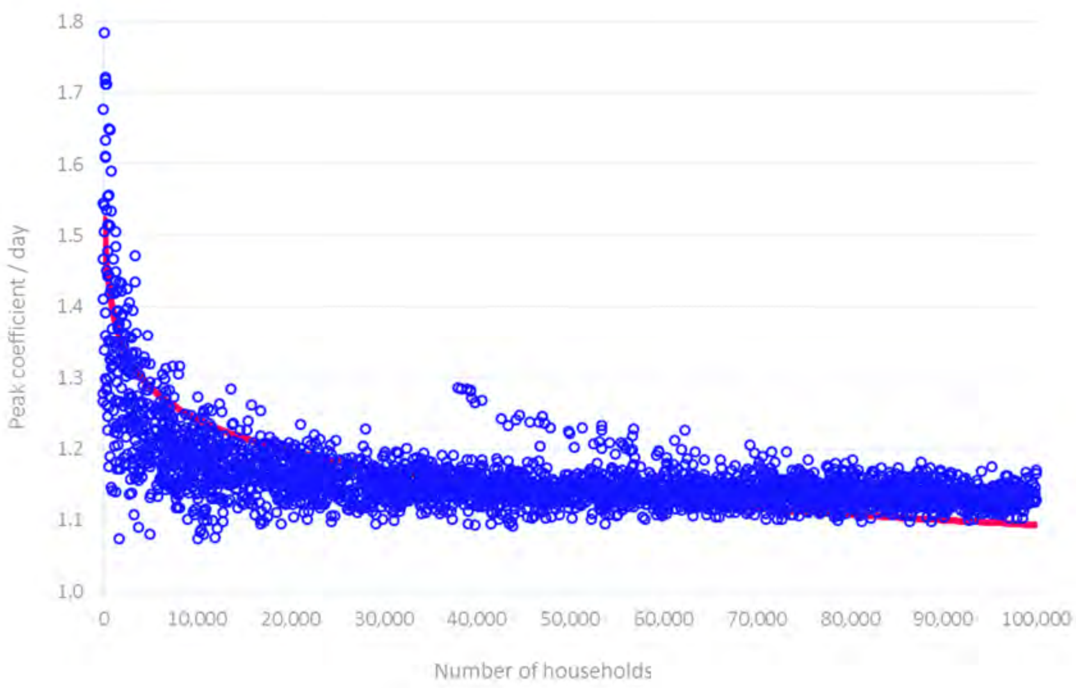


Figure 21 represents the peak coefficient relating to the maximum consumption day, with regard to the average consumption during the summer months (June and July) for various sectors and combinations thereof. It shows that this coefficient presents values of around 1.80 when referring to individual households and asymptotically approaches a value between 1.10 and 1.20 when the number of customers supplied increases. Similar conclusions can be obtained for the relationship between the instant peak and the average daily flow rate.

Canal de Isabel II's Standards for Supply Networks (Normas para Redes de Abastecimiento de Canal de Isabel II) propose a quadratic formula for this coefficient based on the average flow rate, which is an indirect way of relating it to the number of households supplied.

Instantaneous peak coefficient: $C_p = 1{,}4 + 2{,}8 / \sqrt{Q_m}$

FIGURE 21. PEAK COEFFICIENT IN SECTORS VERSUS NUMBER OF HOUSEHOLDS



4.2. BILLED WATER

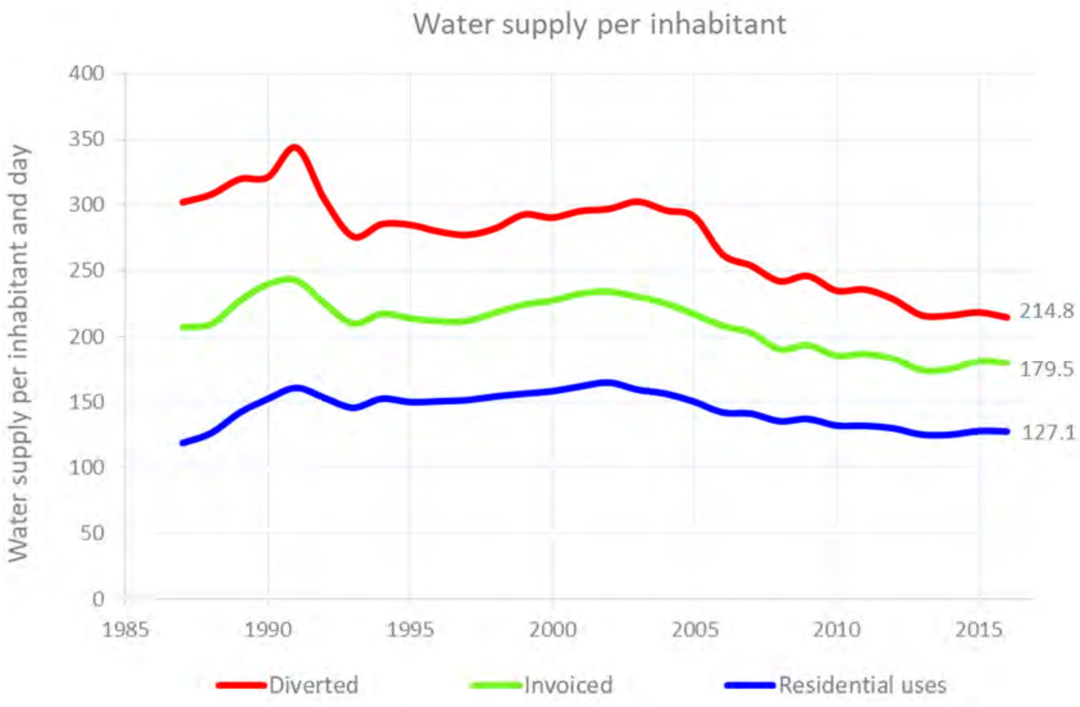
The figures presented in the preceding chapter refer to all the water diverted for consumption from the reservoirs and catchments of the Canal de Isabel II Supply System and the supply to sectors of the Distribution Network. This chapter will illustrate and analyse consumption details measured directly by users' meters and recorded on the Canal de Isabel II Commercial Management System (GRECO).

Today, 100% of Canal de Isabel II's customers have individual meters installed to record, and invoice, their consumption. These meters have been read every two months since 2005, previously they were read every quarter.

The tariff structure applied to the different types of customers, enables the classification thereof by type of activity, distinguishing household, industrial, commercial uses, etc. Furthermore, as all the customers can be precisely located in geographic terms, the analysis of these data enables the geographic distribution of consumption to be known, grouped together by municipalities, districts or neighbourhoods in the case of the capital, by statistical areas or other geographic entities and also, by sectors of the Distribution Network.

The difference between diverted water and water recorded on users' meters (invoiced or not) is called "unmetered water", which mainly refers to operation uses, pipe breaks, and losses on networks, fraudulent or unauthorised uses and submetering by measurement devices. The volume of unmetered water has dropped continuously, thanks to policies to improve the efficiency of the water supply system and currently (2016), represents 16.4% of the total diverted water. Figure 22 illustrates the progress since 1987 of the amounts of water diverted from reservoirs and catchments, and supplied per inhabitant and recorded for billing and, in this section, residential uses.

FIGURE 22. SUPPLIES PER INHABITANT OF DIVERTED AND BILLED WATER 1987-2016



The aforementioned pattern change can be seen previously (2002 - 2003) in billed water supplies, which indicates a change in user habits, which took place before the 2005 – 2006 drought began. At this point, (2005), there is a greater drop in the difference between diverted and billed water, that is, the management of this episode of lack of water had a clear impact on improved efficiency, reducing unmetered water.

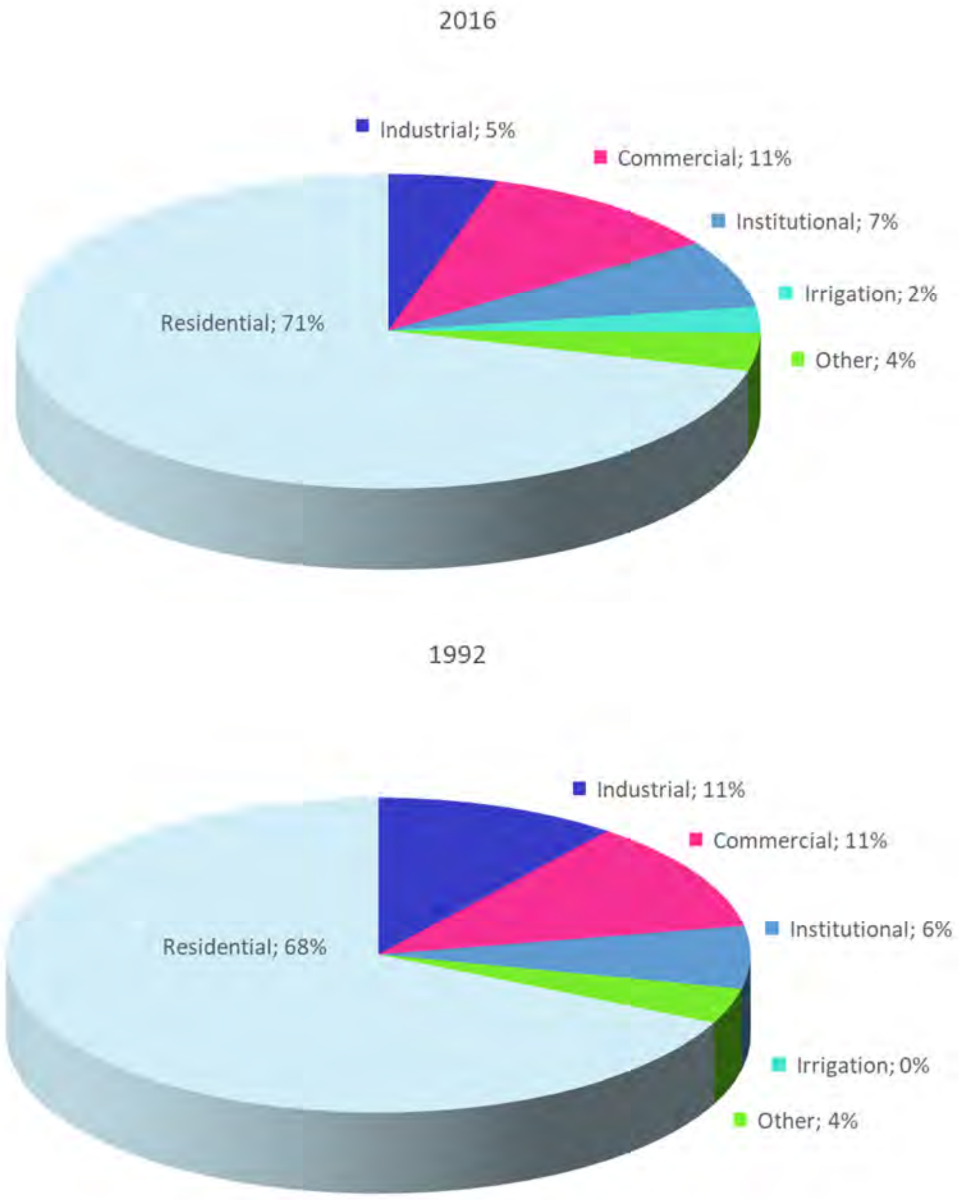
4.2.1. Consumption by economic sectors

In accordance with the type of rates applied to each user, billed consumption can be classified in:

- Residential
- Industrial
- Commercial
- Institutional
- Irrigation
- Other

Figure 23 shows the distribution of annual consumption by types of use, in 2016 (current) and, in 1992. Figure 23 illustrates that **residential** uses currently account for 70.8% of the total water recorded for billing and these are followed by **commercial** uses, with 10.8%. This percentage has varied over the years as a result of various circumstances. Of particular note is **industrial** use, which, in 1992, represented 10.5% of the total and now only 4.7%

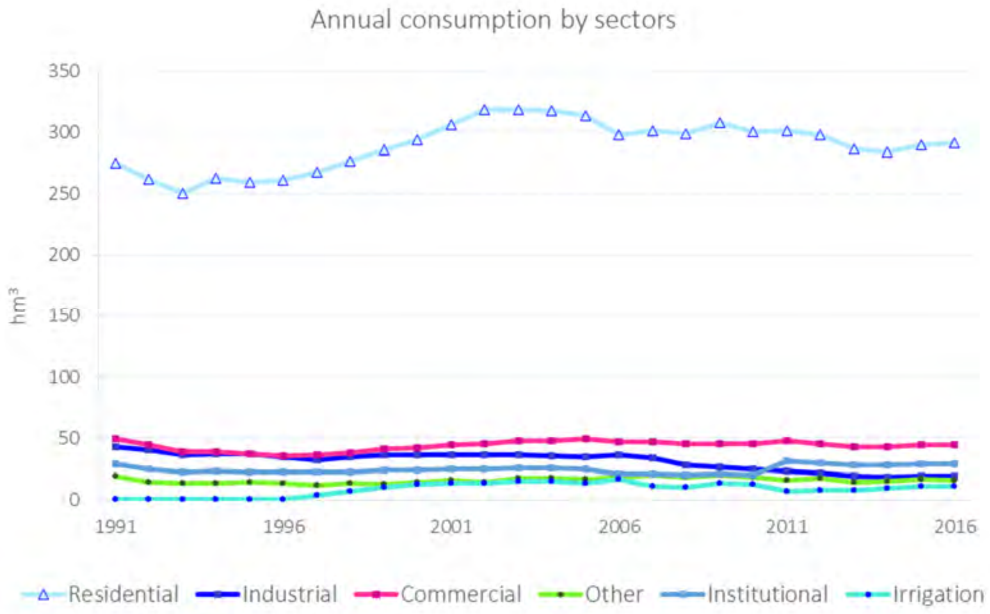
FIGURE 23. **COMPARISON OF BILLED CONSUMPTION BY ECONOMIC SECTORS, 2016 - 1992**

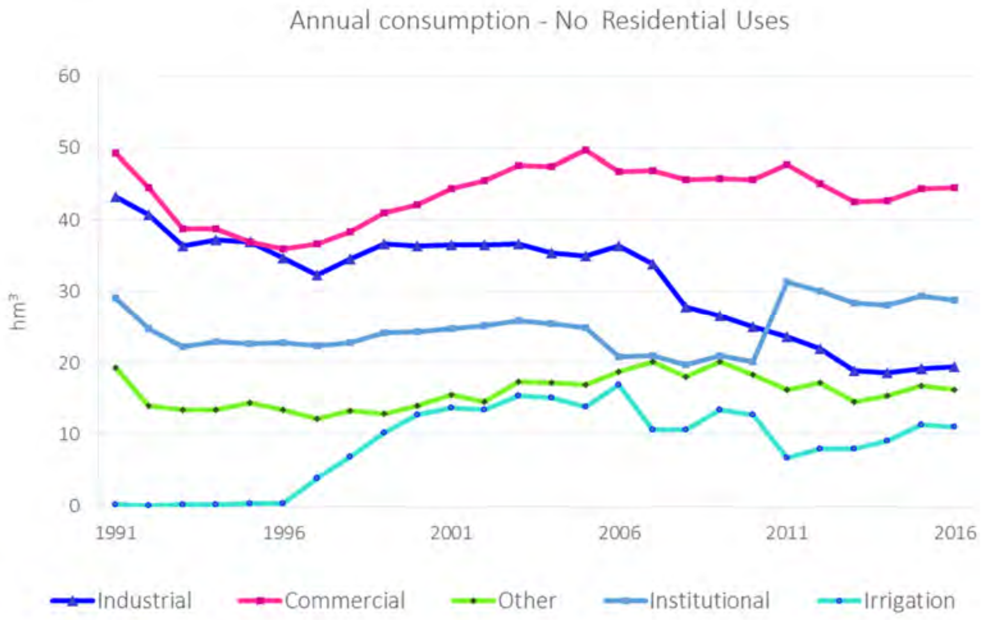


These variations are due, partly, to certain changes in the types of contracts, uses and rates. For example, the rate for **irrigation** was first applied in 1996, and, in 2011, most Madrid City Council contracts with this type of rate, became "**institutional",** which is reflected in the consumption pattern recorded in these types of uses, as shown in the graphs in Figure 24.

The drop in industrial uses is notorious from 2003, coinciding with the last drought episode recorded in the Comunidad de Madrid, and probably related to the optimisation of industrial processes, recycling in companies, and the use of reclaimed water. Institutional uses experienced a significant increase in 2011, coinciding with the replacement of irrigation contracts in the Madrid City Council and with a greater control of irrigation uses in public parks and gardens. Residential uses dropped significantly during the years of drought, 1992-1995, subsequently recovering and beginning the aforementioned pattern change in 2003.

FIGURE 24. EVOLUTION OF ANNUAL BILLED CONSUMPTION BY ECONOMIC SECTORS 1992-2016



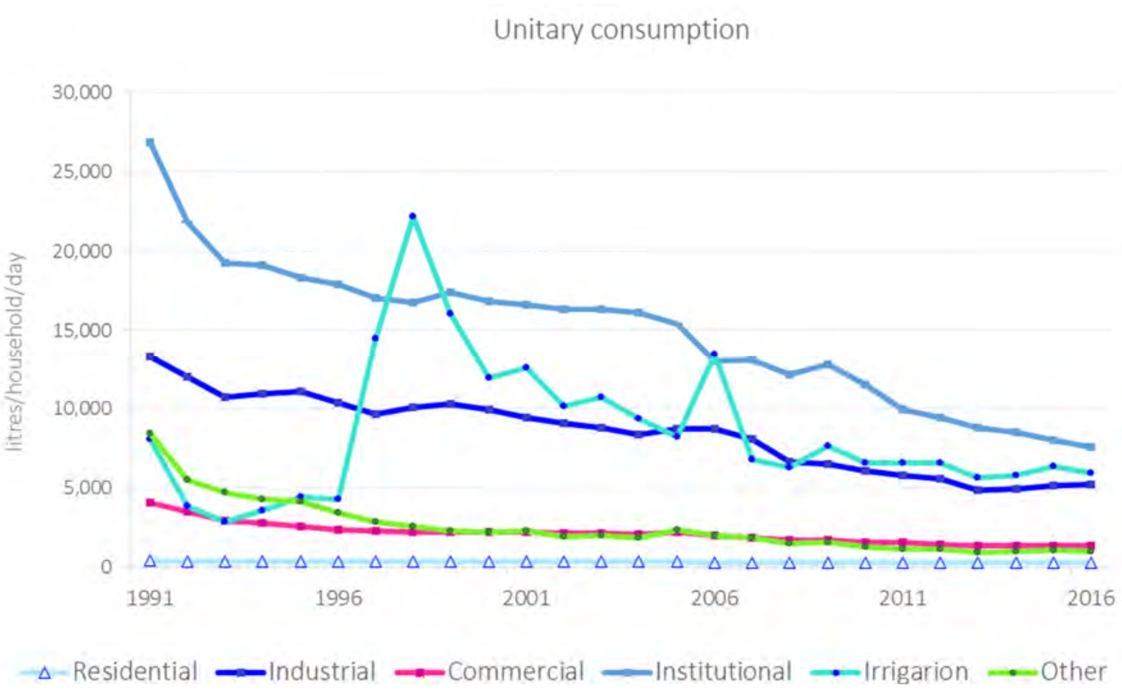


Unitary consumption

In order to observe these pattern changes, regardless of population growth, unitary consumption is used. In terms of uses in the different economic sectors, unitary consumption, instead of referring to the supplied population, normally refers to the number of properties, since it would not be possible to establish, for example, in industrial uses, the number of citizens supplied. Each supply contract is considered a property, except for residential uses, where each household is a property, even if there is a collective contract for the urbanisation or the block of flats.

Figure 25 illustrates the progress of these unitary consumptions since 1991.

FIGURE 25. EVOLUTION OF UNITARY CONSUMPTION BY TYPE OF USE 1992-2016

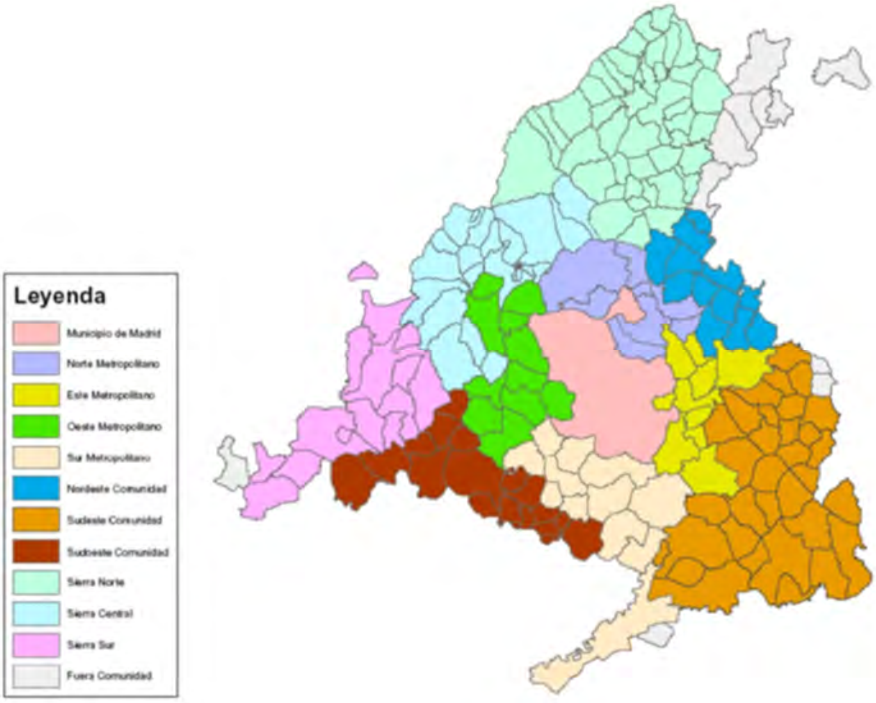


4.2.2. Consumption by geographical areas

The billing data for Canal de Isabel II customers, enable the detailed analysis of the consumption pattern by different geographical areas: municipalities, districts, neighbourhoods, population centers or by sectors of the distribution network.

An initial approach consisted in grouping together municipalities within the region in areas with relatively homogeneous geographic, economic and sociological characteristics. To do so, the zoning of the Instituto de Estadística (statistics institute) of the Comunidad de Madrid has been used, which corresponds with range 4 of the Eurostat NUTS Classification (Nomenclature of territorial units for statistics) and which is illustrated in Figure 26.

FIGURE 26. STATISTICAL ZONING OF THE COMUNIDAD DE MADRID



This classification divides the Comunidad de Madrid into 11 areas:

- Municipality of Madrid
- Metropolitan Ring: metropolitan north, east, south and west
- Areas of the Sierra: north, centre and south
- Non-metropolitan areas; northeast, southeast and southwest of the Comunidad de Madrid[1]

There is a notable dispersion in unitary consumption per household in the various geographical areas, a dispersion, which could be attributed to socioeconomic differences, characteristics of the household and climate conditions, among others.

Figure 27 illustrates these overall consumption figures per household over the last 25 years in the 11 statistical areas and the overall value of the Comunidad de Madrid.

In all the areas, there is a general drop since the initial years of this century. The drop is more noticeable in areas that had the highest values, particularly the Central Sierra region. The overall supply per household currently (2016) ranges between 342 litres per day in Sierra North and, 569 in Metropolitan West. The municipality of Madrid falls within the lowest values, with 355 litres per day, per household.

Considering the different uses, the greatest dispersion can be seen in **Industrial** uses, as illustrated in Figure 28, and is related to changes in industrial processes, or the geographic mobility of industries with greater levels of water consumption.

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1 Some publications by the Instituto de Estadística of the Comunidad de Madrid (Statistics Institute) include, those indicated here and those included in the Sierra as “non-metropolitan municipalities”.

In **Commercial** uses, the dispersion is not so noticeable, and also shows a descending trend throughout the entire period. In this case the highest values refer to the municipality of Madrid and are probably related to the importance of the catering sector in the capital (see Figure 29).

FIGURE 27. UNITARY CONSUMPTION BY HOUSEHOLD IN THE STATISTICAL AREAS 1991-2016

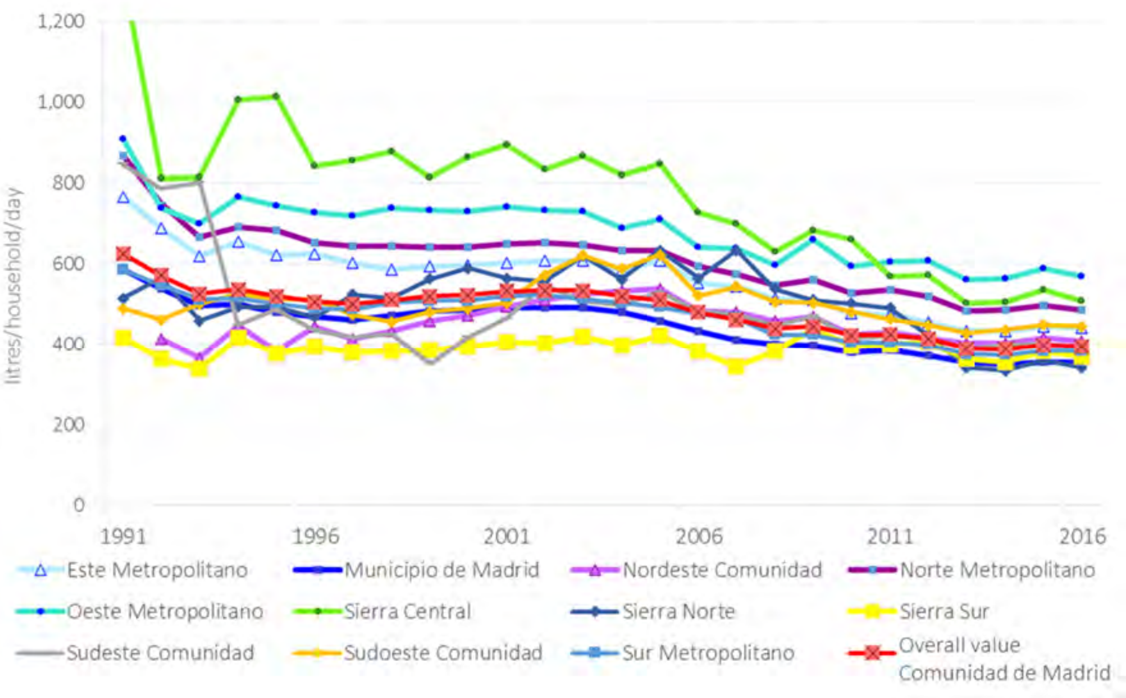


FIGURE 28. UNITARY CONSUMPTION IN INDUSTRIAL USES IN STATISTICAL AREAS 1991-2016

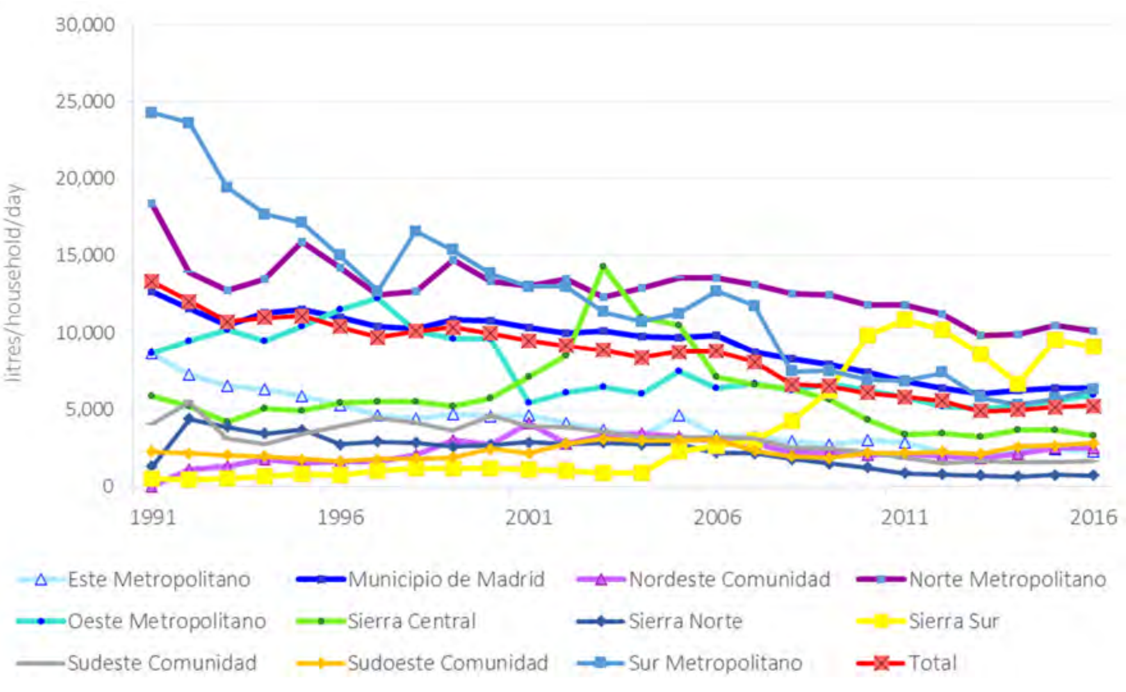
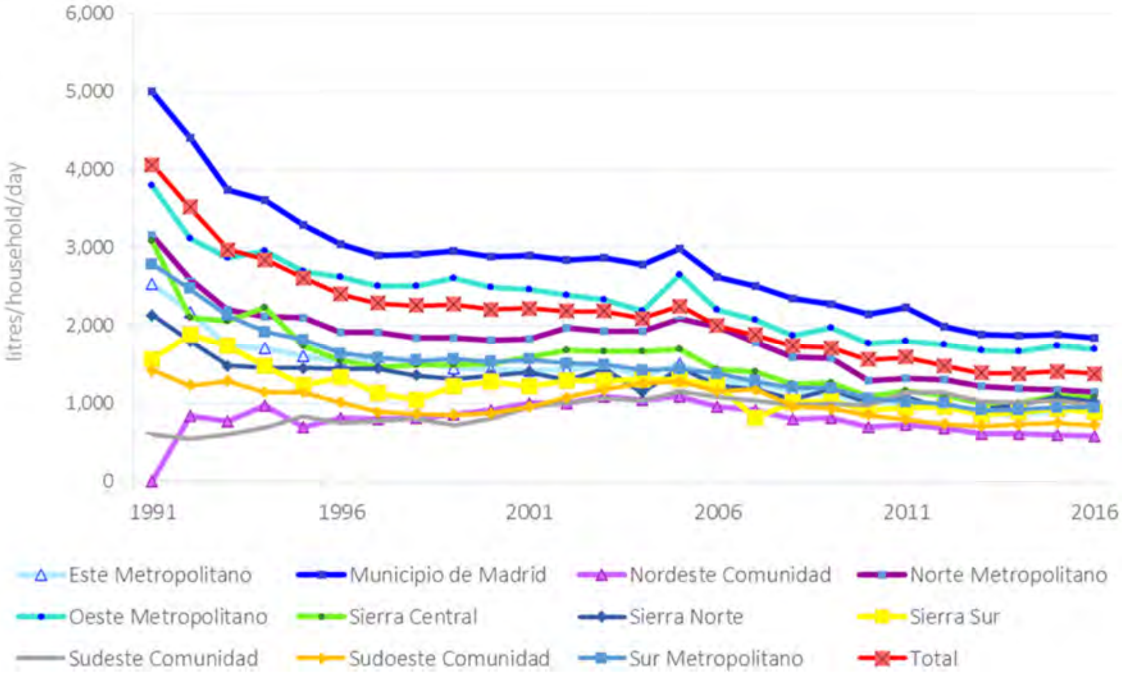
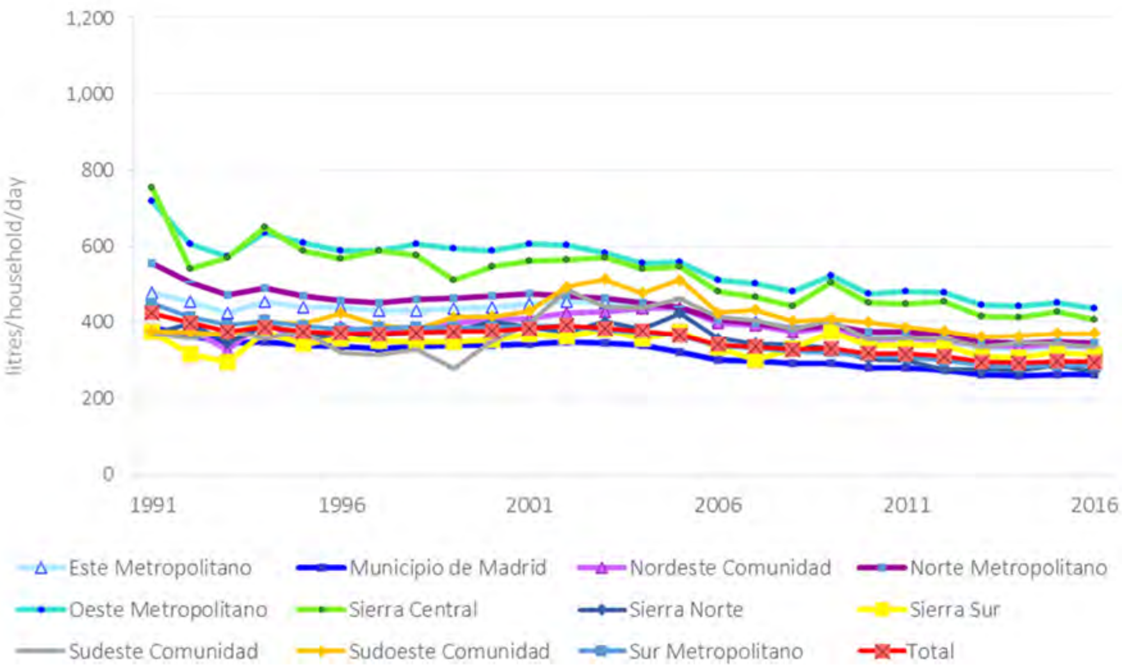


FIGURE 29. **UNITARY CONSUMPTION IN COMMERCIAL USES IN STATISTICAL AREAS 1991-2016**



The most stable behaviour can be seen in **Residential uses**, also following the general downward trend and with inter-annual fluctuations related to the weather. In 2016, supplies per household range between 263 litres per day in the municipality of Madrid and 437 litres per day in the metropolitan west. These differences will be analysed more closely in subsequent chapters, but, in principle, they are related to various factors: levels of income, type of household and degree of occupancy, or outdoor uses in the households (gardens or swimming pools), (see Figure 30).

FIGURE 30. **UNITARY CONSUMPTION IN RESIDENTIAL USES IN STATISTICAL AREAS 1991-2016**



Tables 4 and 5 show average values over the last ten years and those for 2016, for the different uses, in each of the statistical areas of the region. In practically all the values, the 2016 figures are lower than the average for the last ten years, which confirms the aforementioned downward consumption trend in all the uses and geographical areas.

TABLE 4. UNITARY CONSUMPTION (LITRES/HOUSEHOLD DAY) BY USES AND STATISTICAL AREAS. AVERAGE 2007-2016

	Household	*Industrial*	*Commercial*	*Institutional*	*Irrigation*	*Other*	*Total*
Metropolitan East	357.8	2,596.4	1,000.5	13,330.6	8,211.6	1,348.5	**471.8**
Municipality of Madrid	275.6	7,056.5	2,095.4	11,992.0	5,951.0	1,015.3	**375.9**
Northeast Comunidad de Madrid	356.8	2,239.5	699.3	2,525.3	1,842.2	612.4	**430.5**
Metropolitan North	367.0	11,314.2	1,357.2	7,073.2	5,194.3	1,099.2	**521.0**
Metropolitan West	472.1	5,849.4	1,797.4	8,483.7	6,319.4	2,011.1	**598.1**
Central Sierra	443.2	4,350.2	1,139.0	8,226.5	2,282.1	4,465.1	**585.8**
North Sierra	298.3	1,119.3	1,040.0	2,854.6	8,027.1	1,734.5	**447.2**
South Sierra	326.3	7,807.8	918.6	1,050.2	2,036.1	473.7	**383.9**
Southeast Comunidad de Madrid	362.9	2,014.3	1,029.0	2,071.7	1,673.7	416.7	**422.0**
Southwest Comunidad de Madrid	387.5	2,293.5	832.9	5,404.2	4,357.9	898.6	**469.6**
Metropolitan South	303.1	7,088.3	1,044.7	10,004.9	7,483.2	904.0	**403.3**
Comunidad de Madrid	**311.2**	**5,892.3**	**1,550.4**	**10,197.5**	**6,434.8**	**1,256.6**	**417.0**

TABLE 5. UNITARY CONSUMPTION (LITRES/HOUSEHOLD DAY) BY USES AND STATISTICAL AREAS, 2016

	Household	*Industrial*	*Commercial*	*Institutional*	*Irrigation*	*Other*	*Total*
Metropolitan East	333.3	2,284.1	924.5	7,990.0	7,551.7	1,041.3	439.5
Municipality of Madrid	262.7	6,351.4	1,835.6	8,641.8	6,000.5	879.1	355.1
Northeast Comunidad de Madrid	336.0	2,511.5	573.0	2,215.2	1,203.2	595.6	408.6
Metropolitan North	344.4	10,084.6	1,144.3	4,906.3	4,388.7	992.2	484.2
Metropolitan West	437.4	5,919.8	1,692.2	6,257.5	6,750.1	1,800.4	569.2
Central Sierra	407.7	3,274.3	1,075.0	4,908.4	1,759.7	2,925.0	506.2
North Sierra	269.7	734.7	1,018.3	2,384.4	2,573.0	346.4	341.9
South Sierra	311.7	9,063.6	880.4	1,015.1	1,771.2	455.2	369.9
Southeast Comunidad de Madrid	335.1	1,618.6	980.3	2,213.8	2,190.2	362.3	392.3
Southwest Comunidad de Madrid	370.4	2,798.2	722.0	3,597.3	3,823.8	764.1	443.6
Metropolitan South	285.7	6,280.4	944.5	8,014.4	7,504.1	801.4	383.8
Comunidad de Madrid	295.2	5,223.9	1,377.6	7,604.4	5,939.9	1,029.2	393.9

A measurement of the dispersion of the different uses in geographical areas, according to average annual figures over the last 10 years, is obtained by calculating standard deviation, and more specifically, by the coefficient of variation (CV), that is, the quotient between the standard deviation and the arithmetic mean, as shown in Table 6.

TABLE 6. ANNUAL SUPPLY STATISTICS 2007–2016, BY GEOGRAPHICAL AREAS (LITRES/HOUSEHOLD DAY)

	Average	*Standard deviation*	*Coefficient of variation*
Residential	359.15	61.54	0.171
Industrial	4,884.48	3,264.97	0.668
Commercial	1,177.64	424.71	0.361
Institutional	6,637.90	4,377.25	0.659
Irrigation	4,852.59	3,333.55	0.687
Other	1,361.73	1,264.19	0.928

The most disperse values refer to “**other”** uses, followed by **irrigation**, **industrial** and **institutional; residential** uses have a more stable behaviour, together with **commercial** uses.

If these figures are separated in terms of municipality, the dispersion is much greater, as reflected in the following Table 7.

TABLE 7. ANNUAL DISTRIBUTION 2007–2016 BY MUNICIPALITY (LITRES/HOUSEHOLD/DAY)

	Average	*Standard deviation*	*Coefficient of variation*
Residential	316.78	167.13	0.528
Industrial	5,229.37	19,502.05	3.729
Commercial	1,054.83	2,058.73	1.952
Institutional	4,226.75	9,483.85	2.244
Irrigation	3,706.50	14,795.29	3.992
Other	919.99	4,504.04	4.896

Municipalities have been eliminated from this statistic when, as Canal de Isabel II has not been commissioned to carry out the commercial management of the service, the number of households supplied is not available, and normally, consumption is grouped into a single contract, under the category of ***Institutional***, or ***Other uses***.

Although residential consumption shows the greatest homogeneity, the values reflect a wide range of variation, between the 82.9 litres per household and day in La Hiruela, to the 738.7 litres per household and day, in Nuevo Baztán in 2016. The causes of this dispersion will be analysed in subsequent chapters.

4.2.3. Unaccounted for water

The difference between the amount of water diverted from reservoirs and catchments, and that finally recorded by customers' meters, is considered unaccounted for or unmetered water, and it is a volume of water which, apart from losing a natural resource, results in production costs and does not bring in economic income for the supply company. Therefore, reducing this volume of unmetered water is included in the objectives of all the supply system managers.

Unaccounted for water, includes so-called real losses, that is, water that is lost through hidden leaks or breaks on the pipelines or other system elements, and uncontrolled uses (authorised or not), and measurement errors in users' meters or the water remote measurement system.

An indicator commonly used to refer to unaccounted for water, is the ratio in percentage terms of the total water produced. However, for various reasons, this indicator is not considered very appropriate.

International agencies such as the *International Water Association (IWA)* are currently recommending other indicators that consider the specific features of the system. The volume of unmetered water per unit of time and length of network, number of service connections or number of households supplied, is more appropriate.

IWA has developed a methodology for assessing the various components of unaccounted for water, distinguishing between:

- Unauthorised non-billed uses.
- Apparent losses (unauthorised uses or measurement errors).
- Real losses (in pipelines, tanks or other elements of the supply system).

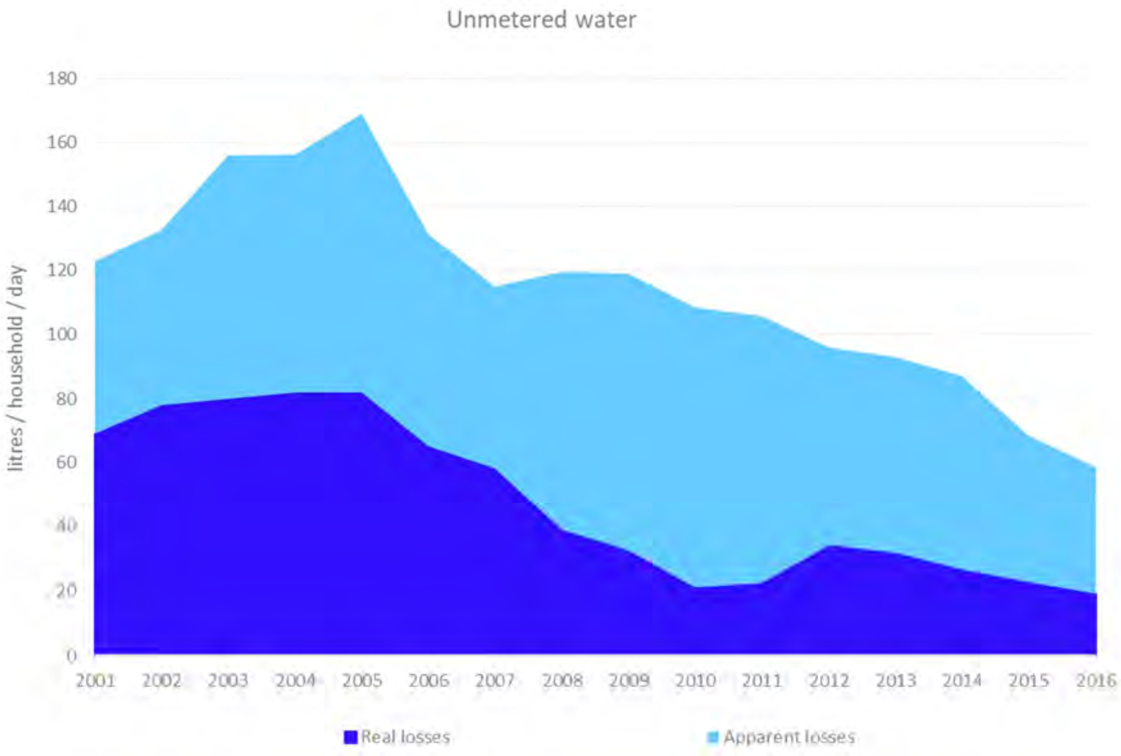
The calculation of each of the components has a certain degree of uncertainty and must very often be estimated. For example, given its actual characteristics, there is not a precise method for assessing the water consumed in illegal, unauthorised or fraudulent uses. The same applies to the water lost through hidden leaks.

The sectorisation of the supply networks enables a balance of unmetered water to be carried out for each of the network sectors, identifying the least efficient ones and directing initiatives and investments aimed at reducing losses in a more efficient manner.

The purpose of this work does not include delving into the management of unaccounted for water. For information purposes, Figure 31 shows the evolution in recent years of the real and apparent losses in the supply system of Canal de Isabel II.

The total volume of unaccounted for water experienced a significant drop during the last episode of drought in 2005–2006, and has continued that downward trend since then, as a result of the application of the Company Plan for Reducing Unmetered Water. Today the total, real and apparent losses are lower than 60 litres per household and day (170 litres/household and day in 2005) and represent less than 14% of the total amount of diverted water.

FIGURE 31. EVOLUTION OF UNMETERED WATER IN CANAL DE ISABEL II, PERIOD 2001-2016



4.2.4. Outdoor uses

Outdoor water uses represent an important chapter in terms of demand in an urban water supply system. It includes the irrigation of green areas in parks and gardens, both public and private; recreational and sports areas, swimming pools, ponds and ornamental fountains. Hosing down and cleaning public roads with drinking water was banned in the Comunidad de Madrid during the drought of 2005–2006. Although the ban is no longer in force, this use has been practically abandoned in all the municipalities in the region and has been replaced by reclaimed water or other forms of cleaning.

Furthermore, according to the Canal de Isabel II supply standards (Normas de Abastecimiento de Canal de Isabel II), for parks with a gross surface area over 1.5 hectares, irrigation water must be obtained from alternative sources other than the network of water for human consumption entrusted to Canal de Isabel II. This category includes most golf courses, large consumers of irrigation water, which must use reclaimed water or water from own supply sources (wells).

Outdoor water uses, apart from its quantitative importance, since it constitutes between 20% and 30% of the total supply, has specific characteristics and therefore requires a differentiated analysis. Some of these are outlined below:

- They have a particularly high seasonal nature, and, to a large extent, they are responsible for peak flow rates recorded at the beginning of summer. They are highly conditioned by the weather and the use thereof increases precisely during dry and hot periods, coinciding with situations of resource scarcity.

- They constitute an indeterminate component of apparent losses of unaccounted for water, since not all municipal uses for irrigating parks and gardens are completely controlled. In private uses, there may also me fraudulent or unauthorised uses.

- They offer a significant potential for improving efficiency, improving irrigation practices or optimising the use of swimming pools: emptying and filling, evaporation.

- A considerable portion of these uses could be covered with lower quality water (reclaimed, non-drinking water), therefore, information regarding the amount and temporal and geographic distribution thereof, is essential in order to effectively implement a plan for the use of reclaimed water.

- In general terms, these uses are considered sumptuary or non-essential, therefore, during periods of water scarcity, they are the first to suffer restrictions or limitations of use.

- In relation to sewerage and public drainage infrastructures, the water used in irrigation does not entail a return flow rate, therefore this needs to be taken into account for the design and sizing of these infrastructures.

Canal de Isabel II has a specific tariff for ***irrigation*** which, in general terms, is only applied to the public irrigation of parks and gardens by the municipal services. However, not all outdoor municipal uses are covered by these types of contracts. Furthermore, since 2011 the most contracts with this type of tariff went on to be classified as "***Institutional***" in the city council of Madrid, therefore they cannot be distinguished from other municipal uses, such as schools, offices, etc.

Private gardens and swimming pools are normally billed together with other residential uses, mainly in single-family homes, although also in urbanisations and neighbourhood communities with communal areas. There are also industrial parks and commercial areas with private gardens which use a significant amount of irrigation water. Therefore, the commercial information system for customers does not provide complete and differentiated information regarding these types of uses. In addition, given the actual characteristics, being located outdoors, make them observable, for example, with remote sensing techniques.

Canal de Isabel II has an inventory of public and private swimming pools and green areas for the entire Comunidad de Madrid, obtained with photogrammetric flights conducted in 1999, 2003 and 2006, at a scale of 1:2000. This inventory includes all the green areas identified, with discrimination of the type of crop; meadow, bushes or forest, and swimming pools, associated with the plots in the urban cadastral registry (figures 32 and 33). Based on this information, an estimate can be obtained of water demand for outdoor uses, at an urban plot scale (Cuaderno 11 de I+D+I, *Técnicas de teledetección y sistemas de información geográfica para la evaluación de la demanda de agua para usos de exterior en la Comunidad de Madrid* - R&D&I Booklet 11, *Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in Comunidad de Madrid).*

FIGURE 32. SATELLITE ORTHOIMAGE URBAN RESIDENTIAL AREAS

FIGURE 33. CLASSIFICATION AREAS WITH OUTDOOR USES

Subsequently, using medium resolution satellite images (SPOT 5, 10/2.5 metres per pixel), in 2008, 2009 and 2010, the information was updated to a lower scale (1: 20,000) for green areas classified by urban and municipal areas, and by the typology thereof (meadow or trees) and the degree of vegetation activity based on the vegetation index (NDVI). This inventory has been updated more recently, using high-resolution satellite images, taken from the Pleiades satellite in August 2014. These types of images available today with a resolution of around 0.5 metres per pixel, enable even small private plots with gardens or swimming pools to be identified. In a few weeks, images can be obtained covering the entire Comunidad de Madrid, which means that all the information obtained is synchronic, obtained on the same dates.

The process of the different spectral bands (R, G, B, NIR and PAN) has been used to classify the soil and to identify different types of green areas through vegetation indexes (NDVI) and water surfaces.

Water demand in green areas is calculated by the water balance, considering the potential evapotranspiration of each type of crop and the meteorological data recorded in the different AEMET and Canal de Isabel II weather stations across the Comunidad de Madrid.

There are various methods for calculating reference evapotranspiration, with the most popular being the Thornthwaite, Papadakis, Blaney-Criddle FAO, Hargreaves, Penman-Montieth methods, which can provide quite different results. In any event, the calculated demand is what is theoretically necessary for plants to maintain their vegetation vigour indicated by the vegetation indexes. As the images are captured in summer, the green areas identified have probably received at least the same amounts of artificial water as those theoretically calculated.

The information using remote sensing, is associated with the urban cadastral registry, obtaining the theoretic water demand for outdoor uses for each cadastral plot.

The contrast of the calculated water demand in each plot with that recorded by the meters for billing, may serve, in the event of significant discrepancies, to identify inconsistencies in the information and to identify potential irregular or uncontrolled uses of the water supplied by Canal de Isabel II.

In total, 28,357 hectares of urban green areas have been identified in the Comunidad de Madrid, with a calculated water demand for 2014 of 134.67 hm^3, which represents 27% of the total water diverted from reservoirs and catchments this year, although, of course, not all the water used for irrigation comes from drinking water sources, as indicated previously.

In terms of swimming pools, 126,000 were identified, with an estimated volume of 8.37 hm^3 (based on an average depth of 1.6 m).

The most relevant details in terms of outdoor water uses in the Comunidad de Madrid and the progress thereof since the first inventory in 1999, are illustrated below (see figures 34 to 35 and tables 8 to 9).

FIGURE 34. EVOLUTION OF SURFACE AREA OF GREEN AREAS

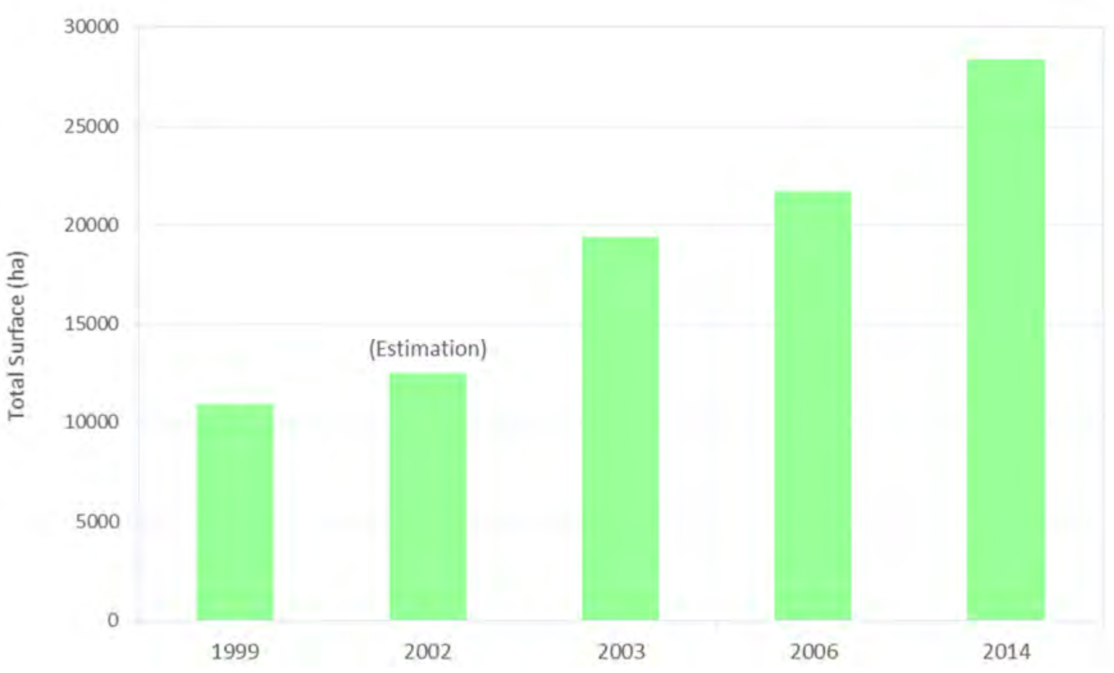


FIGURE 35. EVOLUTION OF SURFACE AREA OF SWIMMING POOLS

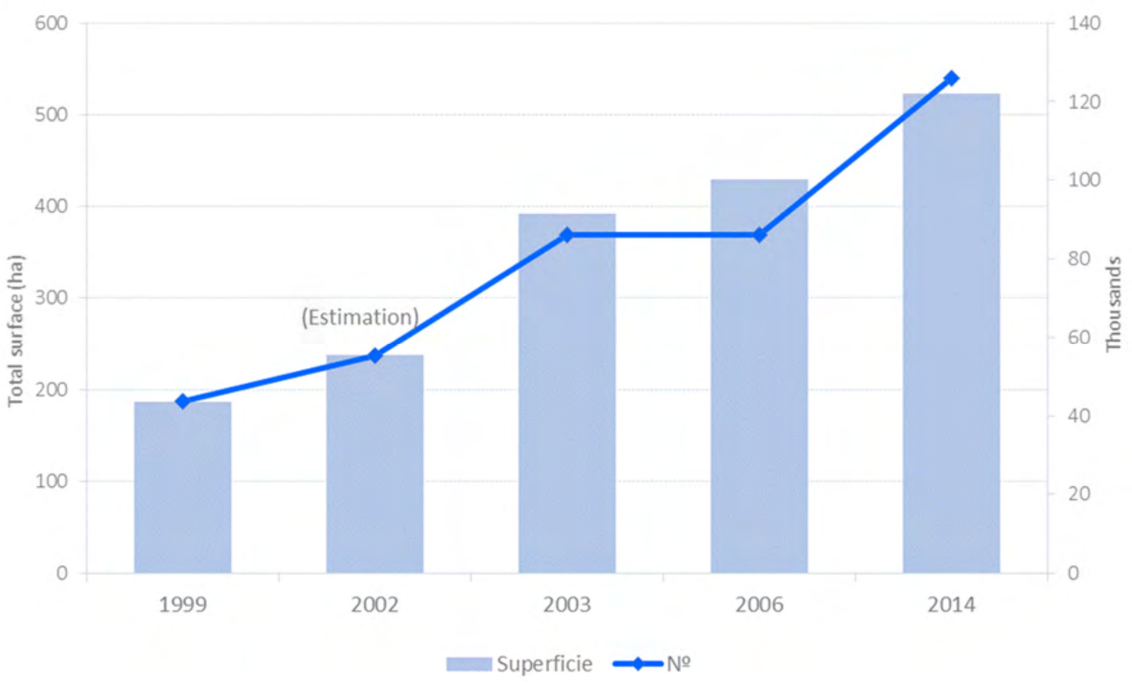


TABLE 8. DEMAND IN GREEN AREAS 2006-2014

Year	*Size (ha)*	*Annual demand (hm³)*
2006	21,697	126.76
2014	23,009	134.67

TABLE 9. ANNUAL DEMAND FOR SWIMMING POOLS

	2006 (hm³)	*2014 (hm³)*
Filling	6.86	8.37
Evaporation	3.97	4.84
Ancillary services (Showers)	5.15	6.27
Total	15.98	19.48

5. Residential Consumption

This section includes a more in-depth analysis of the residential consumption recorded in recent years in the Comunidad de Madrid. As outlined in the preceding points, residential consumption in the Comunidad de Madrid, represents around 70% of the total amount supplied to users. Residential consumption is the most homogeneous, in terms of its geographic and temporal distribution, despite which, there are significant differences in terms of unitary supplies in the various municipalities within the region.

The various factors affecting these differences will be analysed in this chapter, together with seasonal, weekly or daily patterns, and long-term trends that affect the temporal behaviour of water demand for residential uses.

The main source of information are customers' bills on the Canal de Isabel II Commercial Management System (GRECO). There is also a representative sample of around 300 households, with long-term detailed monitoring of their consumption over a period of almost 10 years, which provides much more in-depth information about consumption patterns, and of end uses of water in the residential sector in the Comunidad de Madrid.

5.1. BILLED RESIDENTIAL CONSUMPTION

The information presented in this section was obtained from the Canal de Isabel II Commercial Information System, where all customers' readings are recorded every two months, for billing purposes.

All households constructed from 1993 onwards, within the scope of the Canal de Isabel II Supply System, are equipped with individual water meters for billing purposes. Previously, communities of owners would normally only have one meter for the entire building, which is still the case in older households. In any event, the information from billing records includes consumption data per household (individual, or included in the Community of Owners), and the exact location of the household is known, which can therefore be related to entities, population centers, sectors or areas, for which statistical information is available regarding socioeconomic parameters, which can be analysed as explanatory variables influencing on water consumption.

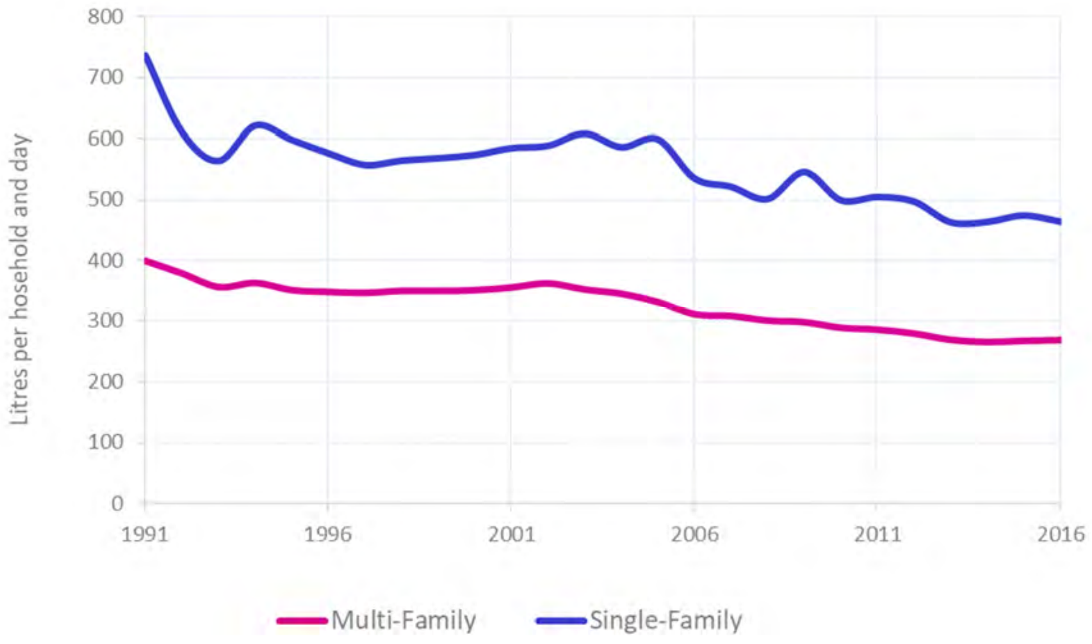
This chapter will analyse the records of bills issued to customers over the last 25 years, which enable long-term trends to be observed in residential consumption recorded during that period. Particular attention shall be given to the data for the 2007-2016 period, which can be considered relatively stable, after the last severe drought episode recorded in the Comunidad de Madrid (2005–2006), and which appears to be the most representative of the current reality and illustrative for possible future patterns. Special attention will also be given to the last available figures for 2016.

5.1.1. Single-family and multi-family households

The analysis of the variables affecting residential water consumption firstly reflects the type of household. There is a clear difference between single-family homes (detached houses, freestanding houses, semi-detached or attached houses), and multi-family homes (blocks of apartments).

The difference between the two types of households is mainly that single-family homes generally have more outdoor uses (gardens, swimming pools), therefore consumption levels are higher and consumption patterns are notably different. Figure 36 illustrates the annual values since 1991 for the entire supply system of Canal de Isabel II.

FIGURE 36. EVOLUTION OF UNITARY CONSUMPTION PER HOUSEHOLD (MULTI-FAMILY AND SINGLE - FAMILY) 1991-2016



Apart from the unitary consumption values being notably different for the two types of households, there is a change in pattern, which occurred before in multi-family homes (until 2003, the number had remained more or less stable), while in single-family homes the drop began in 2006, and, in the latter, there were significant fluctuations from one year to another (2008–2009–2010), possibly related to weather factors, as analysed later.

Despite having a considerably lower unitary consumption, multi-family homes have a considerably larger effect on the overall billed consumption, representing 55% compared with single-family homes with 15%, since their numbers are much higher. In 2016, only 14% of the households supplied by Canal de Isabel II were single-family homes. Figure 37 reflects the significant increase in single-family homes at the end of the last century, since it stood at 7.4% in 1991.

After this initial classification of single-family and multi-family homes, there is still a clear dispersion in unitary consumption data. Taking the figures from all the households recorded during 2016, the frequency distribution can be obtained, which is illustrated in the following graphs.

Distribution in multi-family homes is relatively normal. For the 2016 data (2,426,000 households) a normal distribution with an average of 227.93 litres/household per day, and a standard deviation of 92.71 has been adjusted (Figure 38).

At its tails, 3.3% of households have a consumption below 25 litres per day, and 2.3% have a consumption exceeding 5,000 litres per day.

FIGURE 37. SINGLE-FAMILY HOMES RATIO 1991-2016

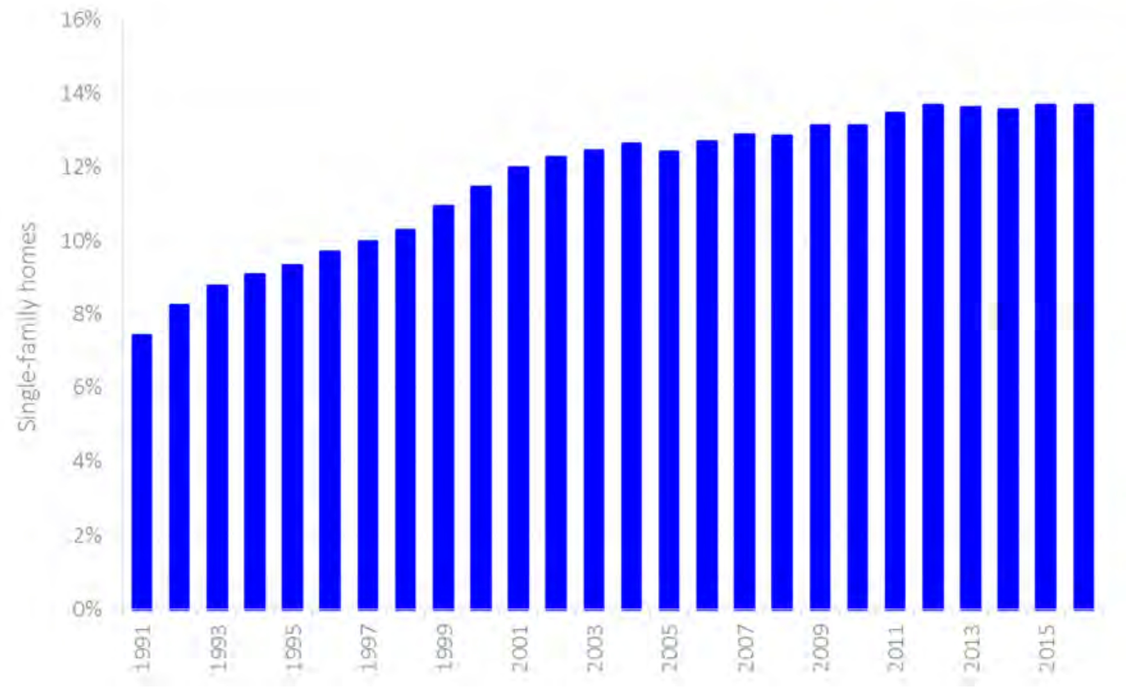
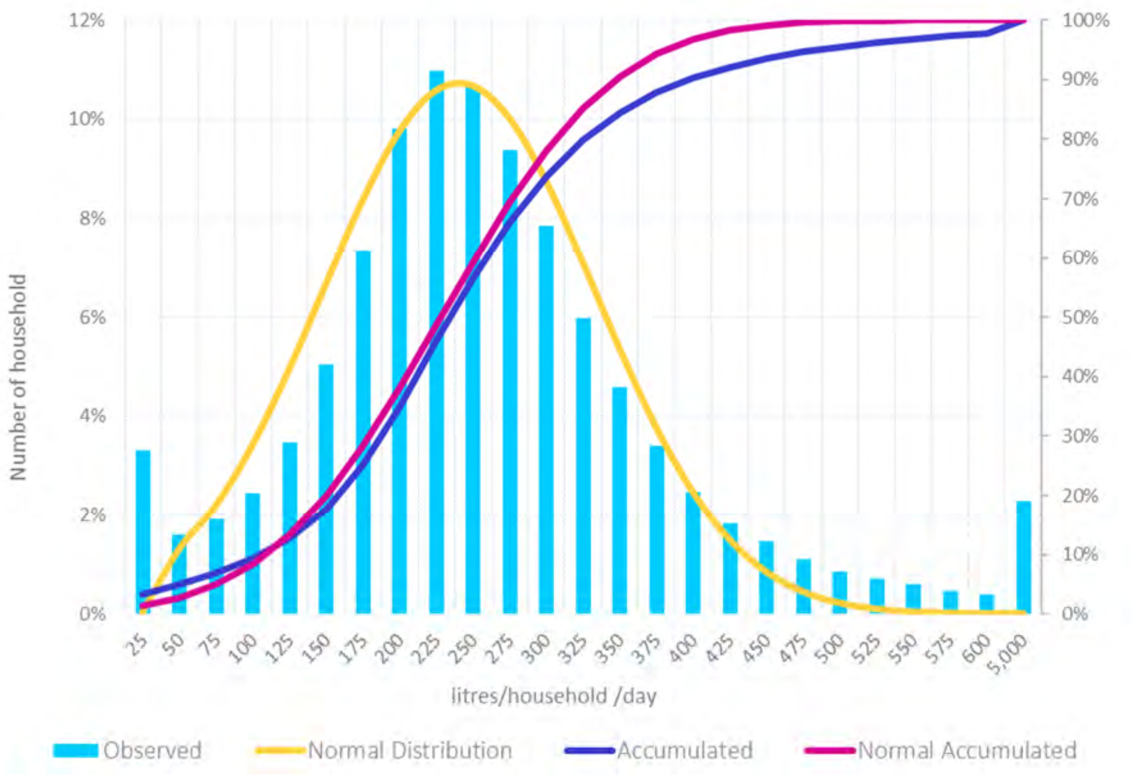
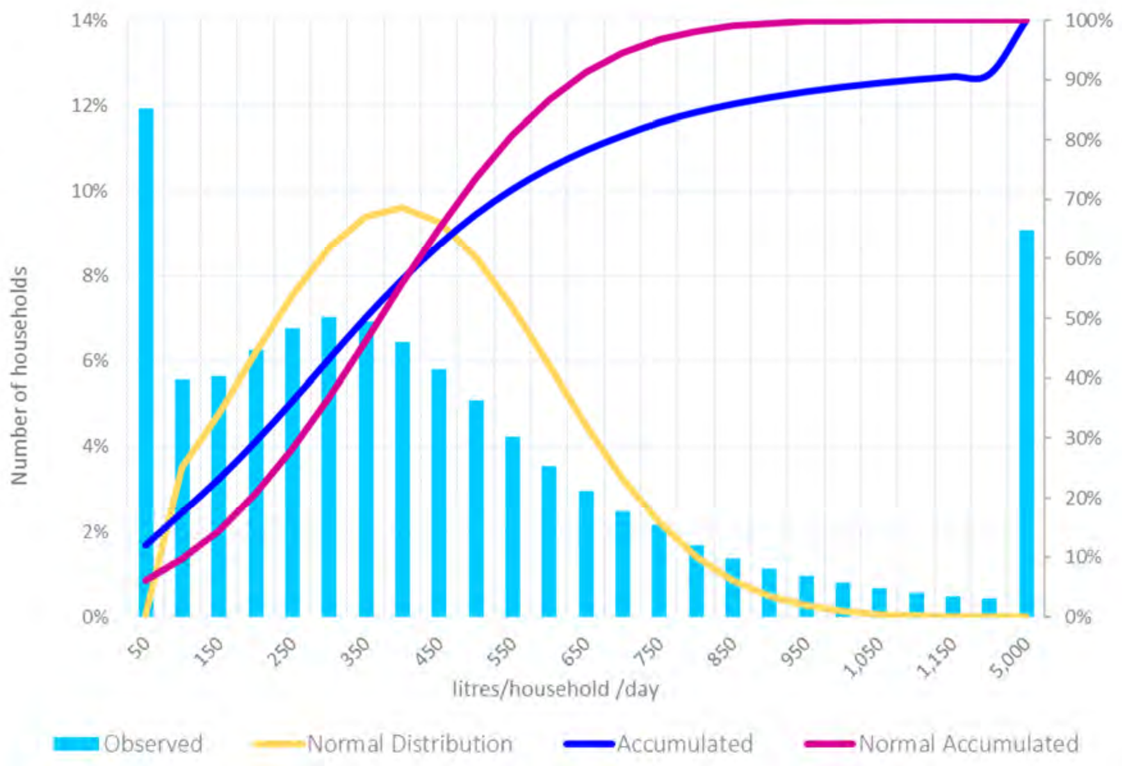


FIGURE 38. FREQUENCY DISTRIBUTION OF UNITARY CONSUMPTION IN MULTI-FAMILY HOMES, 2016



In the case of single-family homes, the frequency distribution is quite different to the normal. Apart from being a lower sample (412,273 households), there is a significant number of *outliers* in both tails. 12% of the households have a consumption below 50 litres per day, which is probably related to being second residences. At the other side, 9.1% of the households recorded an average consumption exceeding 5,000 litres per day in 2016 (Figure 39).

FIGURE 39. FREQUENCY DISTRIBUTION OF UNITARY CONSUMPTION IN SINGLE-FAMILY PRIMARY HOMES, 2016



The adjusted normal distribution has an average of 369.36 litres per household and day, and a standard deviation of 207.0, according to the graph in Figure 39.

If so-called secondary residences are eliminated (those with a consumption below 5 m^3 during January-February), and those with unusual consumptions (exceeding 10,000 m^3 per year), the distribution is closer to the normal, although with a clear skew to the left (see Figure 40).

The difference between the two types of households, single-family homes and multi-family homes, is clear, apart from in the difference in averages, as indicated previously, also in distribution, as illustrated in the graph in Figure 41.

FIGURE 40. FREQUENCY DISTRIBUTION OF UNITARY CONSUMPTION IN SINGLE-FAMILY PRIMARY HOMES 2016

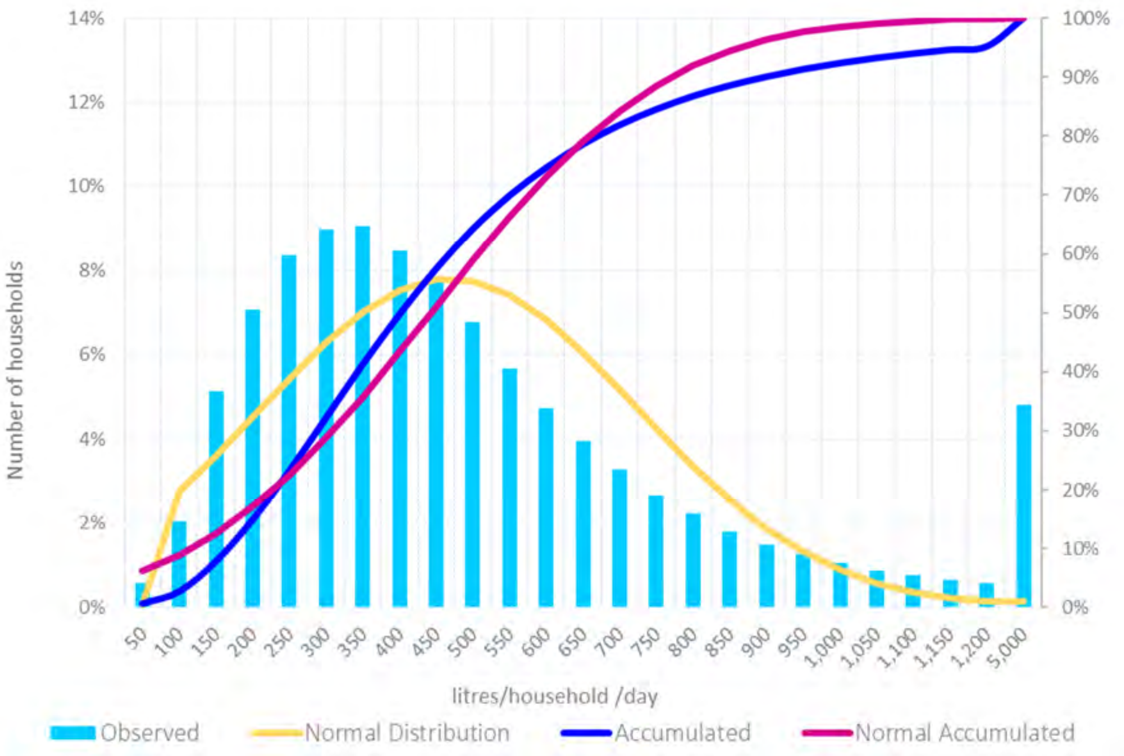
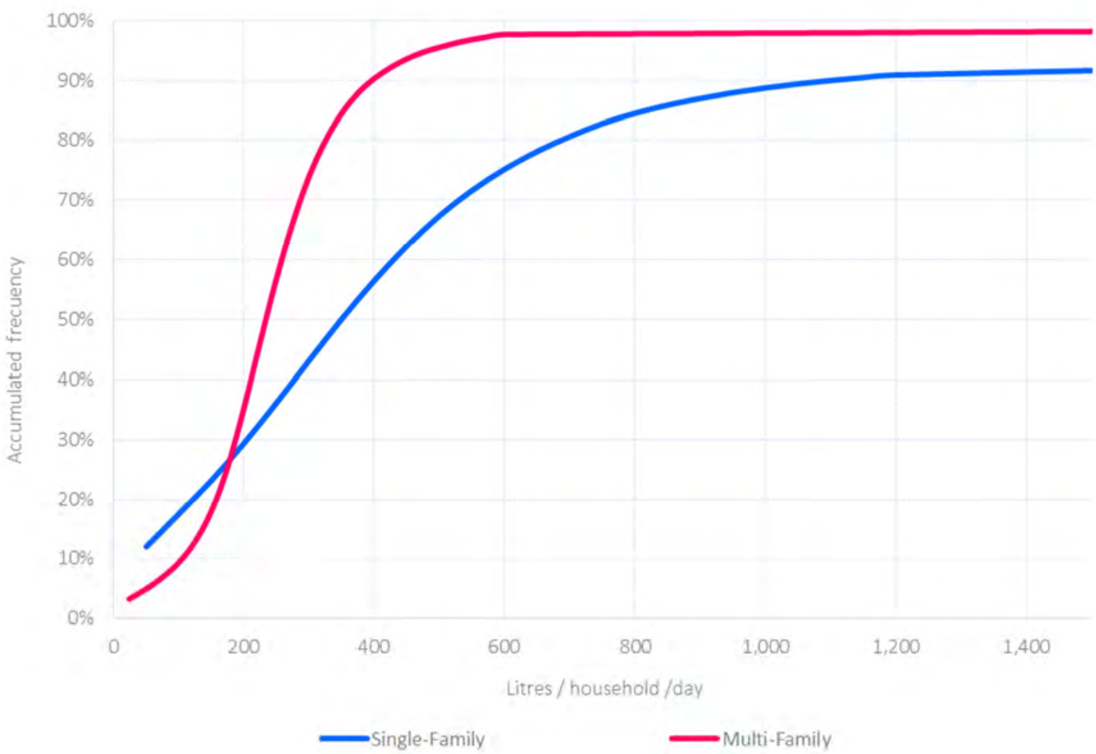


FIGURE 41. FREQUENCY DISTRIBUTION OF UNITARY CONSUMPTION IN SINGLE-FAMILY AND MULTI-FAMILY HOMES, 2016



5.1.2. Geographic distribution by municipalities and statistical areas

Taking the average unitary consumption values per municipalities, there is still a considerable variance, like regarding individual values, as shown in Figure 42 for 2016, and in Figure 43 for average values for the 2007–2016 period.

FIGURE 42. **FREQUENCY DISTRIBUTION OF HOUSEHOLD UNITARY CONSUMPTION BY MUNICIPALITIES YEAR 2016**

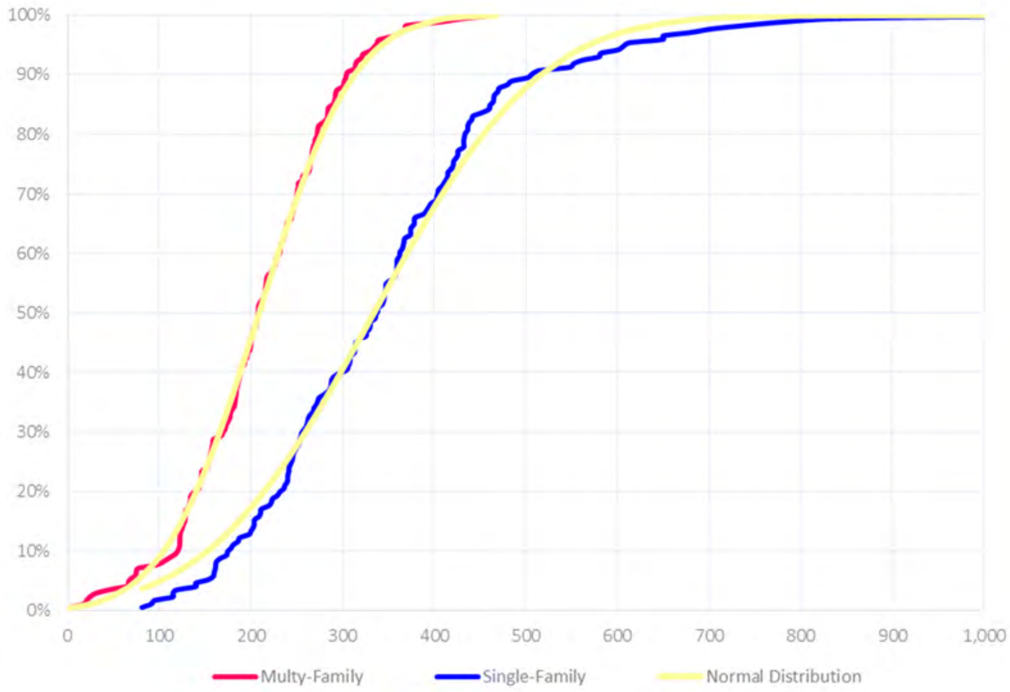
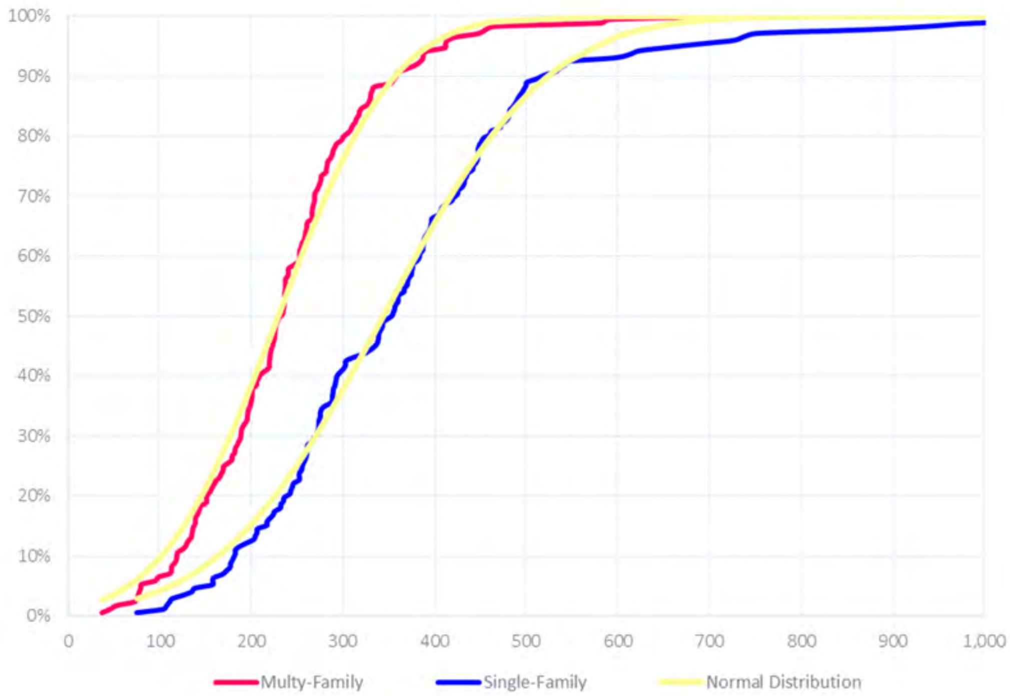


FIGURE 43. **FREQUENCY DISTRIBUTION OF HOUSEHOLD UNITARY CONSUMPTION BY MUNICIPALITIES PERIOD 2007-2016**



During this period, the values range between 37.5 litres per household and per day in the municipality of Canencia, and 757.7 litres per household and per day in Guadarrama, for multi-family homes. The municipality of Madrid, which can be considered the modal value, had an average consumption of 260.7 litres per household and day.

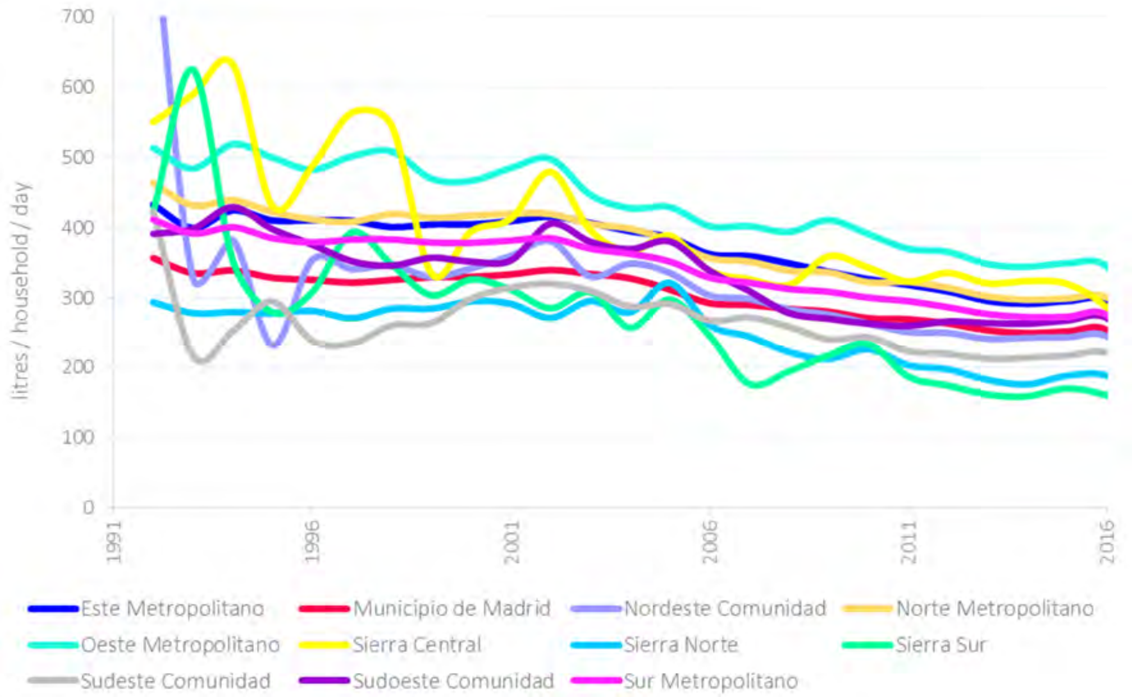
In single-family homes, the minimum value refers to La Hiruela, with 75.4 litres per household and day, and the maximum to Alcobendas with 1,264.6. In the municipality of Madrid, the unitary consumption for single-family homes was 613.4 litres per day. Table 10 shows the reference values for these towns.

TABLE 10. DAILY UNITARY CONSUMPTION IN SINGLE-FAMILY AND MULTI-FAMILY HOMES 2007–2016

Values	*Multi-family homes*		*Single-family homes*	
	Town	*litres-household day*	*Town*	*litres-household day*
Minimum	Canencia	37.5	Hiruela (la)	75.4
Mode	Madrid	260.7	Madrid	613.4
Maximum	Guadarrama	757.7	Alcobendas	1,264.6

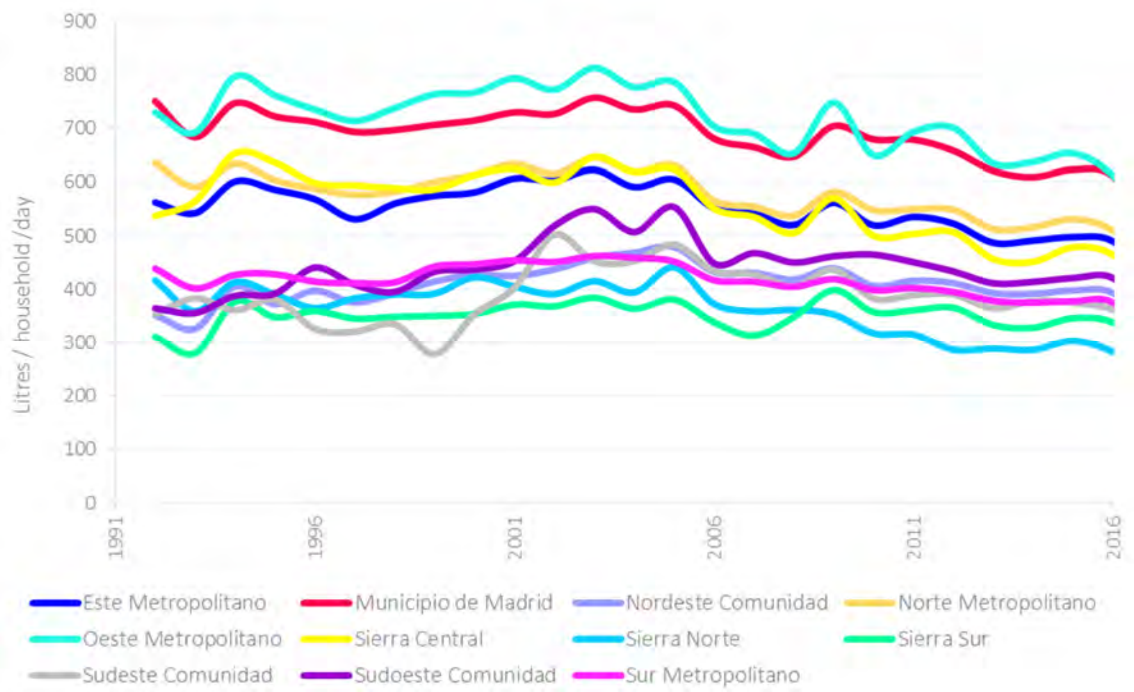
Unitary consumption for multi-family homes and single-family homes, grouped into the eleven statistical areas of the Comunidad de Madrid, offer the results shown in figures 44 and 45, and in tables 11 and 12.

FIGURE 44. UNITARY CONSUMPTION IN MULTI-FAMILY HOMES, PER AREA, 1991-2016



For multi-family homes, the highest values are for the Metropolitan West and the lowest are for the North Sierra area, with an intermediate point referring to the municipality of Madrid.

FIGURE 45. **UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES, BY AREAS, 1991-2016**



In terms of single-family homes, the variation range is greater than in multi-family homes and the highest values are also for the Metropolitan West, together with the municipality of Madrid. At the lower end is the North Sierra area. The downward trend in unitary supplies is present in all the cases, as mentioned, since 2003, approximately.

TABLE 11. **HOUSEHOLD UNITARY CONSUMPTION PER STATISTICAL AREAS, 2007–2016 PERIOD**

Town	*Multi-family homes Litres per household and day*	*Single-family homes Litres per household and day*
Metropolitan East	317.9	516.5
Municipality of Madrid	260.7	613.4
Northeast Comunidad de Madrid	259.6	409.7
Metropolitan North	318.3	539.4
Metropolitan West	371.7	666.3
Central Sierra	325.7	496.8
North Sierra	271.7	303.4
South Sierra	222.9	342.2
Southeast Comunidad de Madrid	307.9	373.1
Southwest Comunidad de Madrid	272.2	439.8
Metropolitan South	292.3	394.1
Comunidad de Madrid	282.7	493.2

TABLE 12. HOUSEHOLD UNITARY CONSUMPTION PER STATISTICAL AREAS, YEAR 2016

Town	*Multi-family homes Litres per household and day*	*Single-family homes Litres per household and day*
Metropolitan East	295.8	489.5
Municipality of Madrid	254.4	610.7
Northeast Comunidad de Madrid	245.2	392.8
Metropolitan North	300.5	509.7
Metropolitan West	344.3	611.1
Central Sierra	286.4	463.6
North Sierra	211.2	279.3
South Sierra	252.8	321.5
Southeast Comunidad de Madrid	311.5	339.7
Southwest Comunidad de Madrid	276.0	419.1
Metropolitan South	275.2	375.2
Comunidad de Madrid	268.1	463.9

5.1.3. Seasonality of residential consumption

Residential water consumption in the Comunidad de Madrid has a significant seasonal component related, partly, to climate and meteorological variables, and also to population habits, particularly during holiday periods. Figure 46 shows the monthly figures for multi-family homes during the 2007 – 2016 period.

Consumption levels have gradually dropped since 2007, but the profile remains the same. Consumption is at its highest during June and drops in July and particularly during August, which is the holiday month par excellence, in which there is a reduction of around 10% compared with June. The municipality of Madrid has a significant effect on this pattern, where around 50% of the population of the Comunidad de Madrid live. In the Metropolitan West area, and in the area of the Sierra, where there is a significant number of second residences, the patterns are different, with the highest consumption being recorded during July and August. Figure 47 illustrates the monthly figures for 2016, for the eleven statistical areas in the Region.

On the other hand, in single-family homes, the highest consumption takes place during the summer months (June, July and August), in which consumption doubles with regard to winter, following a pattern clearly related to outdoor uses, as reflected in figures 48 and 49.

In relation to this seasonal behaviour, the design flows for the planning and infrastructure projects, are calculated according to the records for the June-July two-month period, in which consumption is at its highest. It should be pointed out that, given the two-monthly nature of customers' meter readings, these figures do not provide exact information regarding real peak consumption, however, in any event, these peaks generally take place during these months. In order to obtain daily maximum consumption figures and the hourly profiles, the measurements recorded by the Remote-control system for supplying the water supply network sectors are used.

FIGURE 46. SEASONALITY OF WATER SUPPLY IN MULTI-FAMILY HOMES 2007-2016 PERIOD

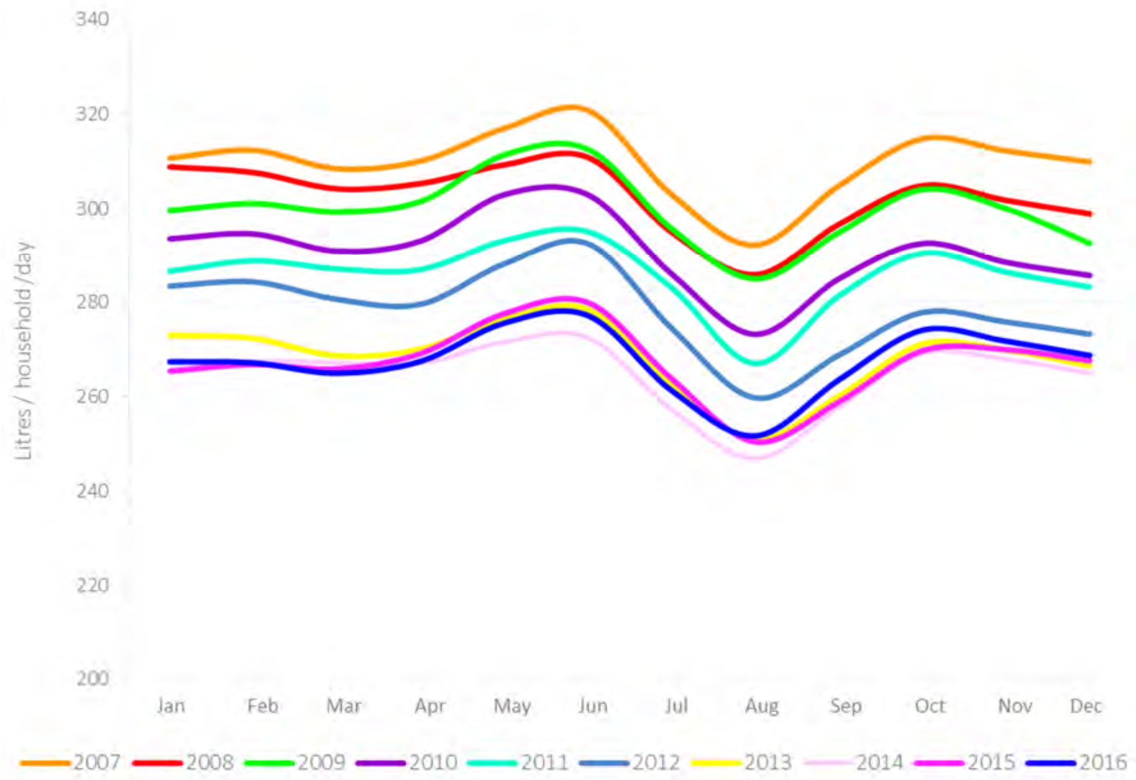


FIGURE 47. SEASONALITY OF UNITARY CONSUMPTION IN MULTI-FAMILY HOMES, BY AREAS, IN 2016

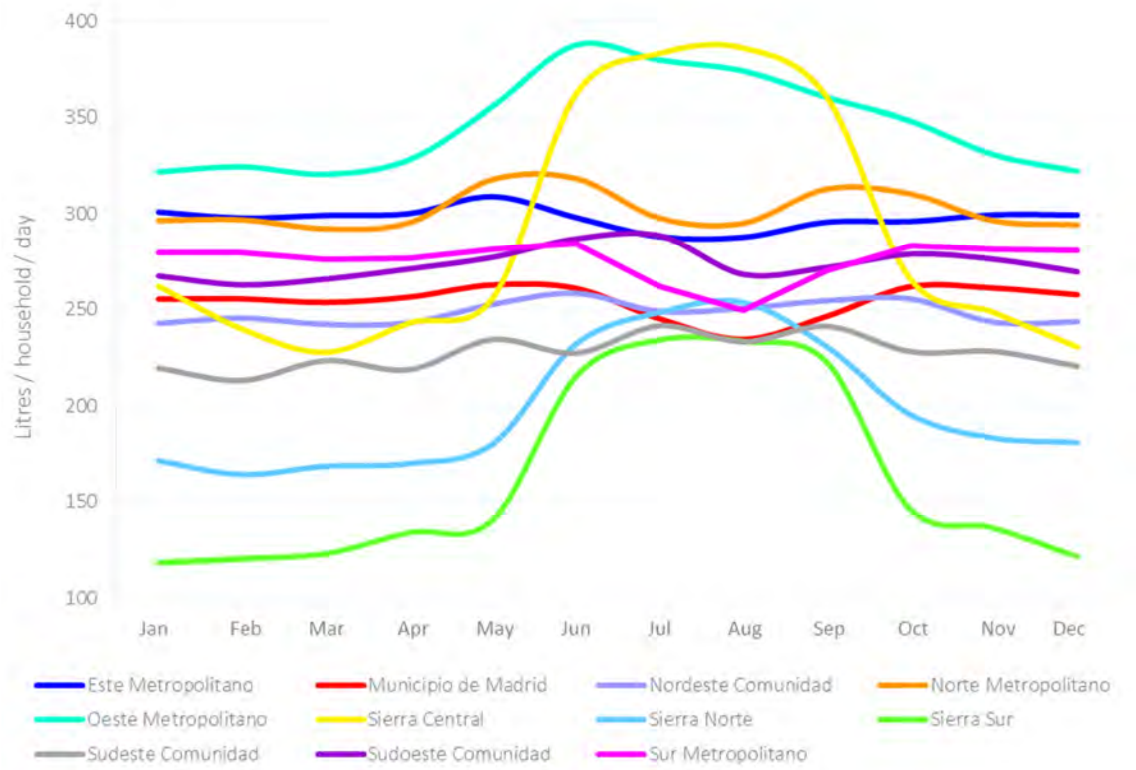


FIGURE 48. **SEASONALITY OF UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES, BY AREAS, IN 2007 _ 2016 PERIOD**

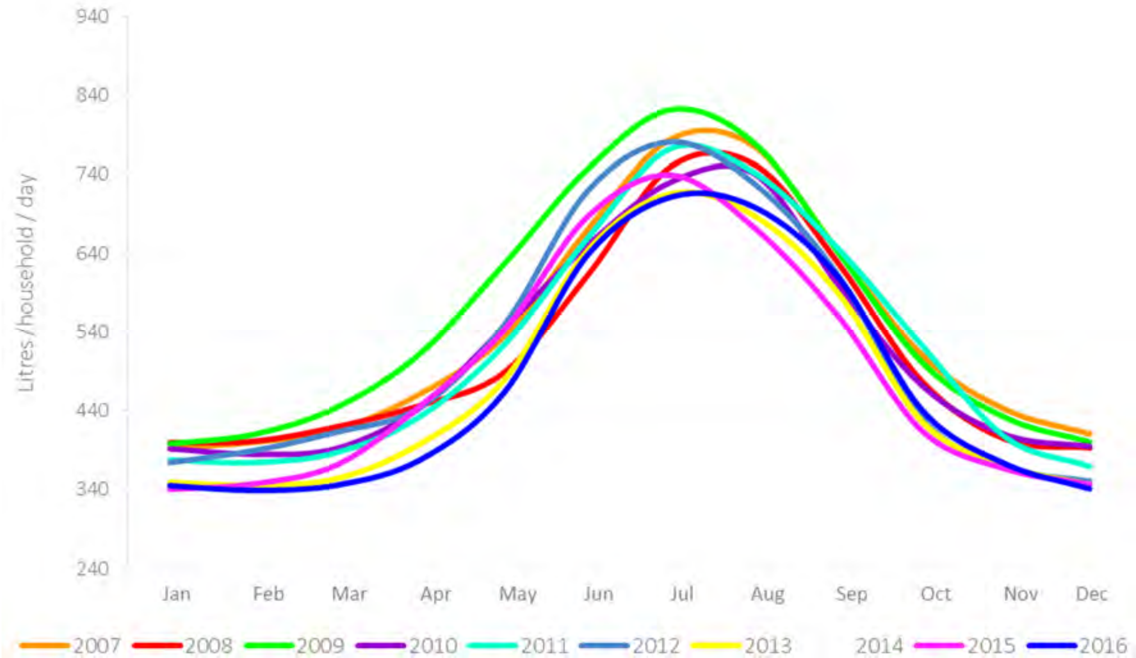
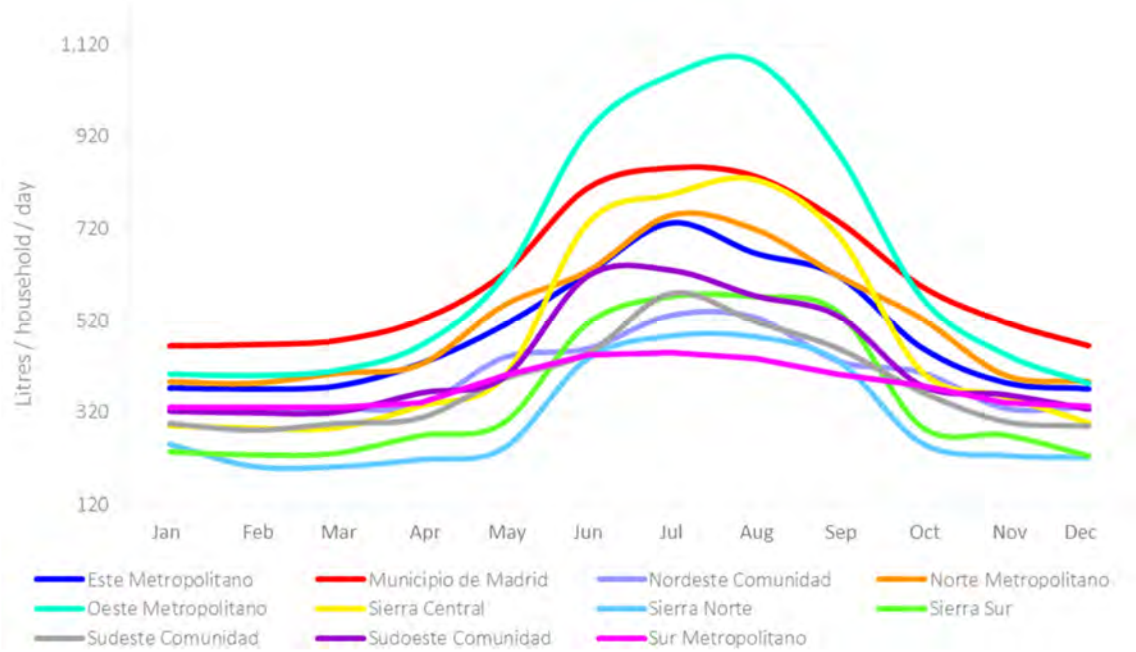


FIGURE 49. **SEASONALITY OF UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES, BY AREAS IN 2016**



An indicator of the seasonality of consumption is the relationship between that recorded during June and July and the average mean. This coefficient is about 1.0 for the whole of the Comunidad de Madrid for multi-family homes. For single-family homes, over the last 10 years, it has fluctuated between 1.36 and 1.51, with the highest values referring to 2012 and 2015 in which the hottest and driest summers were recorded. Figure 50 illustrates this factor in relation to average maximum daily temperatures in June–July.

FIGURE 50. SEASONALITY FACTOR IN RELATION TO MAXIMUM TEMPERATURES DURING SUMMER

There is a certain relationship between seasonality and weather variables, mainly maximum temperatures and rainfall. However, in order to identify these relationships more precisely, measurements with a greater temporal resolution are required, than that provided by two-monthly readings from the billing meters.

By statistical areas, the highest values occur in the areas of the Sierra, the Metropolitan West, reaching, for single-family homes, a value of around 2.

5.1.4. Explanatory factors affecting residential consumption

Climate and meteorological variables were indicated previously as affecting residential water consumption variations. There are other economic and social factors regarding the population and structural factors, in terms of the type of households and their installations, which could explain the geographic and temporal dispersion seen in residential consumption. Apart from these factors, the personal component regarding usage habits is much harder to assess and compare.

This section examines all the variables for which objective information is available and which could affect water consumption.

Disposable income in households

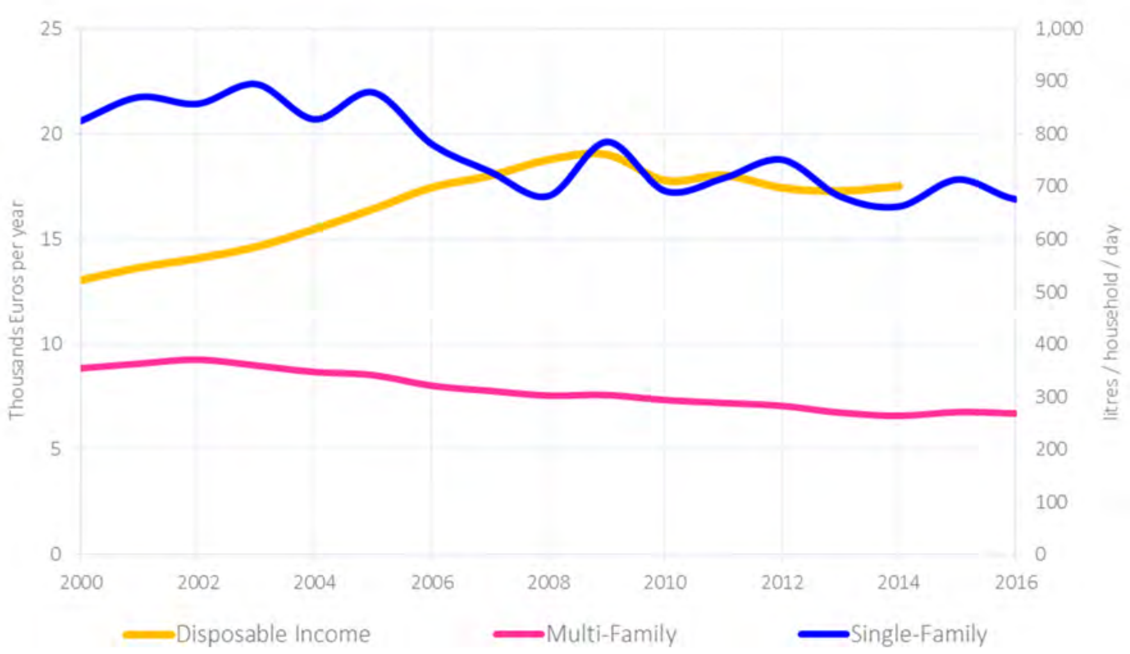
The economic level of families, represented by the disposal income indicator, undoubtedly has an effect on residential water consumption.

The ***Instituto de Estadística*** of the Comunidad de Madrid, (Statistics Institute) publishes this indicator each year for all the municipalities in the region and the 11 statistical areas, apart from the overall value. The calculation method for this indicator has changed slightly since it began, with the most recent figures calculated according to the so-called *Base 2010.*

On the date of drawing up this document, the figures from 2000 until 2014 (advance) are available, with provisional figures for 2012 and 2013.

In the Comunidad de Madrid, the disposable income indicator per capita followed an upward pattern until 2009, when 19,000 Euros per year were reached. From then on, there was a notable decrease, as a result of the general economic recession in the country, stabilising in recent years with values of around 17,000 Euros per year (Figure 51). By relating these figures with unitary water consumption in households, there is not a clear connection between the patterns of the two variables. As indicated previously, residential water consumption experienced a change in pattern in around 2002 for multi-family homes and somewhat later for single-family homes, but, in any event, a considerable time before the economic recession, although this circumstance may have helped accelerate the downward consumption trend.

FIGURE 51. FIGURES IN RESIDENTIAL USES IN RELATION TO DISPOSABLE INCOME 2000-2014



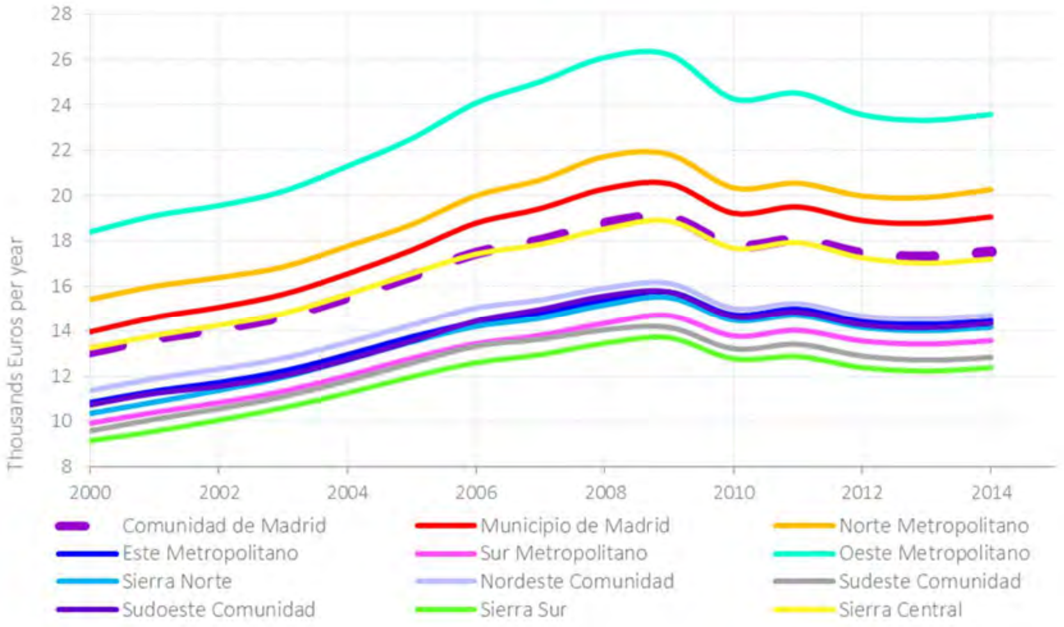
Source: Statistics Institute of the Comunidad de Madrid and Canal de Isabel II

There are significant differences between the different statistical areas of the Community, in terms of level of income, with the highest being in the area of the Metropolitan West (23,562 Euros in 2014), followed by the Metropolitan North and the Municipality of Madrid (19,044 Euros). The lowest were recorded for the Southeast of the Comunidad de Madrid and the South Sierra area (12,805 Euros, and 12,388 Euros, respectively).

Figure 52 illustrates the progress of this indicator for the different areas, during the 2000- 2014 period, with a similar pattern shown for all of them, but with significant differences in the range of income.

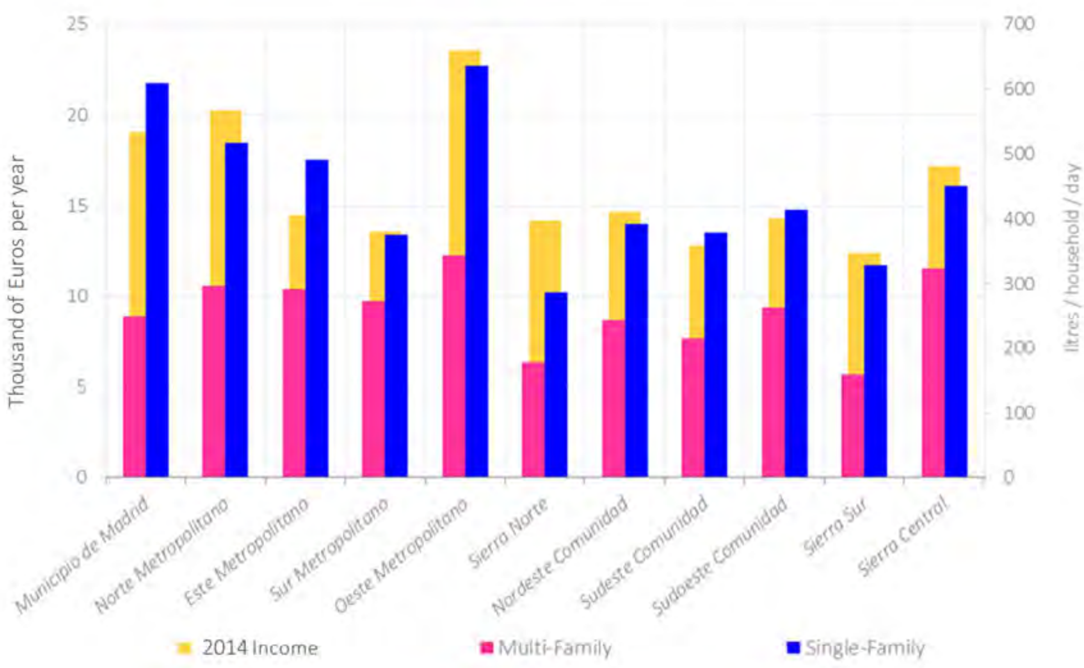
Although the temporal pattern of the income indicator is not clearly related to residential water consumption, the difference between the economic levels in the different areas of the region does seem to partly explain the differences in the figures, as illustrated in Figure 53. The parallelism seems greater for single-family homes than multi-family homes.

FIGURE 52. DISPOSABLE INCOME IN HOUSEHOLDS, PER AREAS, STATISTICS, 2000-2014 PERIOD



Source: Statistics Institute of the Comunidad de Madrid

FIGURE 53. DISPOSABLE INCOME IN HOUSEHOLDS, BY STATISTICAL AREAS, 2000-2014 PERIOD



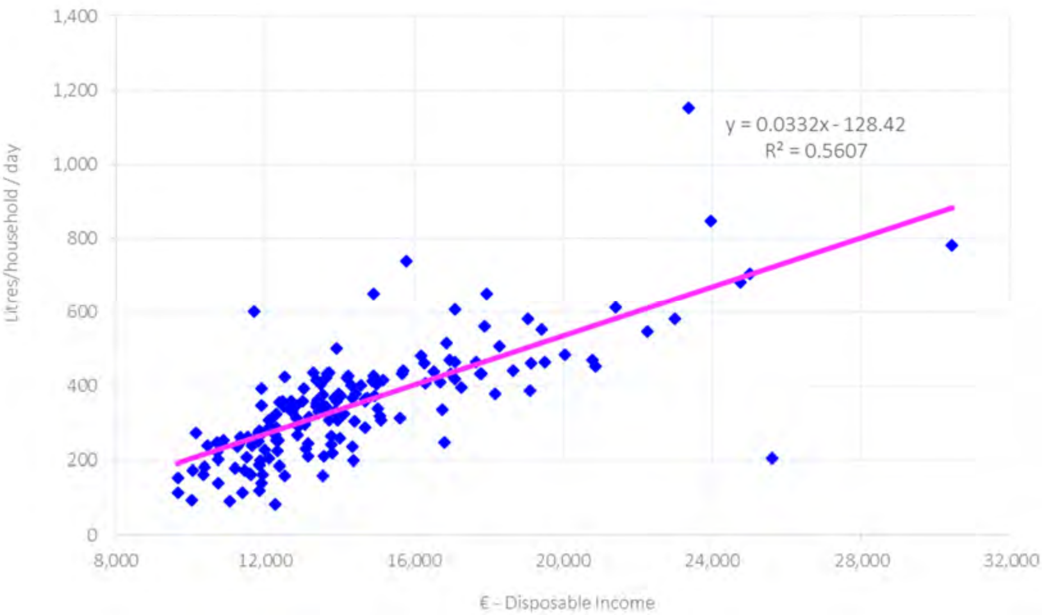
Source: Statistics Institute of the Comunidad de Madrid and Canal de Isabel II

At a municipal level, the dispersion in disposable income is even greater, with values ranging between 9,618 Euros per year in Somosierra, and 30,426 Euros in Pozuelo de Alarcón, for 2014. These differences may be related to the dispersion observed in the figures for residential consumption.

Figure 54 represents this correlation for single-family homes, where a correlation coefficient of 0.75 is obtained, indicating that 56% of the variance observed in consumption of single-family homes at a municipal level, is explained by the difference in levels of income.

For multi-family homes, this correlation is considerably lower, with a coefficient r^2 of 0.32, i.e. 32% of the variance attributable to the income difference. This factor could be attributed to the fact that in multi-family homes, water usage is more closely related to the minimum essential requirements of users, which do not depend on their economic levels, and where sumptuary or additional uses are lower.

FIGURE 54. UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES, BY MUNICIPALITIES, IN RELATION TO DISPOSABLE INCOME IN 2014



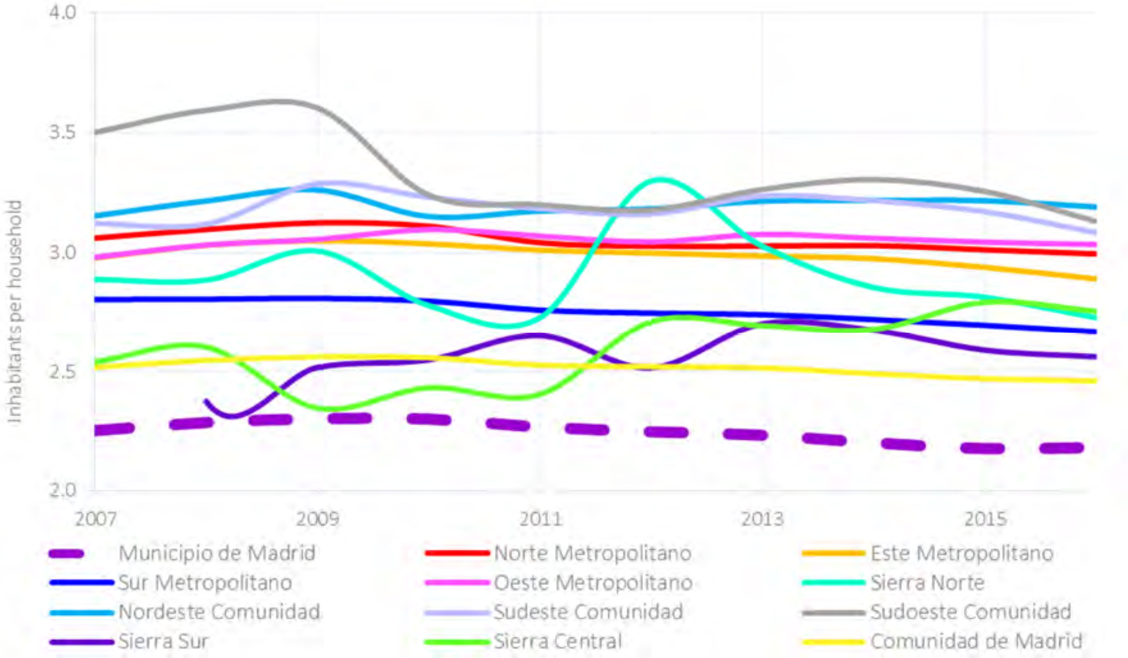
Size of household

It is clear that, the number of people living in the household affects water consumption. The customer files of Canal de Isabel II do not include this figure and it may be variable even over the course of one single year. Therefore, official statistics must be used, with figures grouped together by municipalities. The National Statistics Institute (INE) only conducts a census of households every 10 years, with the last available one being from 2011, and it only includes municipalities with a population exceeding 1,000 inhabitants. One method consists in using municipal population patterns published annually, together with details for the number of households supplied from customer files. These figures do not coincide with those provided by the INE, given the consideration of principal residences, the particular situation of some urbanisations, which are not supplied by Canal de Isabel II, or other discrepancies in the calculation of the number of households.

Since the files within the Commercial System of Canal de Isabel II include figures from every year and these are consistent with one another, this was the chosen source. For 2011, in the Comunidad de Madrid, according to the INE figures, the average occupancy of households would be 2.565 people per household, and according to the GRECO Commercial System, 2.525 people per household, solely considering principal residences (those with a consumption during the January-February two-month period exceeding 5 m^3). In some municipalities, particularly in peripheral areas of the region, the differences are greater.

The size of households in the Comunidad de Madrid has not experienced many changes in recent years, reaching a maximum in 2009 of 2.56 people per household and dropping slightly later. In the Municipality of Madrid, the pattern was similar, with values ranging between 2.18 in 2016 and a maximum of 2.30 people per household in 2009. The fluctuations recorded in other areas are the result of the different treatments applied to some urbanisations incorporated into the Canal de Isabel II supply system during these years. Figure 55 illustrates the data for the different statistical areas, during the 2007-2016 period.

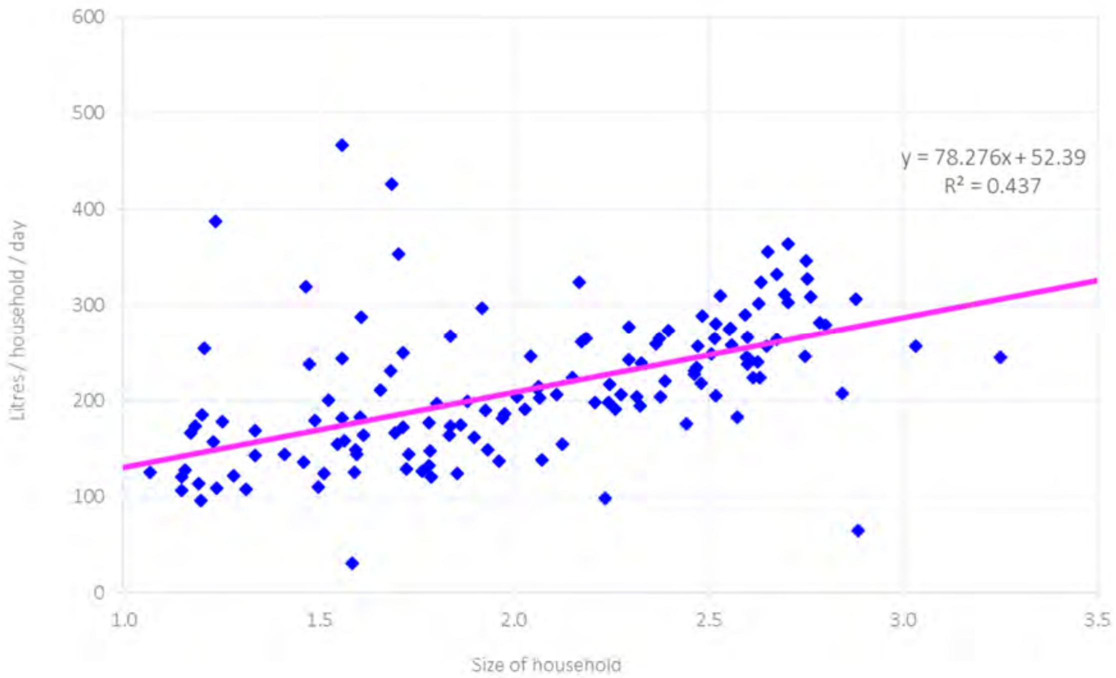
FIGURE 55. SIZE OF HOUSEHOLD PRIMARY RESIDENCES BY AREAS 2007-2016



The variation during these years is not considered significant, but so is it the dispersion between the various areas. In 2016, the minimum occupancy value refers to the Municipality of Madrid, and the maximum to the Northeast Community, with 3.19 people per household.

By municipalities, the range of values is even greater, varying between figures that are lower than unity in small populations and higher values than 4 people per household in other places. In this case, there is a greater correlation with multi-family property figures, where a correlation coefficient of 0.66 is obtained (Figure 56). For single-family homes, this coefficient is 0.62.

FIGURE 56. UNITARY CONSUMPTION IN MULTI-FAMILY HOMES BY MUNICIPALITY, IN RELATION TO THE AVERAGE HOUSEHOLD SIZE FOR 2016



Primary and secondary homes

In some areas of the Comunidad de Madrid, particularly in areas of the Sierra in Madrid, a significant number of households are used as secondary homes and are not occupied the whole year round. The National Statistics Institute (INE[2]) household census distinguishes between "*Primary households*" and "*Total households*". It is understood that the difference between the two are second residences and unoccupied households.

Based on consumption records obtained from user meters, the households solely used for holidays or as second homes can be established. Households with a consumption below 5 cubic metres during January and February, shall be classed as *second homes (*or not primary homes). Empty households are considered to be those that have no consumption throughout the year, but it is more than likely that a large number of empty households do not have active contracts with Canal de Isabel II, therefore there is no information available for these in the customer files.

According to the INE household census for 2011, 14.7% of the households in the Comunidad de Madrid are not considered primary residences, reaching values exceeding 50% in areas such as the North Sierra and South Sierra. In the Municipality of Madrid, 13.7% of the households are second homes or they are empty.

By applying the established criteria to households with contracts with Canal de Isabel II, second homes would be 8.5%. The difference with the census may be attributed to the aforementioned fact that the empty households do not have active contracts. By statistical areas, there is a similarity between the INE figures and those obtained from consumption records (Figure 57).

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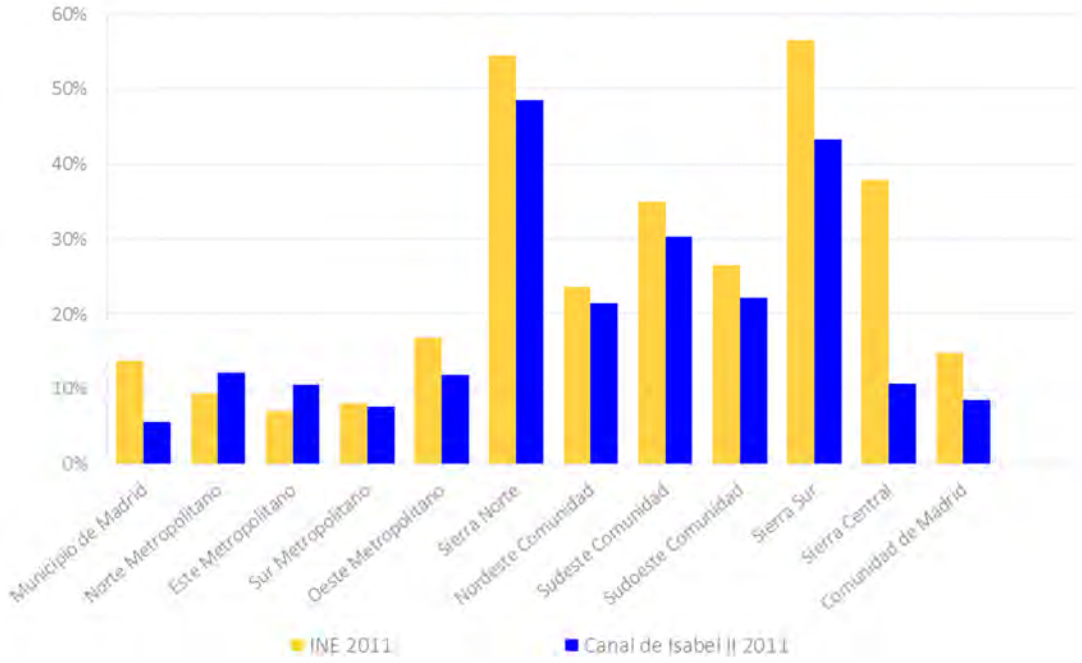
[2] INE: Instituto Nacional de Estadística

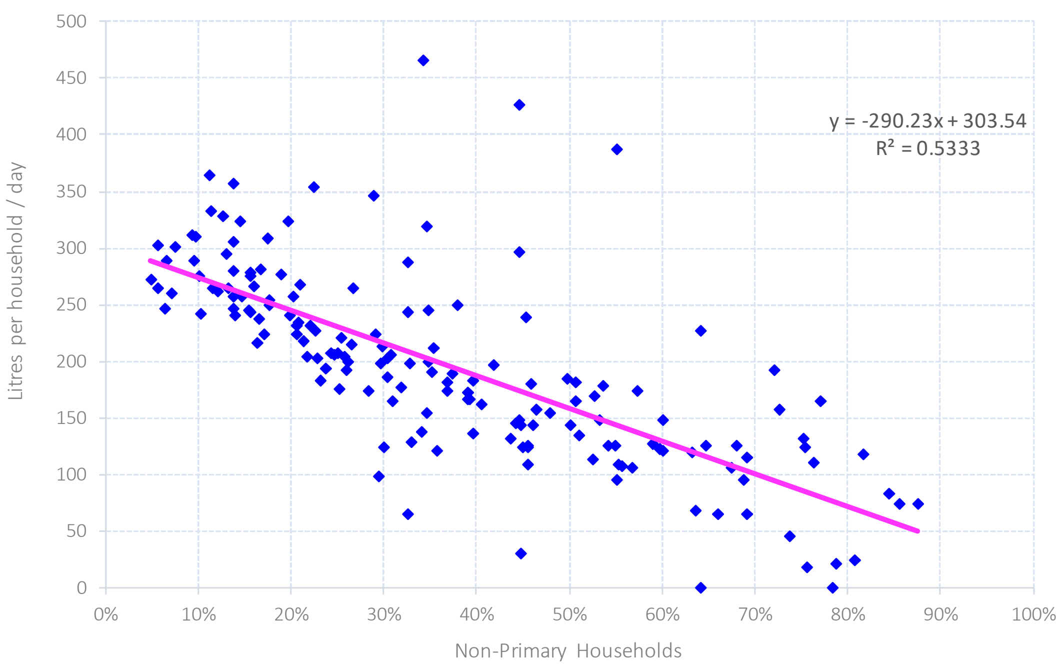
FIGURE 57. PERCENTAGE OF NON-PRIMARY HOMES, BY STATISTICAL AREAS IN 2011



Source: National Statistics Institute and Canal de Isabel II

The percentage value of second or unoccupied residences may be an explanatory factor for the average unitary consumption. By municipalities, with the 2016 figures, there is a clear correlation for both multi-family homes (r = 0.73), and for single-family homes (r = 0.71). Figure 58 illustrates this correlation for multi-family homes.

FIGURE 58. UNITARY CONSUMPTION IN MULTI-FAMILY HOMES BY MUNICIPALITY, IN RELATION TO THE PERCENTAGE OF NON-PRIMARY HOMES IN 2016

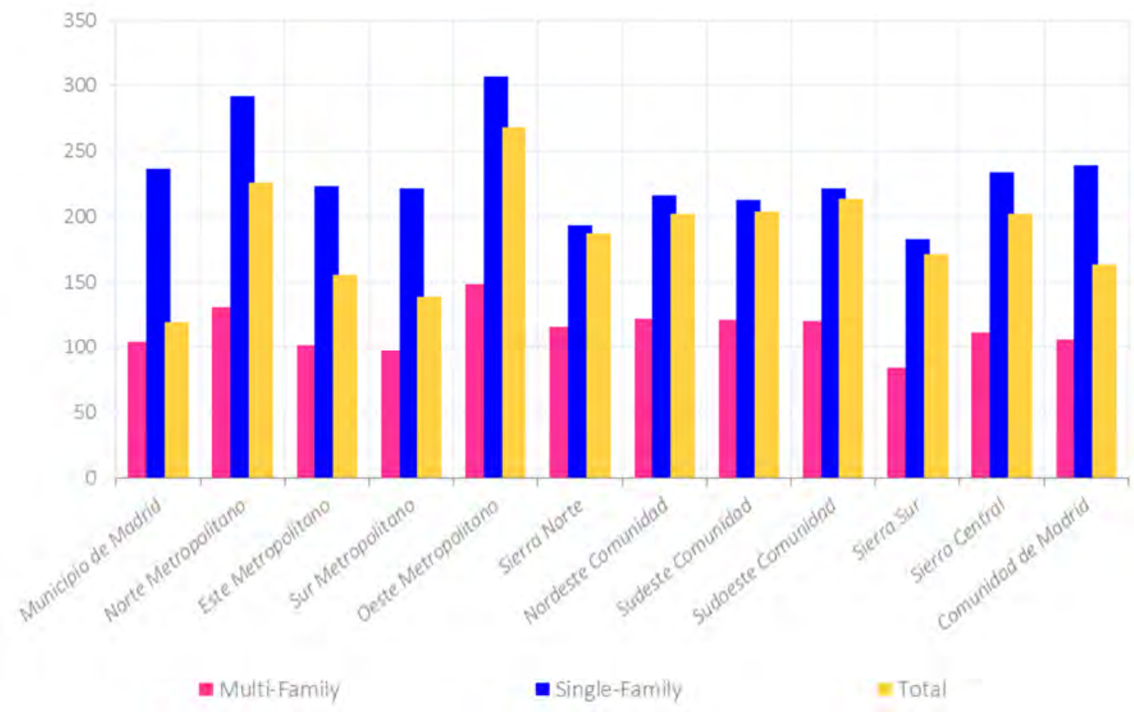


Physical characteristics of the households

The physical characteristics of the households and their installations are another parameter to be taken into account, with an effect on water cosumption. The INE household census of 2011, provides information about primary homes classified by number of rooms and net floor area for municipalities with over 1,000 inhabitants and by year of construction for municipalities with over 10,000 inhabitants. The General Directorate of Cadastre (DGC, for its Spanish acronym) reporting to the Ministry of the Treasury and Public Administration, provides much more detailed information regarding constructions, buildings and houses, with different updates depending on the various municipalities in the region.

It has been chosen the constructed floor area of households according to the DGC figures as an indicator to classify households, updated in 2015 (Figure 59), information which coincides with that used for other types of more in-depth analyses by sectors or cadastral plots.

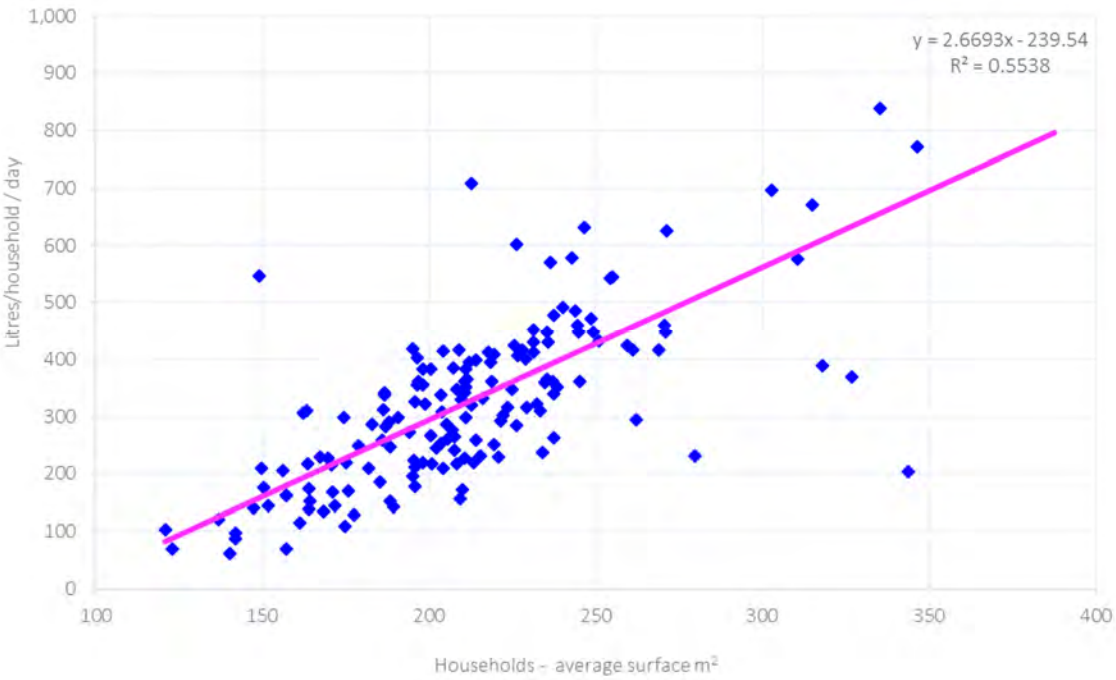
FIGURE 59. AVERAGE FLOOR AREA OF HOUSEHOLDS BY STATISTICAL AREAS. CADASTRAL REGISTRY 2015



Source: General Directorate of Cadastre

By municipalities, as with the indicator for disposable income in households, there is also a significant correlation between the figures for single-family homes and the average floor area (Figure 60), but this is not the case for multi-family homes. In fact, both indicators, income and household floor area indicators, are not completely independent, as there is also a significant correlation between the two.

FIGURE 60. UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES 2016 BY MUNICIPALITIES IN RELATION TO AVERAGE FLOOR AREAS OF THE HOUSEHOLDS



Outdoor uses

According to the provisions of point 3.2.4, outdoor uses represent a significant component in urban water consumption and, in terms of households, they are mainly related to single-family homes, which often have gardens and, in many cases, swimming pools. With the inventory of outdoor uses described in this point, the green areas and swimming pools in the entire Comunidad de Madrid can be located with the cadastral plot. This enables irrigated areas and water surface areas to be related with single-family homes and therefore the average surface area applicable to each household can be calculated. By statistical areas, the results are as shown below in figures 61 and 62.

The differences shown by areas or municipalities are another factor to be taken into account with figures of consumption for single-family homes.

There is a greater correlation between the figures for single-family homes with average swimming pool areas (r=0.64) than with the surface area of green areas (0.35), which is probably due to the various irrigation practices and garden typology (Figure 63).

FIGURE 61. AVERAGE SIZE OF GREEN AREAS IN SINGLE-FAMILY HOMES, BY STATISTICAL AREAS

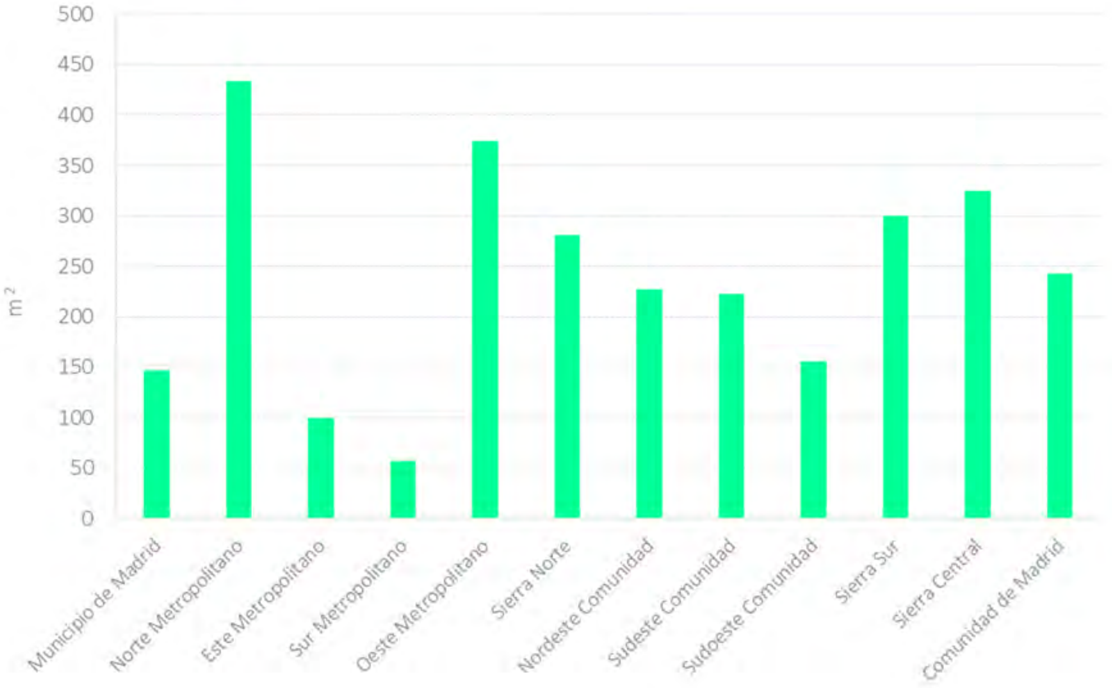


FIGURE 62. AVERAGE SIZE OF SWIMMING POOLS IN SINGLE-FAMILY HOMES, BY STATISTICAL AREAS

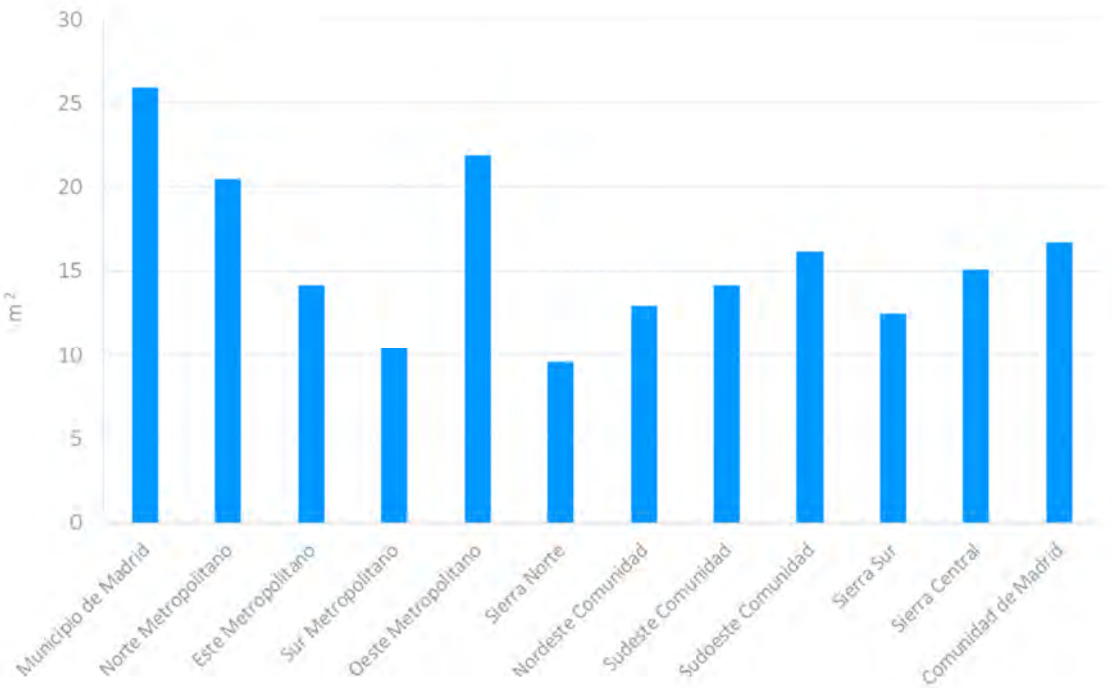
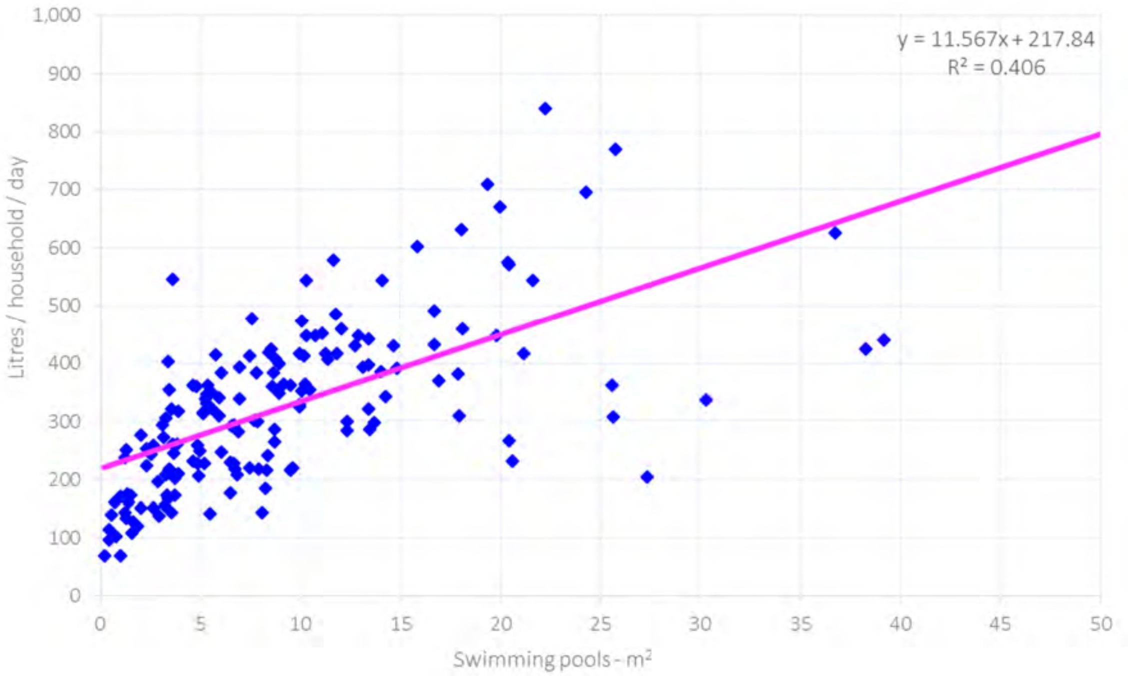


FIGURE 63. UNITARY CONSUMPTION IN SINGLE-FAMILY HOMES 2016 BY MUNICIPALITIES IN RELATION TO THE AVERAGE SIZE OF SWIMMING POOLS



5.1.5. The price of water

According to classic postulates of economics, the price of a product should affect the demand for the product, with an opposite sign variation. In the case of household water demand, this relationship is not quite so clear.

Annual average expenditure on water in the Comunidad de Madrid in 2016, with a consumption of 108 m^3, would be around Euros 196, which accounts for 0.45% of the disposable income in households. Bearing in mind that it is an essential resource and there are no economic alternatives to it, it is understood that there is a minimum water consumption that will not be affected by price.

Water rates in Canal de Isabel II have a binomial structure for the different billing items (water conveyance, distribution, sewerage and purification), with a two-monthly service fee being applied and a variable part related to consumption. For the variable part, various prices are progressively applied by consumption blocks, with the aim of encouraging an efficient water use.

For residential consumption, these blocks are:

- Block 1, up to 25 m^3 every two months.
- Block 2, between 25-50 m^3 every two months.
- Block 3, from 50 m^3 every two months.

Blocks 2 and 3 have a seasonal tariff, which penalises consumption in summer (from 1 June to 30 September).

Average residential consumption in the Comunidad de Madrid does not exceed 11 m^3 per month during any of the months of the year, therefore the third block is never applied for households with such consumption.

Table 13 presents a classification of the households supplied by Canal de Isabel II, in accordance with the billing blocks incurred throughout 2016. As it is a two-monthly billing system, during a calendar year, 6 bills are issued, therefore households are classified by the number of two-monthly periods in the year in which each of the blocks have been billed.

TABLE 13. CLASSIFICATION OF HOUSEHOLDS, ACCORDING TO THE NUMBER OF TWO-MONTHLY PERIODS IN THE BILLING BLOCK

	0	1	2	3	4	5	6	Total
Block 1	6.5%	2.5%	2.3%	3.4%	2.9%	4.1%	78.3%	100.0%
Block 2	79.4%	5.0%	3.9%	3.2%	2.3%	2.5%	3.8%	100.0%
Block 3	94.6%	1.8%	1.1%	1.3%	0.4%	0.3%	0.5%	100.0%

Table 13 illustrates that most households (78.3%) are exclusively billed in the first billing block, and most (94.6%) never reach the third block. Only 0.5% of the households consume water all year round in the third billing block.

For single-family homes, with a higher consumption and greater seasonality, these values are slightly different, as shown in Table 14. In this case, only 41.7% of the households have all their bills included in the first block, and 1.9% are billed in the third block every month of the year.

TABLE 14. CLASSIFICATION OF SINGLE-FAMILY HOMES, ACCORDING TO THE NUMBER OF TWO- MONTHLY PERIODS IN THE BILLING BLOCK

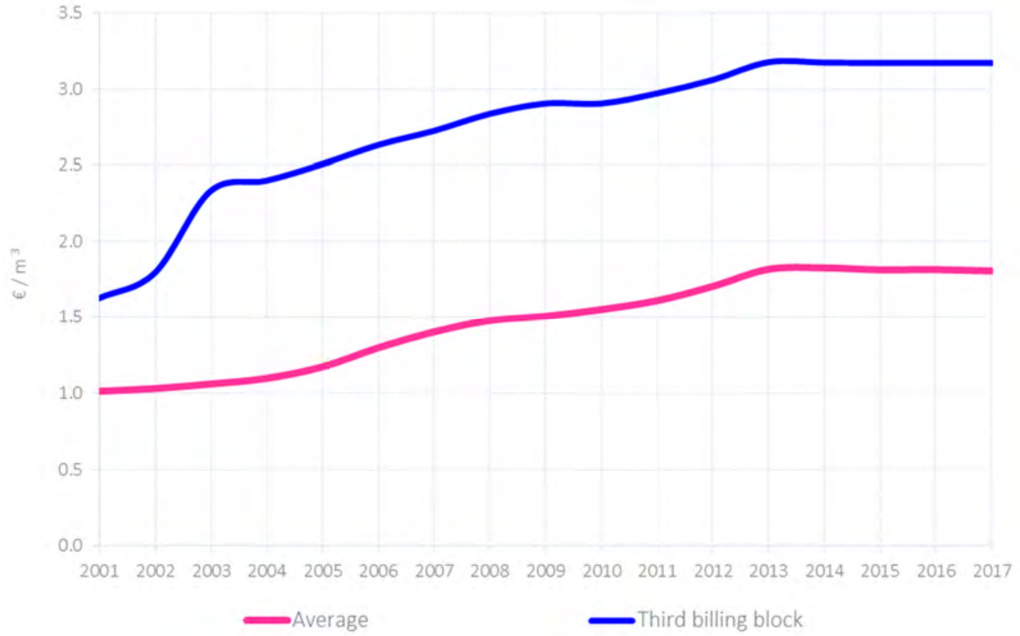
	0	1	2	3	4	5	6	Total
Block 1	18.7%	5.7%	6.6%	11.9%	7.3%	8.1%	41.7%	100.0%
Block 2	46.5%	13.3%	12.8%	9.8%	5.5%	4.9%	7.2%	100.0%
Block 3	73.3%	8.6%	5.6%	7.5%	2.1%	1.1%	1.9%	100.0%

Evolution of the price of water since 2001 is shown in the graph in Figure 64, illustrating the average price per cubic metre, including all the items, for a household with a consumption similar to the average for the Comunidad de Madrid, together with the marginal price for the most expensive cubic metre, in the case of the third billing block during the summer months.

Since 2013, the tariffs have been practically the same, even dropping slightly in 2015. The current average price stands at around 1.81 €/m^3.

The seasonal tariff was first applied in 2003, which is reflected in the price increase for consumption in the third billing block. This increase coincides with the time of the aforementioned change in pattern in residential consumption (see subsection 4.2. Billed Water, and Figure 22). However, a causal relationship between the two events could not be established, since the tariff increase only affected the third billing block (until 2005 it was not applied to the second) and, as mentioned previously, this billing interval is only applicable to 5.4% of the households, most of which are single-family units and the downward trend in consumption in this type of household was first seen at a later date, from 2006 onwards. It would seem that the effect of the tariff on residential consumption is considerably limited and almost exclusively affects users with higher consumption levels and it is observed with some delay.

FIGURE 64. **EVOLUTION OF THE AVERAGE AND MARGINAL PRICE (BLOCK 3) OF WATER IN RESIDENTIAL CONSUMPTION**



In 2008, the start level for the third billing block was amended, with bills for most consumers increasing. This increase in the tariff also coincided with the start of the economic recession and a drop in income in households. However, in 2009, there was a significant increase in consumption in single-family homes (see Figure 36), probably related to the weather, and it was not until 2010 when a notable drop in these types of households could be seen. Figure 65 illustrates user behaviour based on their level of billing in 2009, according to the number of two-monthly periods in which their bills included the third block.

FIGURE 65. **CONSUMPTION INCREASE IN SINGLE-FAMILY HOMES 2009 – 2010, ACCORDING TO THEIR BILLS IN THIRD BLOCK**

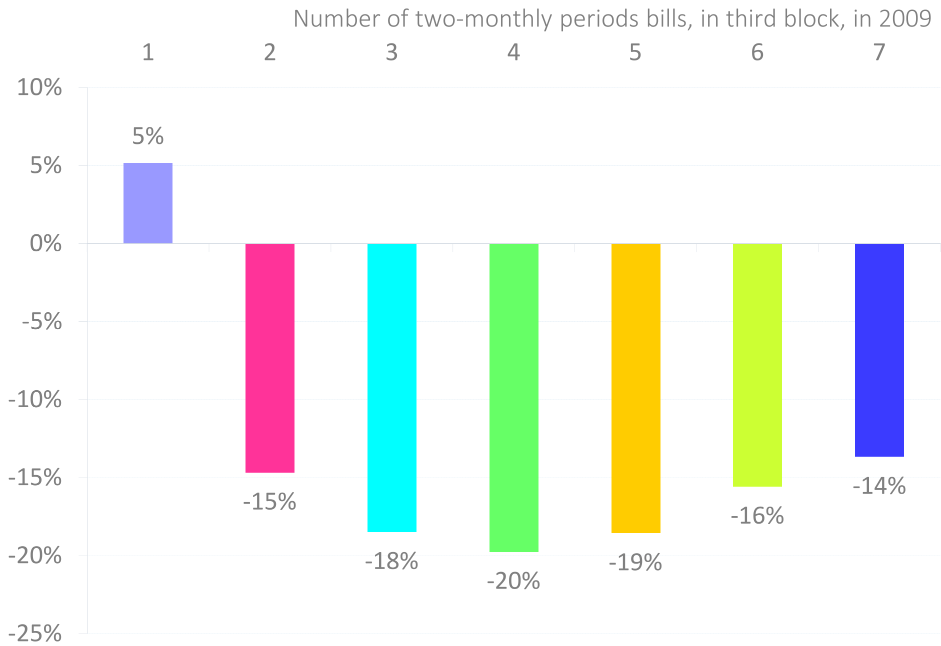


Figure 65 shows that users with moderate consumption, whose bills in 2009 never reached the third block, even increased their consumption while, the decreases occurred in users who, in 2009, suffered mostly from the tariff increase, recording a drop in consumption of up to 20%. It seems quite possible that the significant drop in the recorded consumption, particularly in single-family homes in 2010, is related to the tariff increase, although it happened quite late and along with other unfavourable circumstances, such as the weather and the general economic situation.

5.1.6. Statistical modelling

The preceding points have already indicated the major dispersion in unitary figures for residential consumption in the Comunidad de Madrid, which implies that the use of average figures for designing, planning or operating infrastructures is, in no way, appropriate. A series of factors have also been identified that are clearly related to water consumption in households and which may explain these variations.

Using multiple regression statistical techniques, a quantitative assessment has been performed regarding the real effect of the various explanatory factors outlined in previous points on the recorded unitary consumption.

Different models have been built for the two categories, in which single-family homes and multi-family homes have been classified. They can also be built for other types of consumption (Industrial Commercial, Institutional, etc.) although, as mentioned previously, these other categories show much greater variability and are conditioned by many variables that are hard to assess.

The models have been parameterised and calibrated independently for each of the 11 statistical areas of the Comunidad de Madrid, and the models have been built for the average monthly supply figures, taking into account seasonality, and particularly, for the months of June and July in which peak consumptions are normally recorded. Various explanatory factors were used, such as disposable income in households, the size of the household (number of people per household), the percentage of secondary residences, the average floor area of households and the extent of outdoor uses, based on the inventory mentioned in point 4.2.4. (Outdoor uses) and, taking into account weather variables that determine this.

Linear models have been chosen, with the following type of formulation:

$$D_{c,m} = (A_c + \sum_{i=1}^{n} K_{c,m,i} \times F_{c,m,i}) \times E_{c,m}$$

Where:

$D_{c,m}$ *:* unitary supply figure for category *c* and month *m*

Ac*:* independent term category *c*

n*:* number of factors (independent variables) considered

$K_{c,m,i}$: coefficient for category *c* and variable *i* and month *m*

$F_{c,m,i}$: value of variable *i* for category *c* and month *m*

$E_{c,m}$: seasonality factor for category *c* and month *m*

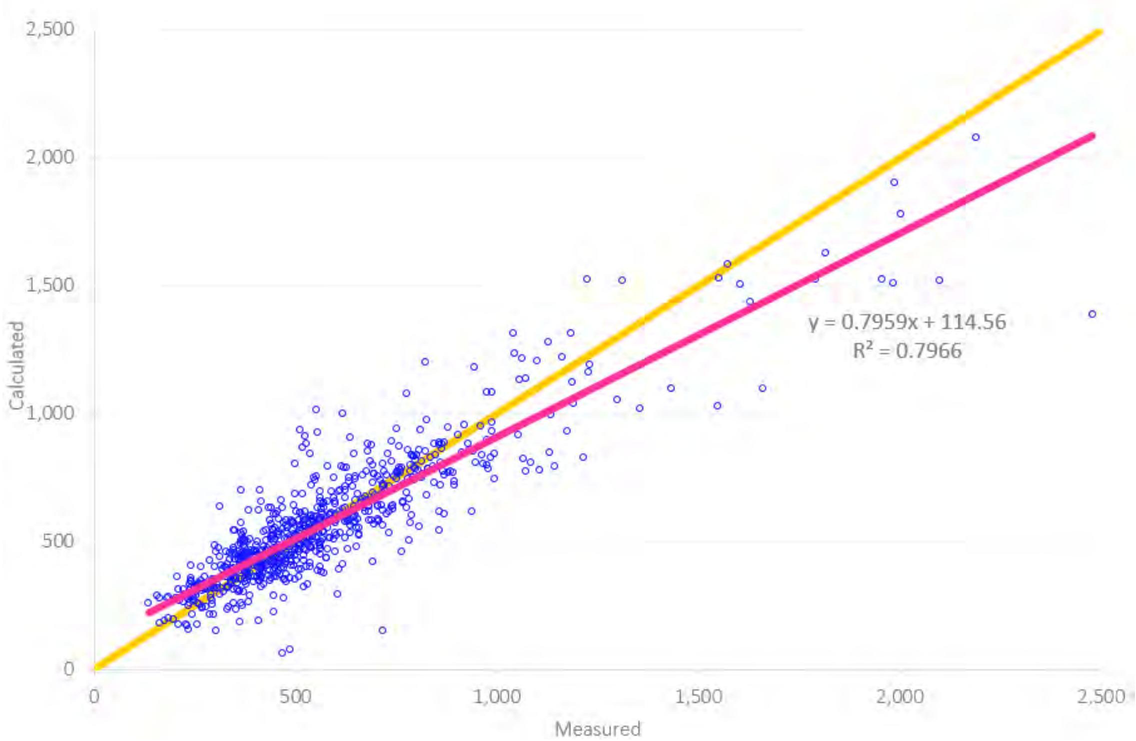
Non-linear models, for example exponential or polynomic models, can provide better adjustments, but when they need to be extrapolated, if the variables considered have values that are outside of the spectrum with which they were adjusted, it may lead to absurd results. Once the model has been numerically adjusted for each of the areas and type of household, this has been applied to each of the municipalities in the area with the data from 2011–2015, comparing the figures calculated by the model with the real recorded results.

The best adjustment reached is the one shown in Figure 66, with a correlation coefficient of $R^2 = 0.796$, which indicates that 80% of the variance between the figures for the 167 municipalities modelled over these five years can be explained by the indicated factors. This adjustment could be considered satisfactory; however, it is important to bear in mind that it is simply a numerical adjustment obtained through optimisation to minimise the quadratic error. If this model is to be extrapolated, conceptual aspects would need to be introduced as a restriction. For example, a negative correlation between the total figure and the estimated figure for outdoor uses should not be accepted. By introducing these concepts, the best adjustment achieved would be $R^2 = 0.689$, that is, 70% of the variance, approximately.

The chart in Figure 66 illustrates how the results obtained, in various occasions are below the recorded values, and the differences are significant, particularly in municipalities with higher figures. This is a normal behaviour in mathematical models, which tend to estimate average or more common values and deviate from extreme values.

In the case of multi-family homes, the adjustment is much poorer, pursuant to the provisions outlined in previous sections about the effect of the different factors on consumption of these types of households.

FIGURE 66. CORRELATION BETWEEN MEASURED AND CALCULATED SUMMER CONSUMPTION FIGURES, IN SINGLE-FAMILY HOMES



Bearing in mind the difficulty in estimating the values of these variables in the future, together with the uncertainty regarding maintaining existing ratios with water consumption, the advantages of these types of models are, to a certain degree, limited. In order to estimate short-term demands, it may be more appropriate to use statistical models that analyse the recent historical series for each municipality or sector and extrapolate them to the calculation horizon.

It is also clear that, apart from the analysed explanatory variables, there are many other factors that are hard to quantify and which are not in official statistics, such as the type or conditions of the plumbing facilities, or user habits, the degree of awareness regarding the efficient water use, etc. This type of information can be obtained through surveys conducted among the general public, which is not a very expensive method, but not very accurate either. Directly measuring water consumption on a continuous basis in terms of various household appliances, provides information regarding the end use and consumption micro-components, which provides the knowledge regarding the behaviour of water demand in the household arena. If that direct measurement with regard to all users of the supply system is not feasible in the current state of technology, a representative sample may be sufficient.

The following sections outline the methodology used and the results obtained in the *Monitoring Panel* made up of 300 households, which Canal de Isabel II has been monitoring since 2008, to study the consumption habit patterns and end uses of water.

5.2. END USES IN RESIDENTIAL CONSUMPTION. METHODOLOGICAL APPROACH

The aim of this part of the work is to gain greater knowledge of residential water consumption patterns in the Comunidad de Madrid, by monitoring a representative sample of households over a long period of time, identifying the end uses of such consumption and analysing the effect of explanatory factors thereof and their temporal modifications.

This chapter aims to answer specific questions regarding how families in Madrid use the water they receive and the factors that determine such use. The study focused on residential end uses or micro-components.

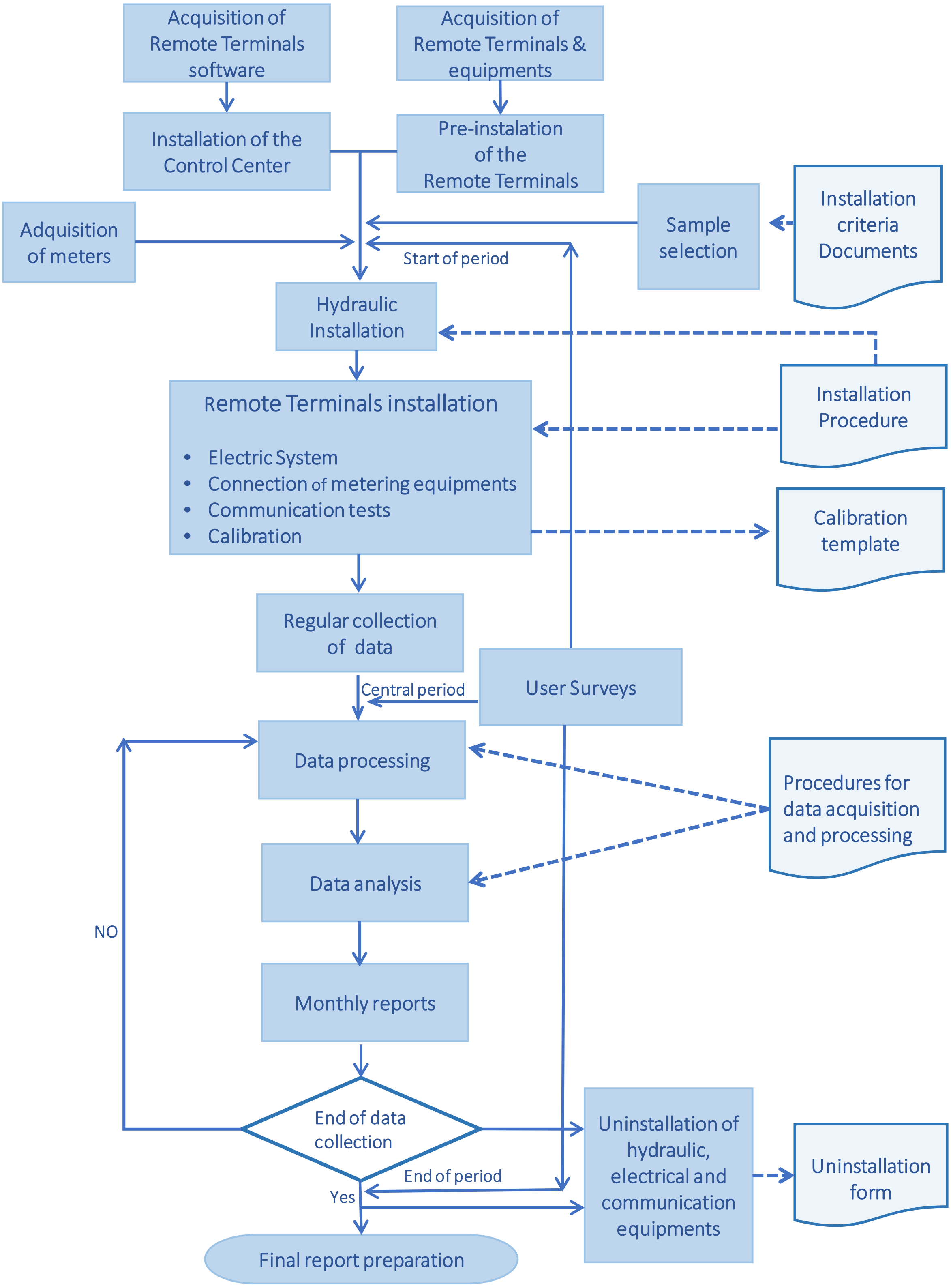
The figures included herein were collected between January 2008 and June 2017, based on a relatively stable sample of between 200-300 households distributed across the entire Comunidad de Madrid. During this period, around 15.8 million hours of consumption were monitored and the use of around 208 million litres of water were recorded and analysed.

No references were found in any equivalent studies of the end water use with such a high volume of data and over such a long period of time, which enables the long-term use patterns and changes in trend to be monitored.

This section explains the methodological approach used in the different parts of the study and which can be summarised in the content outlined below: the selection of the sample, the technology used to measure and transmit the data, the processing of the information in order to identify the end uses and additional information for the final analysis of data. Particular attention has been given to the assessment of the results in the following chapter.

The process diagram followed is reflected in Figure 67.

FIGURE 67. PROCESS DIAGRAM FOR END USES MONITORING



5.2.1. Sample selection

One of the essential elements of the project consisted in selecting a sufficiently representative sample of all the households in the Comunidad de Madrid, which therefore needed to be stratified in terms of type of household, occupancy, etc. and with a geographic distribution that could cover, insofar as possible, the entire region with all its diversity.

The key aspects to be considered to correctly establish this sample were as follows:

- ✓ *Stratification*
- ✓ *Representativeness*
- ✓ *Stability*
- ✓ *Client collaboration*
- ✓ *Personal data protection*
- ✓ *Technical feasibility of installing devices: Availability of power, GPRS coverage*

The aim was to obtain a sample of around 200-300 households, with as much stability as possible, although this was not always possible to achieve over the entire monitoring period, due to the abandonment of some users, households that have been vacated or technical problems.

The users were mainly selected from among Canal de Isabel II customers, although in some cases, it included households supplied by Canal de Isabel II, but which were not equipped with individual meters, since they were integrated in a Community of Owners or an urbanisation.

Sample progress

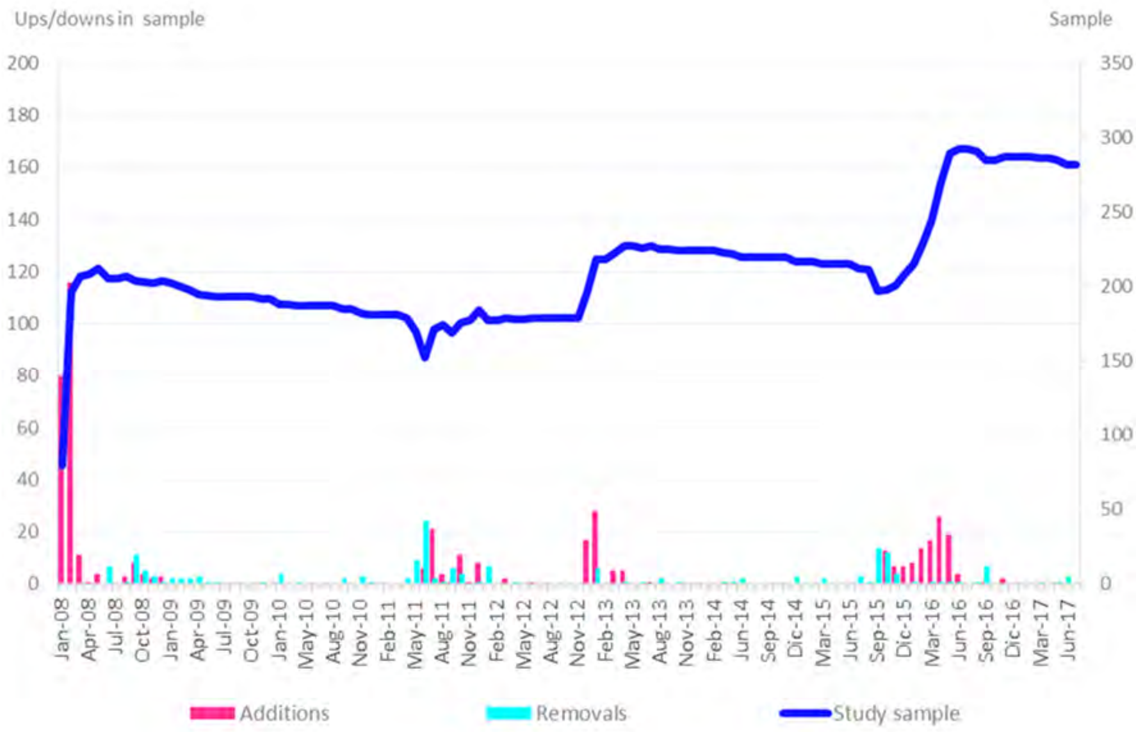
A factor that affected the analysis of the data was the variability of the sample over a period of almost ten years that the study lasted, in terms of the inclusion and elimination of elements over the entire period. This change of users in the study distorts the analysis of the progress of consumption (overall or by uses), although it does not affect those related to the weekly or hourly distribution of each of the uses analysed.

The start of the study dates backs to December 2007, with the first installations, although the *Monitoring Panel*[3] was established in February 2008. Since then, until June 2017, 475 users or households (installations carried out) took part in the study, of which, 282 (60% of the total) continued until the end, with figures being obtained for the last month of the project (June 2017).

The progress of the sample over the period, since the start of the work with the number of active users, additions and removals are illustrated in Figure 68.

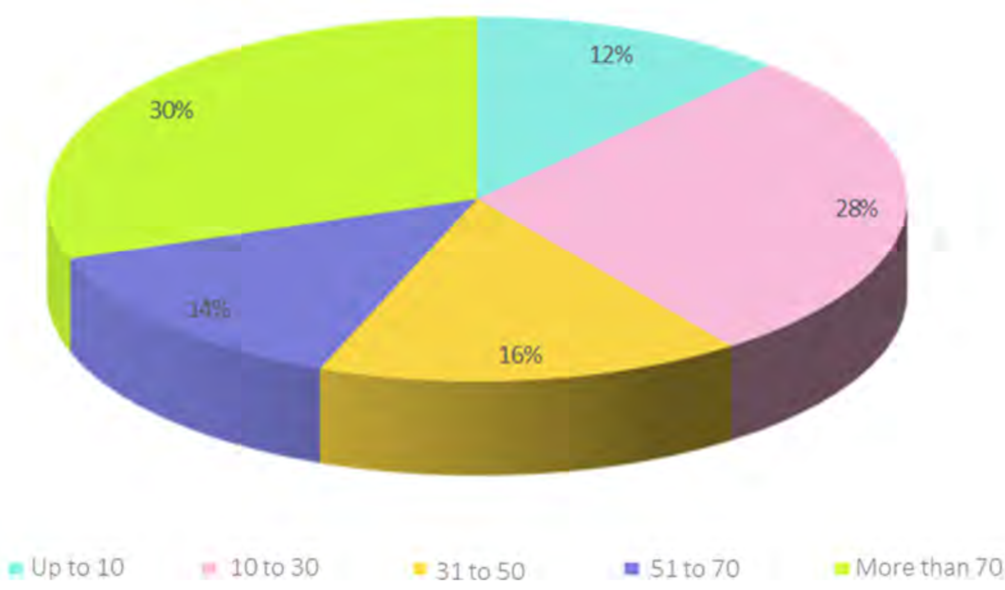
[3] Monitoring panel was the name given to the sample of clients for the study

FIGURE 68. TEMPORAL PROGRESS OF THE SAMPLE



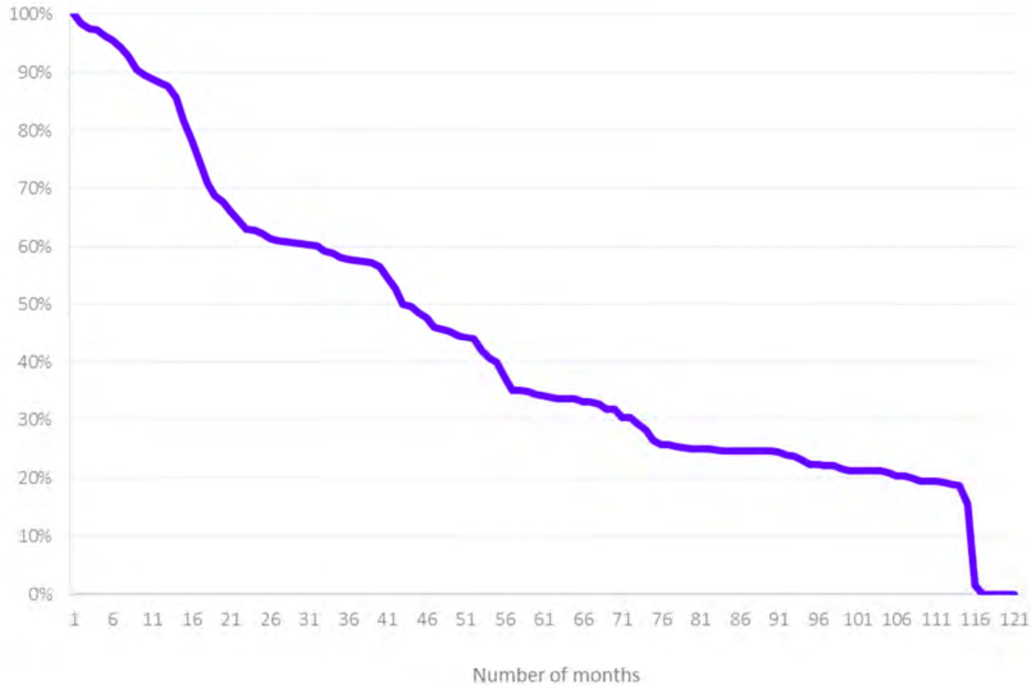
As shown in Figure 69, if users are grouped together based on their months of continuity on the *Monitoring Panel,* it shows that 60% continued in the study for more than 30 months and 30% continued for more than 70 months.

FIGURE 69. USER CONTINUITY ON THE MONITORING PANEL BY RANGE



The accumulated percentage of users based on the months of continuity thereof on the Monitoring Panel, is illustrated in Figure 70, outlining how the quartiles refer to 16, 42 and 80 months of continuity.

FIGURE 70. ACCUMULATED CONTINUITY OF USERS ON THE MONITORING PANEL

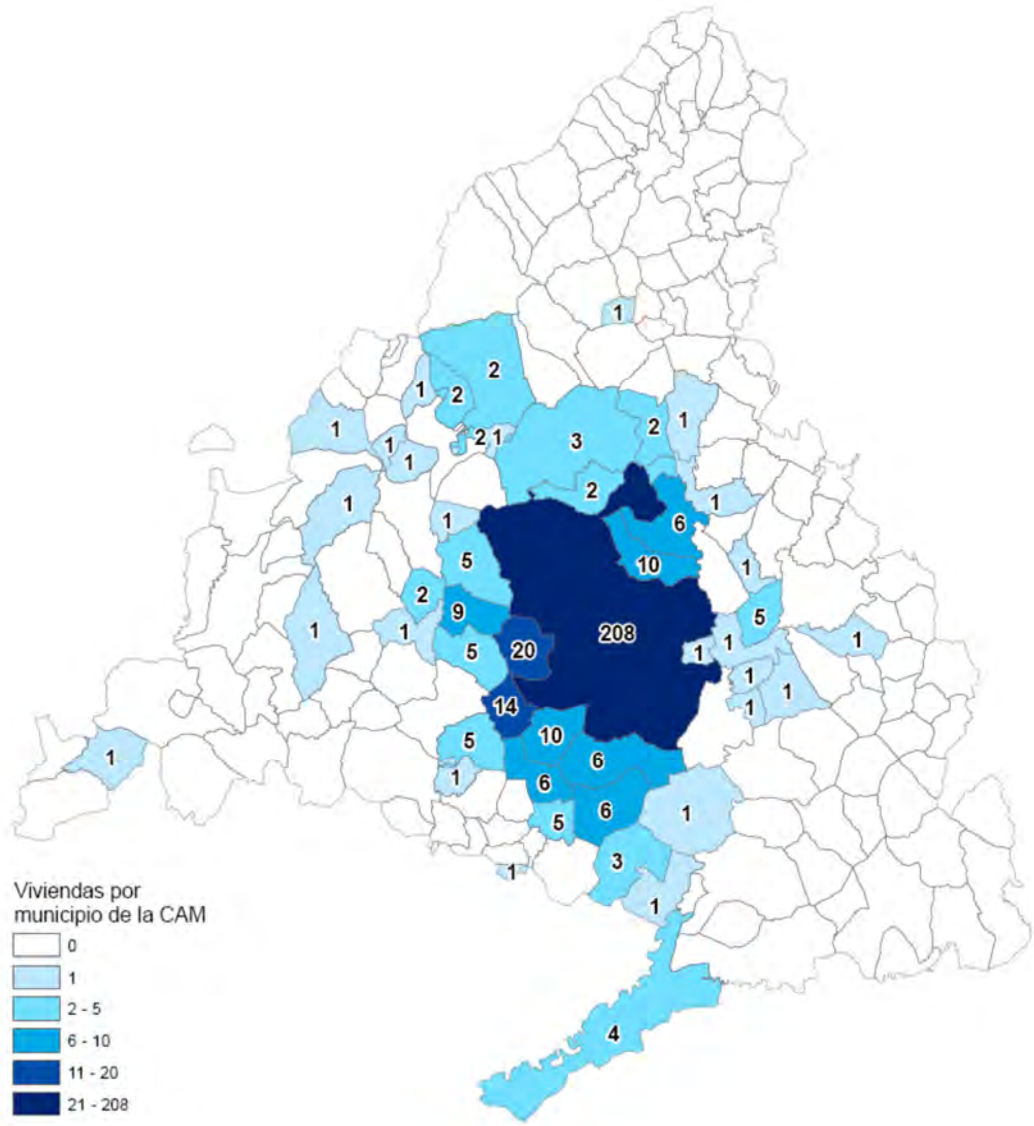


Although during the study, an analysis was conducted on the sample that made up the *Monitoring Panel* at each given time, occasionally, an analysis of a subpopulation with 45 or more months of continuity in the study was included, called ***stable sample***, of 155 households (40% of the entire sample).

Geographic distribution of the sample

The geographic distribution of the sample over the work period, is as outlined in figures 71 and 72. The highest number of households are located in the Municipality of Madrid and its metropolitan ring, where the majority of the population lives, but peripheral areas are also represented.

FIGURE 71. **SAMPLE DISTRIBUTION BY MUNICIPALITIES. COMUNIDAD DE MADRID**



Stratification and representativeness

The characteristics of the households included in the *Monitoring Panel,* in order to conduct the study are outlined in the graphs and tables below. The sample representativeness was assessed by comparing the characteristics regarding the data from the National Statistics Institute, or the Statistics Institute of the Comunidad de Madrid.

The type of household was one of the characteristics collected to characterise the households. In general terms, the classification conducted in the study was more detailed than that from the statistical reference, as illustrated in Figure 73.

At present, the percentage of single-family homes in the sample is 13%, similar to the average in the Comunidad de Madrid (13.7%), although this was not always the case, in 2011 it was only 9%. This type of household has generally been poorly represented, given the difficulties in installing metering devices in them (see Table 15).

FIGURE 72. SAMPLE DISTRIBUTION BY POSTAL DISTRICTS, IN THE MUNICIPALITY OF MADRID

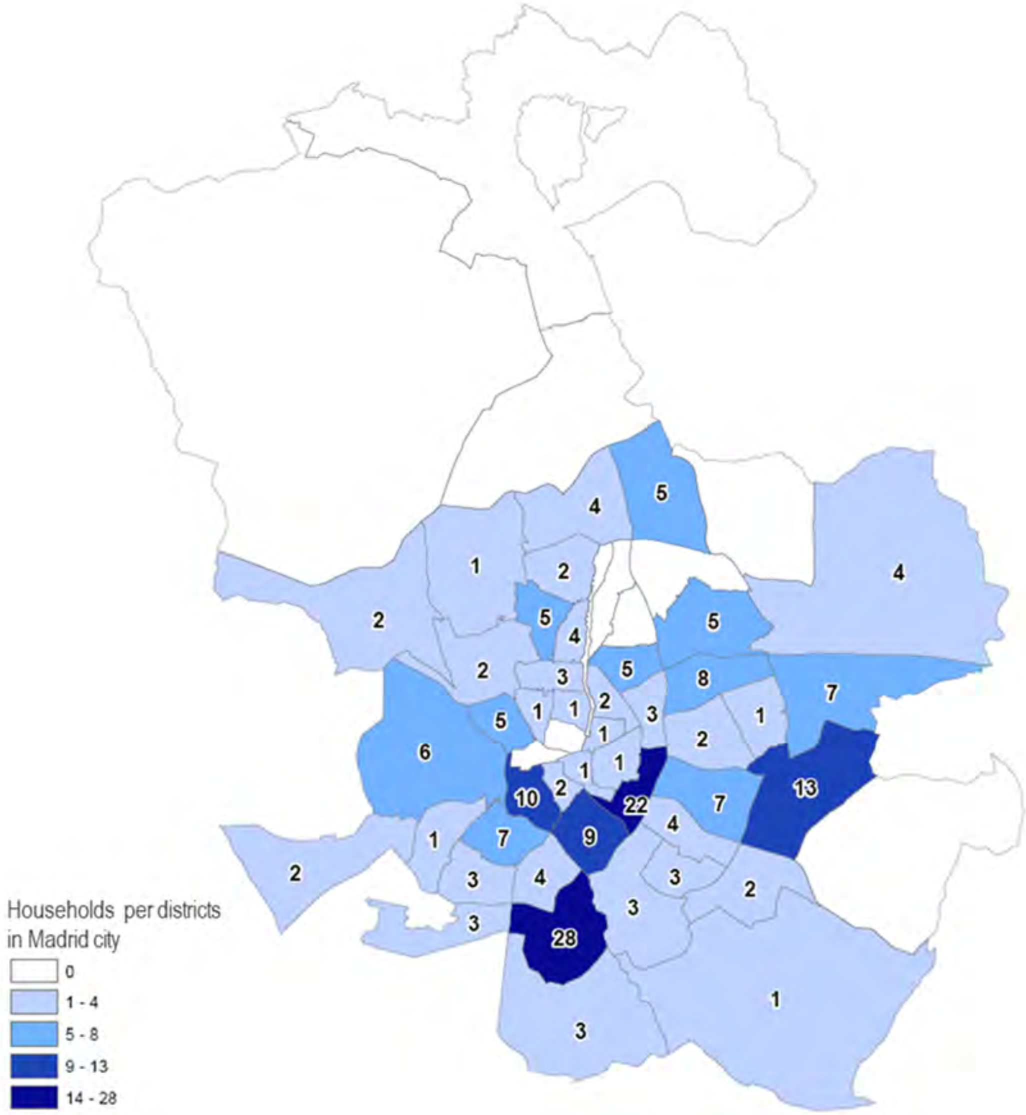


TABLE 15. STRATIFICATION BY TYPE OF HOUSEHOLD, SINGLE-FAMILY OR MULTI-FAMILY

Type of household	*Sample*	*National Statistics Institute (1)*	*Statistics Institute Comunidad de Madrid (2)*
Single-family	13%	14%	10%
Flat/Apartment	87%	86%	90%

(1) Figures from the 2011 INE demographic census for the Comunidad de Madrid

(2) Figures from the Statistics Institute of the Comunidad de Madrid for 2001

Another characteristic collected from the households that formed part of the *Monitoring Panel* is the size of the households, these figures are reflected in Table 16.

FIGURE 73. **STRATIFICATION BY TYPE OF HOUSEHOLD**

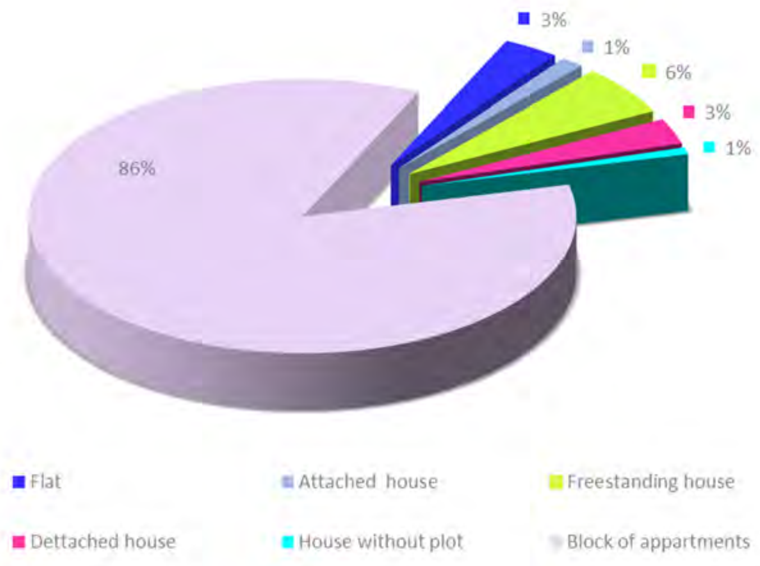


TABLE 16. **STRATIFICATION BY TYPE OF HOUSEHOLD M^2**

Type of household in m²	*Complete sample*	*Stable sample*
Less than 50	7	3
Between 51 and 70	34	13
Between 71 and 90	86	40
Between 91 and 110	69	40
Between 111 and 125	26	16
Between 126 and 150	27	13
Between 151 and 175	8	4
Between 176 and 200	2	2
Between 201 and 250	14	7
Over 251	8	2
Don't know/No answer	21	15

As with the type of households, the classification applied in the study was more detailed than that used by statistical censuses, therefore they have been grouped together to provide an appropriate comparison, as illustrated in Figure 74. The most notable aspect is the low representativeness of households in the 51 to 70 m^2 interval and the high representativeness in the 91 to 120 m^2 interval.

The range of occupancy is the most variable aspect of the stratification, due to some changes in owners and/or tenants in the households with the elimination of some users and the addition of new households to the study throughout the period.

These figures are presented in Table 17 where those of the Statistics Institute of the Comunidad de Madrid and those of the INE, National Statistics Institute are added.

FIGURE 74. **STRATIFICATION BY SIZE OF HOUSEHOLD M²**

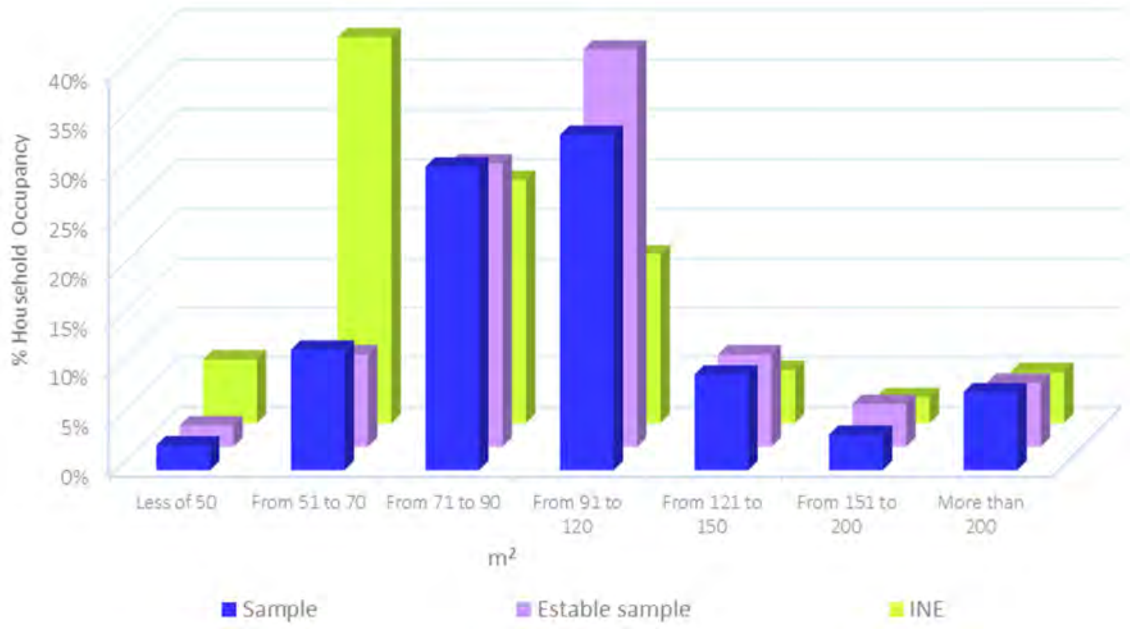


TABLE 17. **OCCUPANCY COMPARISON BY HOUSEHOLD, IN THE SAMPLE AND IN THE COMUNIDAD DE MADRID**

Occupancy Nº of inhabitants	*Sample*	*Stable Sample*	*INE National Statistics Institute (1)*	*Statistics Institute of the Comunidad de Madrid (2)*
1	10.2%	6.0%	23.6%	19.4%
2	23.4%	15.4%	29.7%	25.5%
3	22.0%	27.5%	21.1%	21.5%
4	34.9%	38.9%	18.7%	22.4%
5	8.1%	11.4%	5.0%	7.4%
6 or more	1.4%	0.7%	2.0%	2.2%

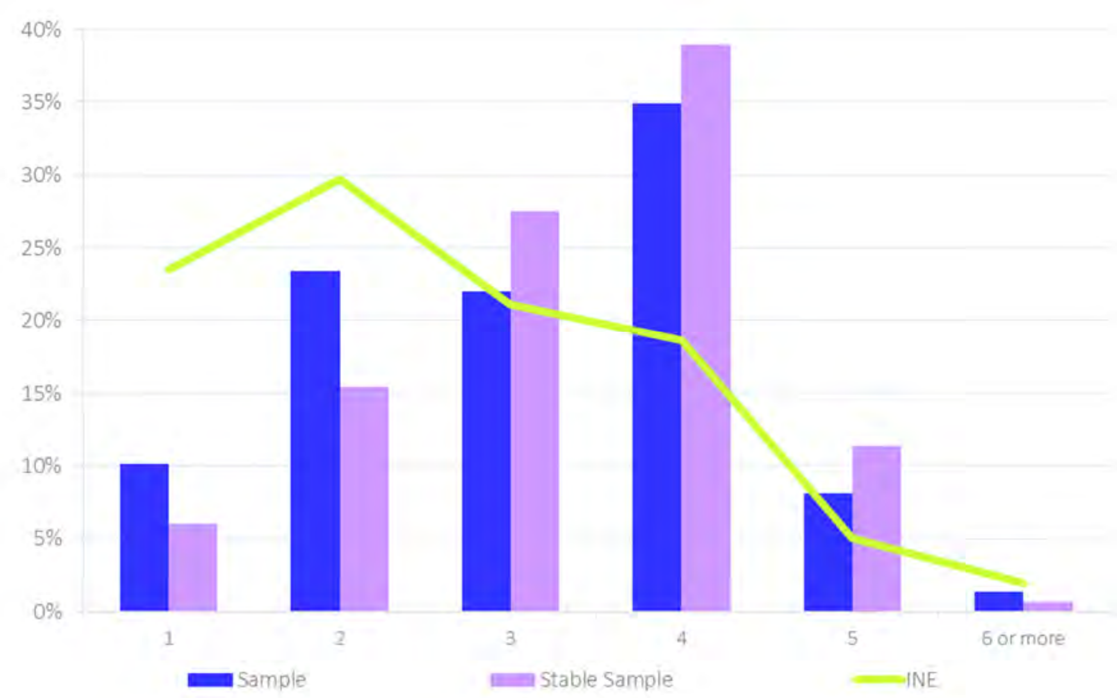
(1) *Figures from the INE 2011 demographic census for the Comunidad de Madrid*

(2) *Figures from the Statistics Institute of the Comunidad de Madrid for 2001*

Between 2001 and 2011 there was a 21% and a 17% increase in the percentage of 1 and 2 inhabitant households, respectively, the number of 3 inhabitants (-2%) was practically maintained and those with 4 (17%), 5 (32%) and 6 (11%) inhabitants dropped. This occupancy pattern has a negative impact with regard to the representativeness of the sample, since it increases the differences with the statistical figures.

In Figure 75, it is shown that households with 3 inhabitants and with 6 or more, are those that are best represented. It also shows how the complete sample offers a better representation of occupancy levels than the stable one for the Comunidad de Madrid.

FIGURE 75. STRATIFICATION BY HOUSEHOLD OCCUPANCY



In terms of household occupancy, the most notable change was the increase in the representation of households with 1 occupant and the drop in those with 2 occupants, since the start and until the end of the study, as illustrated in Figure 76.

The average occupancy is 3.2 inhabitants per household, higher in the study sample than the statistical figures (2.58 inhabitants per household, according to the INE figures for 2011 and, 2.71 inhabitants per household, according to the Statistics Institute of the Comunidad de Madrid for 2001) although the trend decreased throughout the study period, as in the whole of the Comunidad de Madrid.

In terms of water usage in households, the existence of gardens and terraces with plants and flowers is relevant, which determine the outdoor uses in irrigation, therefore, this was another characteristic taken into account in the surveys. The subsequent analysis of uses identified irrigation, even in households where this use had not been declared. As illustrated in Table 18, the stable sample does not include potential large water consumers in gardens.

The existence of private swimming pools in households is minor, there were only 11 cases in the entire study, of which, only 6 remain (2%).

The range of consumption (unitary figures) in the sample in 2016, was 313 litres per household per day, somewhat higher than the average for the Comunidad de Madrid.

In previous years, particularly in 2011 and 2012, the figure was lower than the average in the region, precisely due to the lower number of single-family homes. Figure 77 illustrates the progress of this average annual figure, in comparison with the average residential consumption and that of multi-family homes in the Comunidad de Madrid.

FIGURE 76. STRATIFICATION BY HOUSEHOLD OCCUPANCY PER YEAR

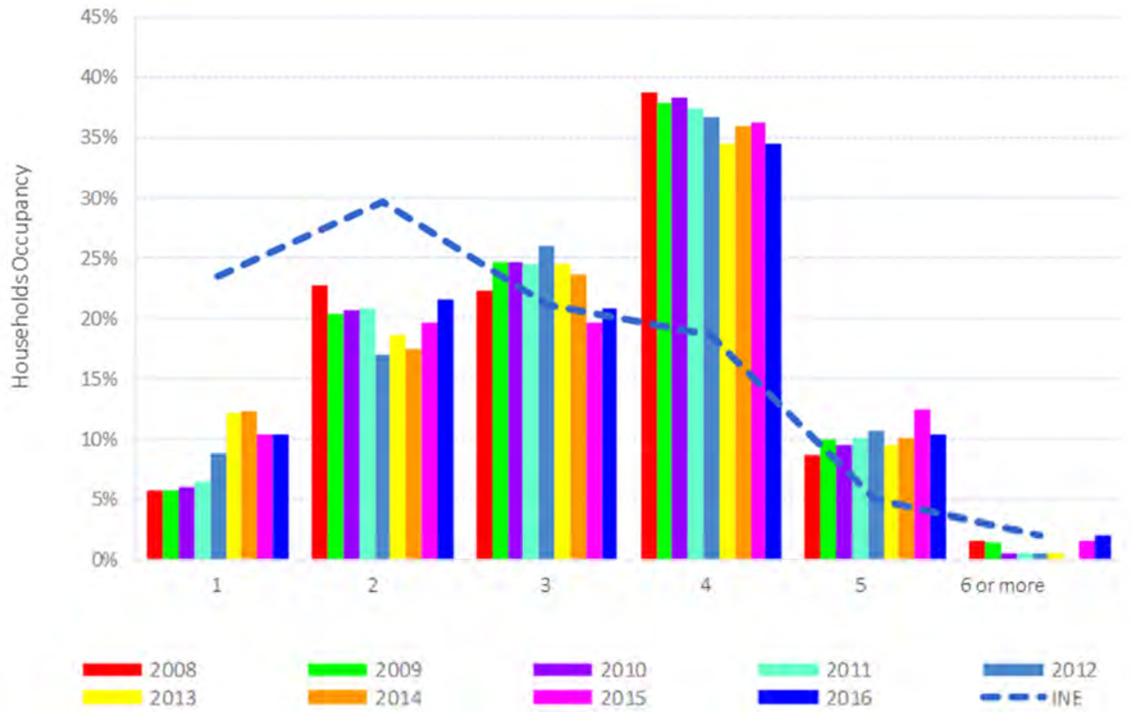
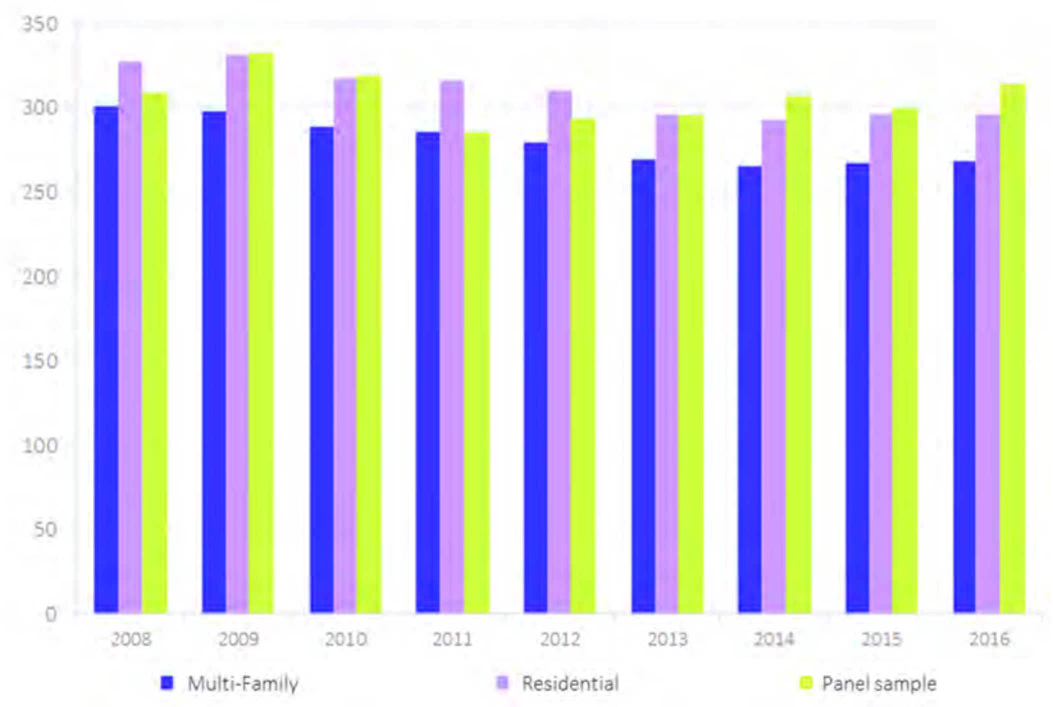


TABLE 18. PERCENTAGE OF HOUSEHOLDS WITH GARDEN OR TERRACES IN THE SAMPLE

Terrace	*Complete sample*	*Stable sample*
Do not have	44.5%	45.6%
Yes, with plants and flowers	36.1%	33.6%
Yes, without plants	19.4%	20.8%
***Garden - Number of* m²**	***Complete sample***	***Stable sample***
Do not have	81.6%	87.2%
Between 25 and 75	14.5%	10.4%
Between 75 and 200	2.6%	2.4%
Between 200 and 500	0.9%	
More than 500	0.4%	

FIGURE 77. **ANNUAL UNITARY CONSUMPTION FOR THE MONITORING PANEL SAMPLE AND FOR THE COMUNIDAD DE MADRID**



5.2.2. Data measurement and transmission technology

The technical requirements needed for the purpose of this study were difficult to cover with normal commercial solutions available on the market. Therefore, ad hoc solutions were developed, based on previous experiences and the study specifications, including:

- characterising consumption curves in the controlled households, with sufficient accuracy to classify water uses and to establish consumption volume at the lowest flow levels,
- during extended time periods of up to 3 years, and
- in locations where between 1 and 8 meters were controlled simultaneously.

The solutions initially analysed from a technical and economic point of view were two:

- Instant flow control recorded with a fixed frequency.
- Fixed volume control with consumption time control.

For each of these solutions, the following considerations were applied.

Instant flow rate control recorded with fixed frequency: local computers and electronic meters.

The metering device would need to be able to provide the instant flow rate figure on a continuous basis and the recording device would need to be able to store that figure with high frequencies, at around a second. This involved to have a very high storage capacity, although the use of computers could make up for the limitation of the acquisition and recording interfaces provided by commercial electronic meter brands.

In terms of the meters, there were a whole host of flow measurement devices available on the market, providing instant flow rate with great accuracy, although the devices are designed for controlling processes or higher diameters than those used for residential consumption, and they are also very expensive. However, the use of electronic meters aimed at controlling consumption for billing purposes is becoming more frequent. Both the meters and the reading interfaces and operating software are designed to enable a large number of meters located in nearby areas to be read, but only the figures for the volume consumed over long periods of time. Although some devices enable additional data to be obtained, as well as presenting good metric characteristics, they also provide additional information, such as the instant flow rate required in this case, consumption time during the period, maximum and minimum flow rates, etc.

The problem with these meters is that, although they facilitate centralisation, they have an acquisition stage that is not optimised for monitoring instant consumption curves in real time.

This solution was finally rejected, since it does not guarantee frequencies below 5 seconds for blocks of up to 8 meters, with storage in computers and, technically, it was not proven with other similar prior experiments (the time required for reading the microprocessor memory plus that of the port opening and data transmission was estimated to be around 600 ms. Since a 13 mm meter will have a maximum flow rate of $3m^3/h$, equivalent to 0.8 l/s, then each litre is consumed in 1.2 seconds, therefore, more than two metres cannot be recorded simultaneously). These meters are not designed for these reading frequencies, although their electronics may allow it (they are designed for monthly readings at least).

Controlling fixed volumes with consumption time control: remote stations and volumetric meters.

This solution is based on the use of commercial remote-control stations, with MODEM GSM integrated for the transmission of data records to the control centre. The metering device would be a rotary piston flow meter, and this was the one chosen for conducting this study.

Since the accuracy of the meters and the measurement at low flow rates should be very high, volumetric flow meters equipped with impulse transmitters were used, to be centralised on datalogger devices. These devices have a memory limitation for recording data and for the number of input channels they allow.

In order to optimise this memory, an advantageous procedure was used, to only record volume based on pulses generated as events. That is, each pulse generates an event on the programme of the device, which will be recorded in the memory together with the date and time at which it took place.

This study includes a pulse per litre or decilitre consumed. This therefore characterises the consumption curve also controlling the water volume consumed.

In view of the foregoing, the precision meters installed, need to be accompanied by a device that records the moment and the amount of water consumed. This device is located close to the precision meter and it is connected to this via a cable. The station automatically and periodically transmits the recorded data, consuming a minimal amount of power (1.5 to 2-watt power and an annual consumption of approximately 18 kWh).

Based on the historical data available, and taking into account that these devices have a storage capacity of up to 25,000 readings, considering a model of consumption per household, of two hundred litres per inhabitant and day and an average of four inhabitants per household, the following storage capacities are obtained:

- An installation for one meter (household): 1 meter with resolution of one litre per pulse involving 800 pulses (readings) per day, that is, a capacity for over 30 days.
- An installation for more than one meter (various households): 8 meters with resolution of one litre per pulse involve 6,400 pulses (readings) per day, that is, a data storage capacity for over 3.9 days.

This initial scope was greatly exceeded throughout the study:

- A maximum volume recorded during the study of 10,100.6 litres in one day, in a user with a decilitre meter (101,006 records), and 29,041 litres in one day, in one user with a litre meter (29,041 records).
- Average single-family homes, during summer months, exceeding 500 litres per household and day.
- This number of records did not pose a problem, since the central control system was parameterised to conduct daily calls, and the remote stations were configured to:
    a) Automatic preventive download of memory overflows. It prevented any loss of data during extraordinary consumption days, such as filling swimming pools, and high consumption days, such as irrigation.

       The remote station made the call automatically, emptying the memory.
    b) Alarm configuration. Preventive and corrective incident alerts.

In short, the selected devices were:

Hydraulic devices: volumetric meter (main cold-water intake).

Electronic devices: remote control station (MODEM GSM integrated) for data recording and transmission, connected to each general intake meter by means of a pulse emitter.

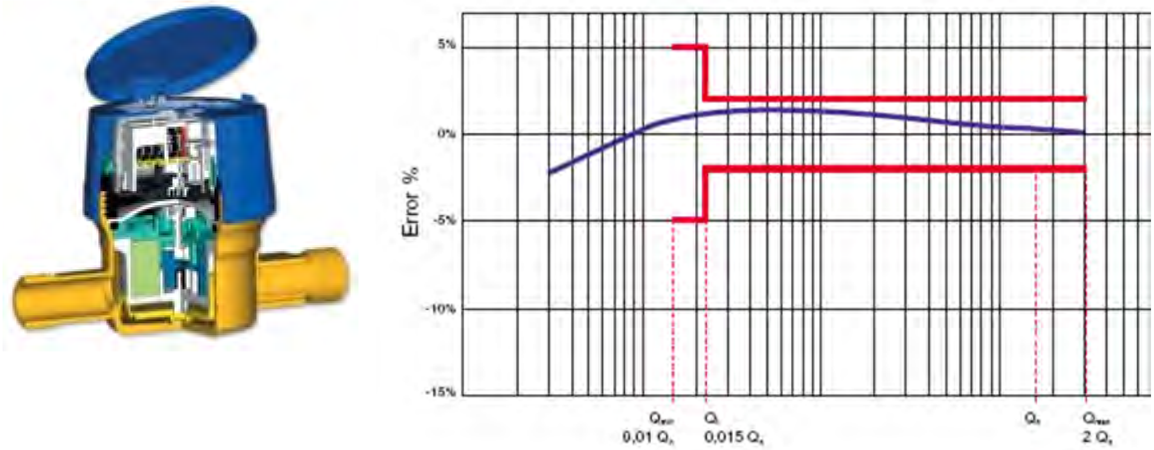
Devices used

Below are the devices that were used.

Class C volumetric meter (620C)

Rotating piston meter, equipped with a pulse emitter that generates an impulse each time one litre passes through. (See Figure 78). This emitter is connected to one of the remote station's digital intake channels. DN 13 mm meters were used, and only where there was a drop in pressure, which involved visible signs of a drop in service quality, DN 20 mm meters were installed

FIGURE 78. CLASS C PRECISION METERS



This meter was used in the installations carried out during the 2008-2011 period, the characteristics of which are outlined in Table 19. It was also used in installations after the indicated period, where the reading and billing meter had to be replaced, since this meter is homologated in Spain to be used for these purposes, which is not the case with the class D meter which is outlined in Table 20.

Class D volumetric meter [4] (Aquadis+ by Actaris)

Rotating piston meter, equipped with a pulse emitter that generates an impulse each time one decilitre passes through. (See Figure 79). This emitter is connected to one of the remote station's digital intake channels. DN 13/15 mm meters were used. This is the meter that was installed in nearly all the users incorporated into the study since 2011 (see Table 20).

Pulse emitters (See Figure 80).

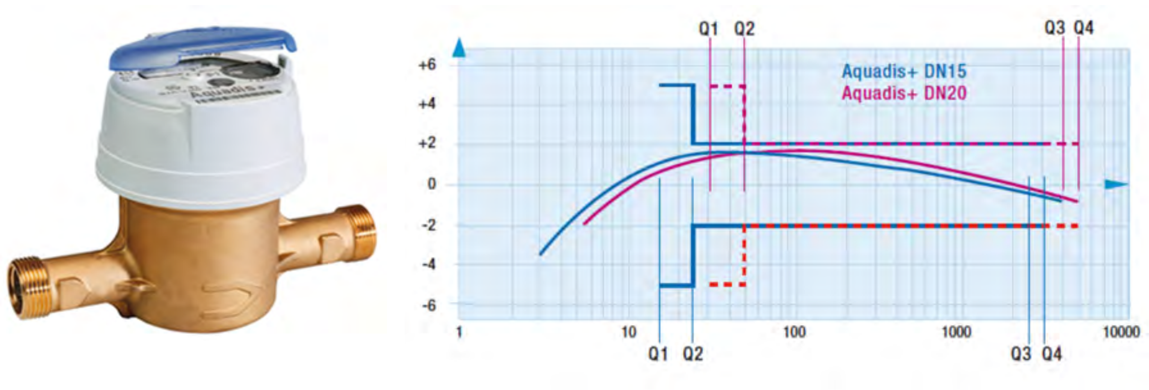
The meters controlling the household's general intake have been equipped, on the upper part, with a pulse emitter, which transmits the signal of the volume passing from the meter that measures it to the remote station, via the cable that links them. The minimum volume that can be transmitted is one decilitre (if it is a class D meter), or one litre (if it is a class C meter), with this being the exact reading obtained, at the precise time at which it was measured.

[4] Pursuant to British Standard 5728/7·

TABLE 19. TECHNICAL CHARACTERISTICS OF THE CLASS C VOLUMETRIC METER

Nominal diameter (DN)		***13 mm***	***20 mm***
Metrological class EEC		Class C all positions	Class C all positions
Maximum allowable temperature	°C	30	30
Maximum temperature (short period)	°C	50	50
Maximum allowable pressure	Bar	16	16
Pressure test	Bar	25	25
Pressure drop unit at Q_{max}	Bar	1	1
Nominal flow rate Q_n	m^3/h	1.5	2.5
Maximum flow rate Q_{max}	m^3/h	3	5
Minimum flow rate Q_{min} (Precision ± 5%)	l/h	3	6
Transition flow rate Q_t (Precision ± 2%)	l/h	5	12
Start-up flow rate	l/h	<1	2
Maximum reading capacity	m^3	105	105
Minimum graduated unit	m^3	0.0001	0.0001
Pre-device communication		Cyble Technology	Cyble Technology

FIGURE 79. CLASS D PRECISION METERS



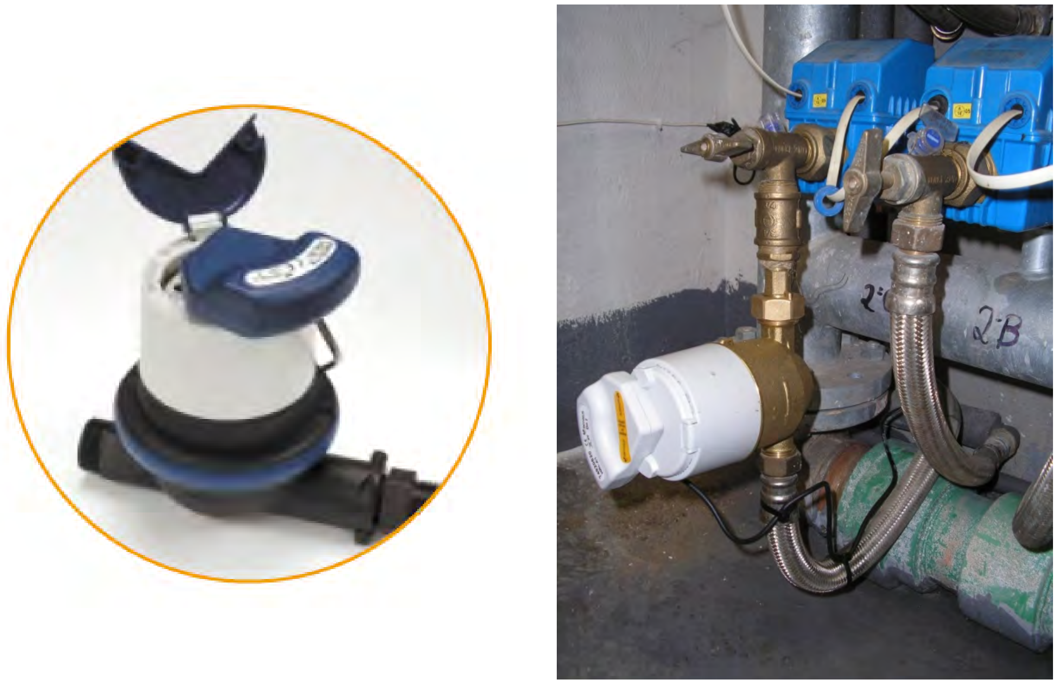
Remote control station with integrated GSM MODEM

Sofrel Model S510, for data transmission to the control centre (see Figure 81) These devices have provided the system with flexibility, they are modular, extendable, totally configurable and have a storage capacity of up to 25,000 readings. The remote station is equipped with a transmission antenna that enables the best signal to be obtained, or the aerial to be taken out to the station's surrounding areas.

TABLE 20. TECHNICAL CHARACTERISTICS OF THE CLASS D VOLUMETRIC METER

Metrological class		*Class D all positions*
Maximum allowable temperature	°C	30
Maximum temperature (short period)	°C	50
Maximum allowable pressure	bar	16
Pressure test	bar	25
Pressure drop unit at Q_{max}	bar	1
Nominal flow rate Q_n	m^3/h	1.5
Maximum flow rate Q_{max}	m^3/h	2
Minimum flow rate Q_{min} (Precision ± 5%)	l/h	7.5
Transition flow rate Q_t (Precision ± 2%)	l/h	11.5
Start-up flow rate	l/h	1
Maximum reading capacity	m^3	9,999
Minimum graduated unit	l	0.02
Pre-device communication		Cyble Technology

FIGURE 80. INSTALLED PULSE EMITTERS



As described previously, each meter recording the main intake of the household has been equipped with a pulse emitter that generates an impulse each time one litre or one decilitre passes through the meter. This emitter has been connected to one of the digital intake channels of the remote station. Each channel has been given a reading function per rising pulse edge, which results in the data being stored with the date and time at which the event takes place. The stored data is always the fixed volume unit (1 litre or 1 decilitre), although the total volume could be stored instead.

The devices are powered at 220 VAC. The consumption takes place via the power supply, that has to be provided to the pulse emitter and solely increases during the communication phases via the GSM MODEM, with its duration being lower than one minute (power of 1.5 at 2 watts, and an approximate annual consumption of 18 kWh).

Given that the installation of the remote-control stations has been carried out near the general water input meters, water-resistant boxes have been prepared to prevent splashing (installations under sink), or rain (outdoor installations). Therefore, the stations have been installed inside an IP 68 box in which a fixation plate from the state has been installed previously and they have been prepared for the wiring to pass through to ensure water tightness (Figure 81).

FIGURE 81. REMOTE CONTROL STATION. RIGHT (INSIDE THE PROTECTIVE BOX IP 68)

Lastly, on the outside of the actual remote station box, a label is placed to identify the study being conducted, specifically stating to which remote station it belongs and the contact details in the event of an incident (Figure 82).

FIGURE 82. LABEL IDENTIFYING THE REMOTE STATIONS

The Control Centre has been equipped with a PC for receiving signals, equipped with a GSM modem, for receiving calls from the remote stations, with the aim of distributing the number of communications along two lines. The device has been installed with Sofrel *PCwin* software, managing the installed remote stations and interrogating them according to a schedule. This software has also allowed remote configuration operations on the stations.

The meters employed for this study were installed, whenever possible, in series with the existing meter, with the aim of not interfering with customers' bills. When, for space-related reasons, this has not been possible, the billing meter has been replaced by a volumetric one.

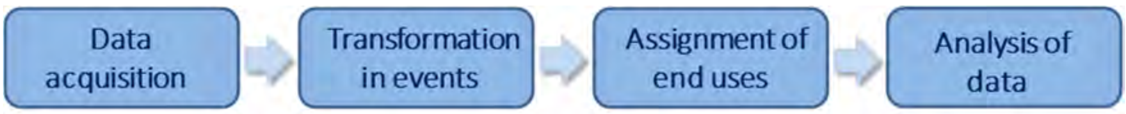
Figure 83 illustrates two examples of some of the installations carried out.

FIGURE 83. METER FOR CONTROLLING WATER CONSUMPTION IN THE HOUSEHOLD (LEFT) REMOTE STATION FOR DATA RECORDING AND TRANSMISSION (RIGHT OF THE FIGURE)

5.2.3. Data processing for identifying water end uses

In order to carry out this complete process, the following phases were carried out (Figure 84).

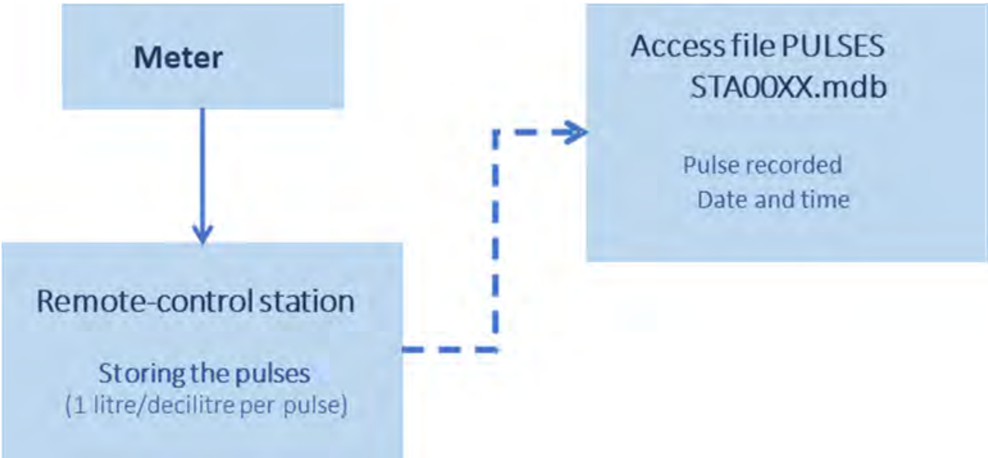
FIGURE 84. DATA PROCESSING PHASES



Data acquisition: recording consumption data from each user and transmitting them to a server with storage and processing capacity. As described previously, data collection was carried out via meters with output via pulse emitters. This emitter generates a pulse each time a fixed volume of 1 litre passes through the meter, if it is a class C meter, and 1 decilitre if it is a class D meter. The pulse emitter is connected to the digital input channel of the remote-control station and has a reading function associated to it which stores the pulses with the exact time at which they take place. These data, thanks to the integrated GSM MODEM are transmitted to the control centre. The control centre automatically communicates and downloads data on a daily basis, updating the data of said communication (Figure 85). Similarly, a technician verifies this procedure is working correctly on a daily basis.

An *Access* file is generated for each remote station and these files are stored in independent folders that identify the calendar month and year of the data reading.

FIGURE 85. DATA ACQUISITION METHOD



Each of these files have an independent table for each meter, controlled remotely, therefore, the remote stations of households with hot and cold-water meters and households with meters located in the same battery of meters, generate a single Access file with various tables. Each table contains the date, hour, minute and second of the reading and the accumulated volume recorded.

Apart from the consumption data, the remote stations have been configured to generate alarm notification tables (in the event of such alarms taking place) in the following cases:

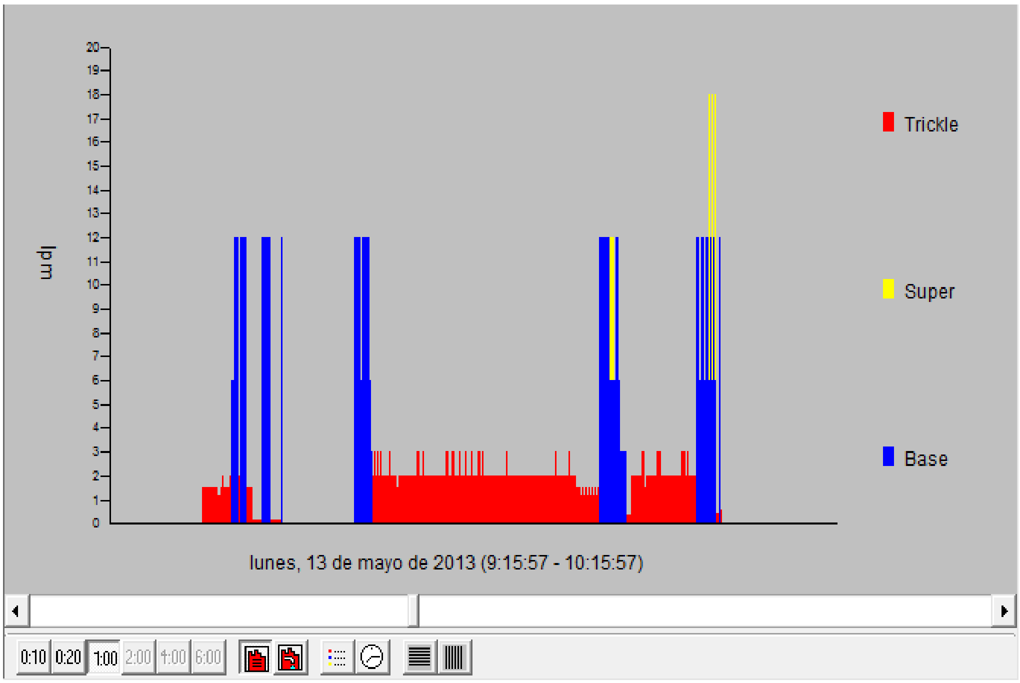
- If the batteries are running out.
- If there is a transmission error.
- If the device's memory is full. The remote station is equipped with a specific function that forces the download of data when the memory is running out.

Transformation in events: conversion of pulse/time data collected by volumetric meters and from those flow rates, consumption events are created.

The data obtained from the remote stations are databases with tables containing records of pulses that have taken place. The data recorded in these tables are discrete, that is, a pulse is recorded when a specific volume has passed through the meter. Therefore, they need to be transformed into a continuous value that reflects the reality of the consumption over time. Subsequently, based on the time-flow rate curve, the different water usage events are identified. For these operations, an ad hoc application has been developed to directly transform pulses into events, automating the file conversion process for all users. Via this procedure, the recorded consumption has been separated into various water usage events, characterised by a series of attributes, such as the start and end time, the duration, the maximum or peak flow rate and the total volume, and these are organised in categories called "**base**", "**super**" or "**trickle**".

"***Trickle***" events are events that are initially identified by their scarce flow rate as potential trickles or drips of water (leaks or open taps mainly). The other events potentially identifiable by their use attributes, which are either unique in the "***base***" time, *o*r superimposed, if, given their attributes, they cannot be attributed to a single "***super***" or superimposed use, (see Figure 86).

FIGURE 86. CONSUMPTION EVENTS



Assignment of end uses: correlation of consumption events and each of the possible uses in each household. This is carried out according to characteristic data of the event (duration, volume, maximum flow peak). One of the project's challenges was relating the type of water usage to the different events identified.

At the beginning of the project the commercial software *Trace Wizard*® was used [5] This application carries out a preliminary classification of the different identified events, based on simple decision trees. This classification must be supervised by an operator, who will decide the final usage assignment. This method requires an operator to work a significant number of hours, estimated between 1–2 hours per week of consumption records in one household[6], which makes it practically unfeasible for monitoring a somewhat large sample over a period of various years. Therefore, a procedure had to be developed that would allow a quicker automatic assignment of uses, since the volume of data to be analysed did not allow for a monthly consumption and usage analysis with the month following the one that generated the pulse data.

In any of the initial tested procedures, a manual assignment was always performed, of at least 2-3 months per household (training period), by technicians via the *Trace Wizard*® graphic interface programme (Figure 87).

The assignment of uses is based on the knowledge of the theoretical shape of the consumption curve for a specific use, and the particularisation obtained for each household in the calibration of devices (see Figure 88).

[5] Trace wizard version 4.1 R17, by the company *Aquacraft* by *Boulder,* CO, USA

[6] Mayer, P.W., W.B. Deoreo, E.L.Towler, and D.M.Lewis (July 2003). Residential indoor water conservation study

FIGURE 87. EXAMPLE OF MANUAL ASSIGNMENT OF USES USING THE TRACE WIZARD SOFTWARE

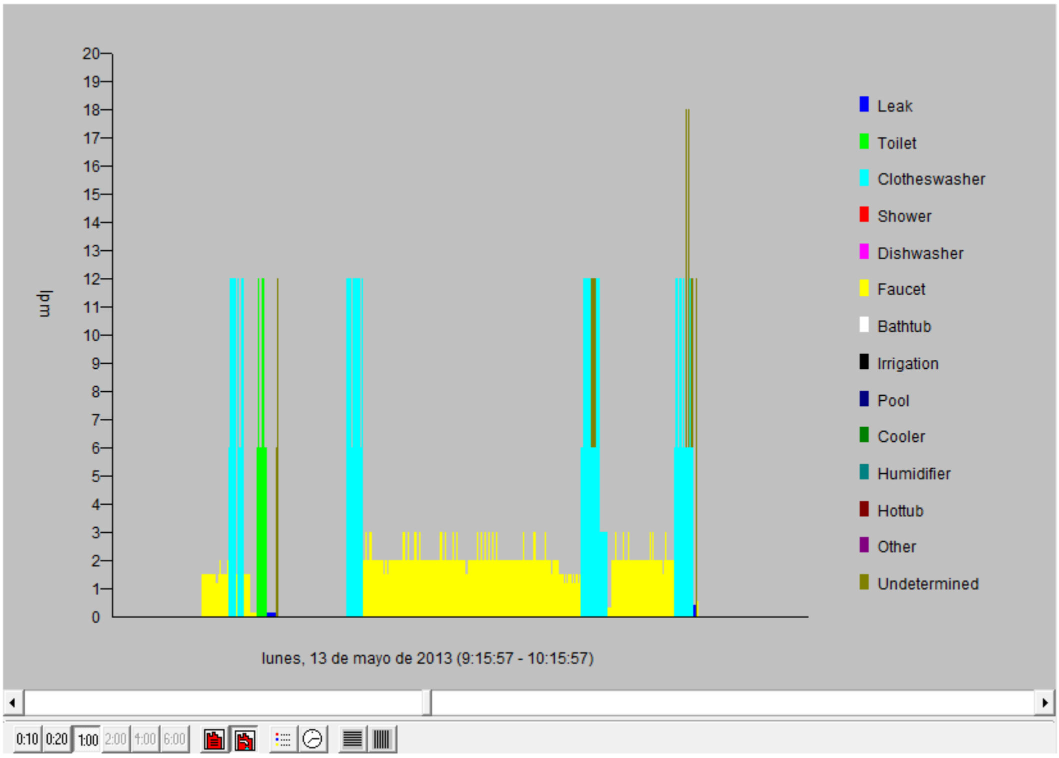
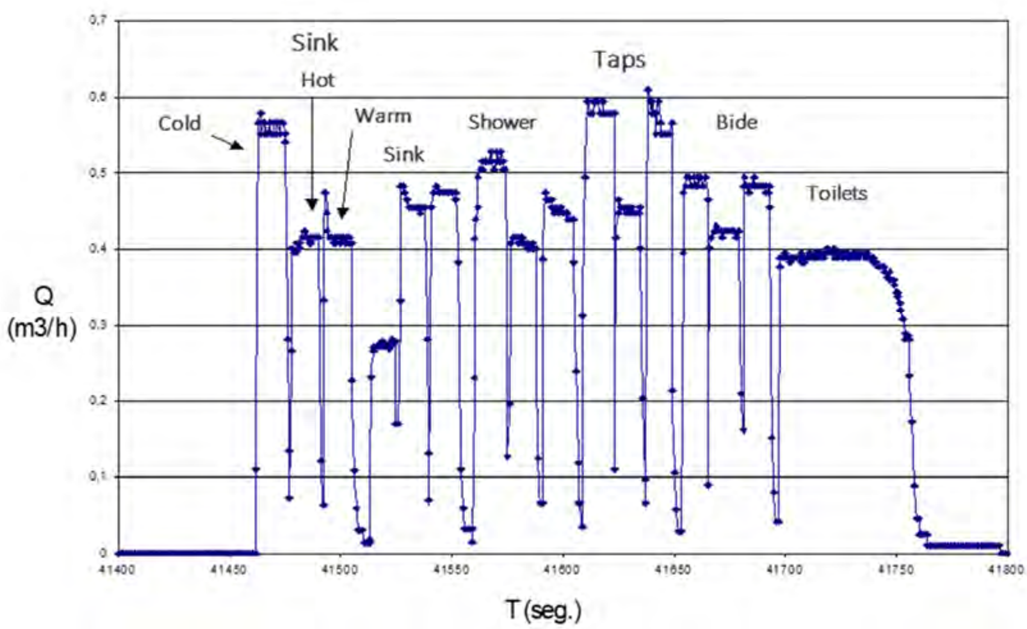


FIGURE 88. EXAMPLE OF TYPICAL CONSUMPTION CURVES



Trained technicians have manually assigned the uses to each event for, at least, two months of data for each meter. The manual assignment of uses provides a great deal of quality in assignments, but a trained technician uses an estimated 2 hours for 15 days of data.

The data for these months of training have been statistically studied using three statistics for each event: **volume**, **peak** or **maximum flow** of the signal and **event duration**.

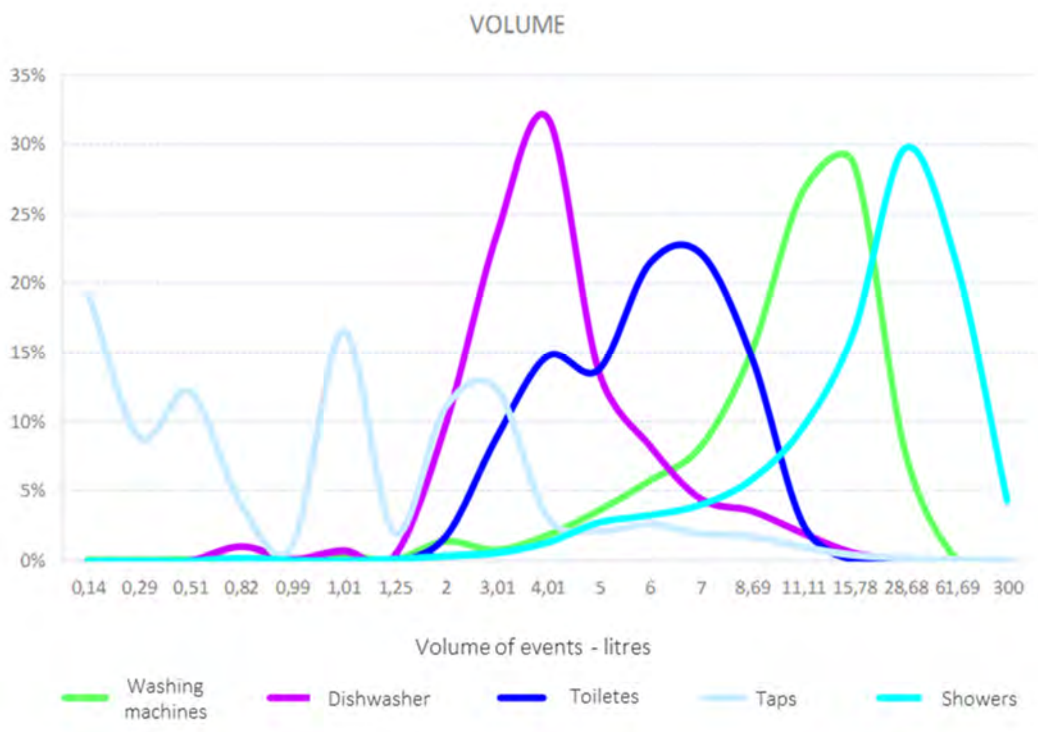
Firstly, different parametric distributions were tested (normal, Student's t, Fisher-Snedecor F and, Pearson's X^2) and taking relationships between independent variables or as dependent variables and their conditional probabilities (Bayes' Theorem). The conclusions were that the data do not respond to any of the studied distribution functions and the results obtained for the assignment of uses were far from the spectrums managed in the analyses carried out by technicians.

Given that the tested theoretical distribution functions did not reveal satisfactory results, the empirical distribution obtained was used for the data corresponding to the training period.

For the discretisation of these series of data, a (*Minimal Entropy Heuristic)* [7] algorithm was used, calculating the probability intervals for the three variables considered (volume, peak and duration), on a sample of different users and months analysed monthly by the technicians. This discretisation was used subsequently for all users' data. For the total volume of water in one event, 19 intervals are defined, 16 for the duration and 14 for the maximum flow rate.

Figures 89 to 91 represent the frequency distribution observed in the sample and discretised in these intervals, for the aforementioned variables and for the use of taps, showers, toilet flushes, washing machines and dishwashers, which reveals significant differences among different appliances.

FIGURE 89. FREQUENCY DISTRIBUTION OF THE VOLUME OF EVENTS IN DIFFERENT APPLIANCES



[7] Jaroslaw P.Sacha. (1999). New synthesis of bayesian network classifiers and cardiac spect image interpretation

FIGURE 90. FREQUENCY DISTRIBUTION OF THE DURATION OF EVENTS IN DIFFERENT APPLIANCES

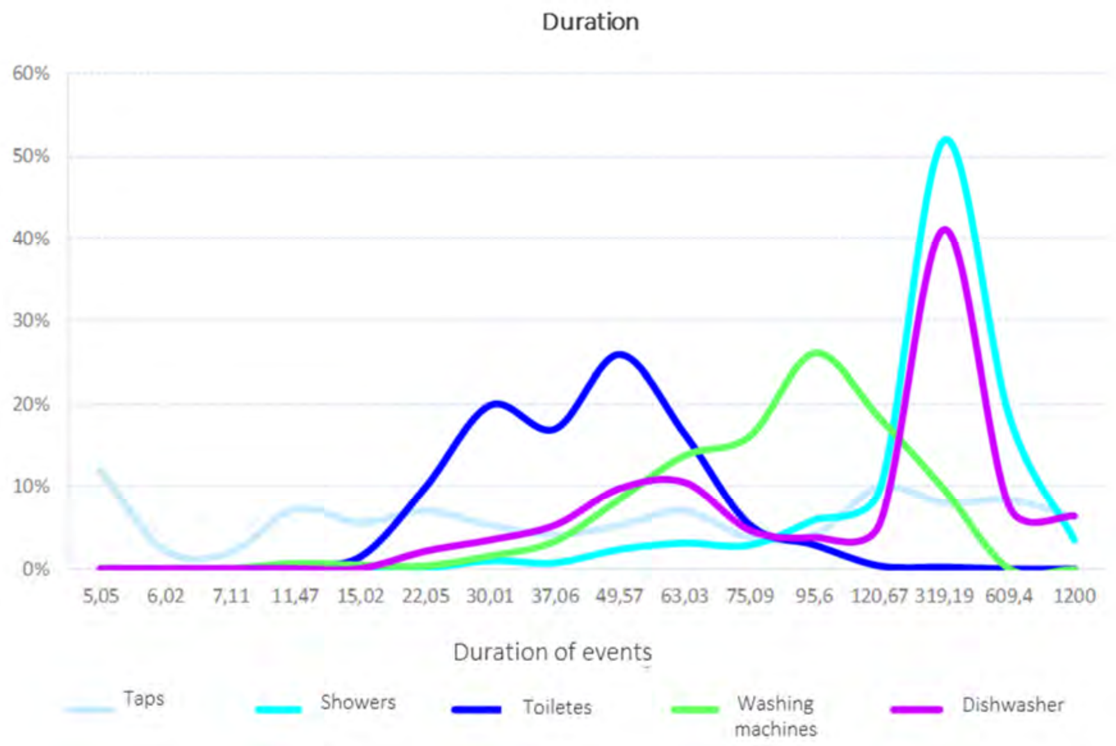
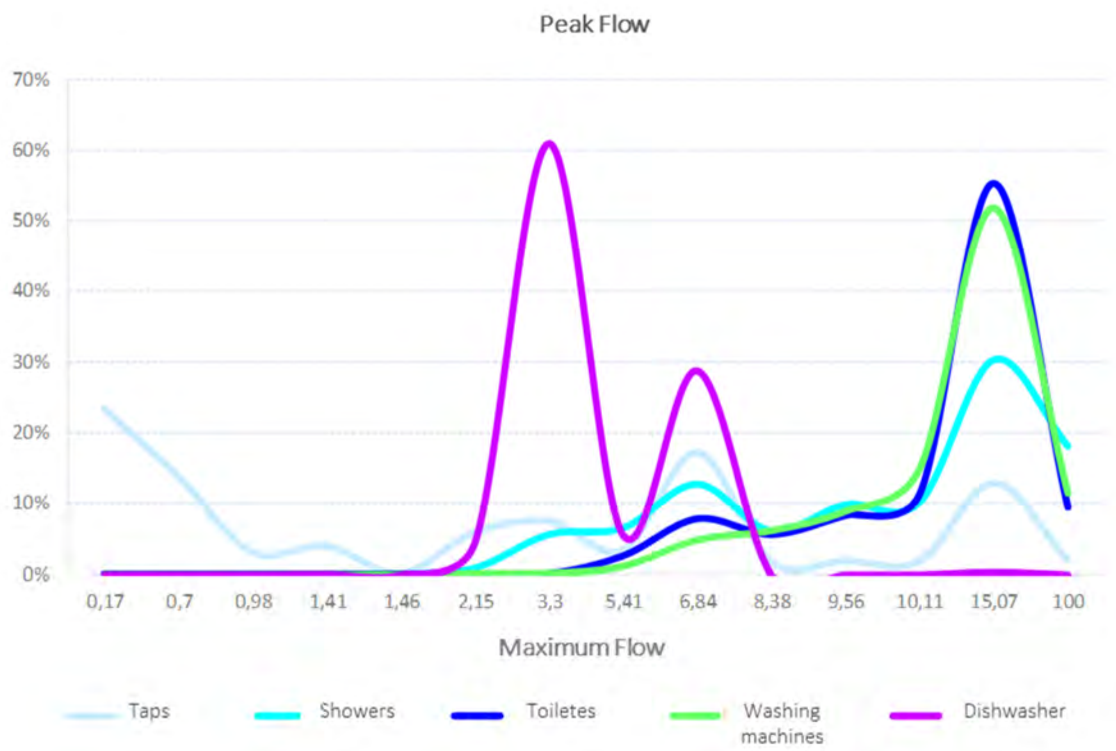


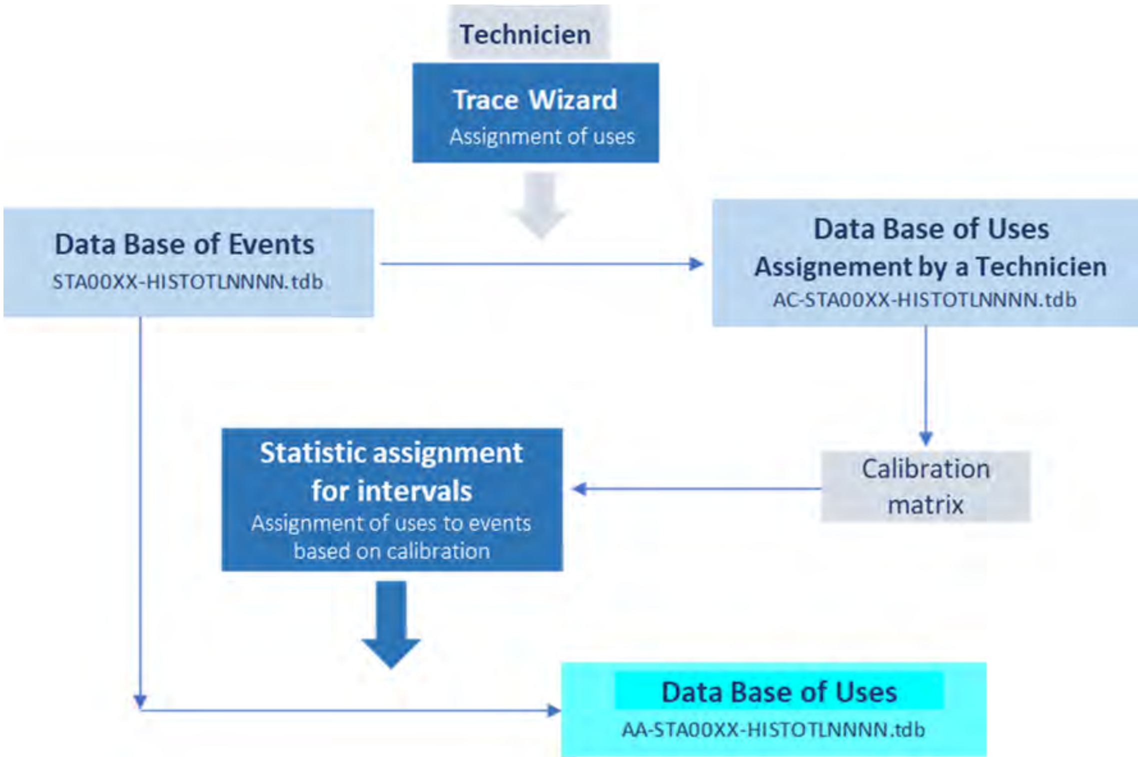
FIGURE 91. FREQUENCY DISTRIBUTION OF THE MAXIMUM FLOW OF EVENTS IN DIFFERENT APPLIANCES



Considering possible dependencies between the three variables, a very simple Bayesian network has been built (three nodes), which allows the probability of a specific event to be calculated (given its volume, duration and maximum flow characteristics) belonging to each of the different water usage categories and the most probable of these to finally be assigned. The events identified by the technicians as consumption in swimming pools, irrigation and leaks have been excluded, since these events have a high singularity that allows them to be identified independently, through preestablished criteria. Figure 92 illustrates the outline of the aforementioned end use assignment process.

The tests offered an acceptable concordance (above 97% in assigned volumes) between the results assigned by technicians, with regard to those assigned by the Bayesian network based on the empirical distribution of probabilities.

FIGURE 92. END USE ASSIGNMENT METHOD



5.2.4. Additional information for the final data analysis

Before the data analysis itself, activities have been carried out to obtain information regarding the characteristics of the households and the occupants thereof, via surveys, tests on the households to characterise the different water uses, by calibrating devices and also climate data downloaded from official agencies.

Additional information: surveys, calibrations and climate data

The surveys were carried out simultaneously with the installation of the devices and they were subsequently reviewed, generally each year, and also when there were uninstallations. These surveys characterise the sample used in the *Monitoring Panel* and are used in both the analysis of consumption and usage data and in the actual assignment of end uses or consumption micro-components.

A structured questionnaire has been used as an instrument for collecting information. The components of the survey and the subject-matter thereof are outlined in Figure 93.

FIGURE 93. DATA COLLECTION QUESTIONNAIRE

0-Prior questions (and authorisation)

Non-subjective personal data, regarding the respondent. They carry out a control and verification function, since very often these are known beforehand. Furthermore, authorisation included for use of the data in the rest of the questionnaire.

I-General Data

This consists of an identification code that is solely used to disassociate the personal information, subject to Data Protection Laws, from the rest of the usage data in the analyses, thus guaranteeing the anonymity of data.

II-Physical characteristics of the household

This section includes information concerning the type of household, its age, number of rooms, bathrooms, terrace, garden, swimming pool, water storage tank, etc.

III-Characteristics of the plumbing facilities

Elements that consume water (toilets, showers, bath tubes, taps, washing machines, heating, etc.) and the characteristics thereof (number, type, existence of saving devices, etc). Refurbishments carried out in these types of installations are also specified.

IV Occupancy characteristics

Number of inhabitants and external people, age and absences from home (holiday periods).

V-Consumption habits and socioeconomic data

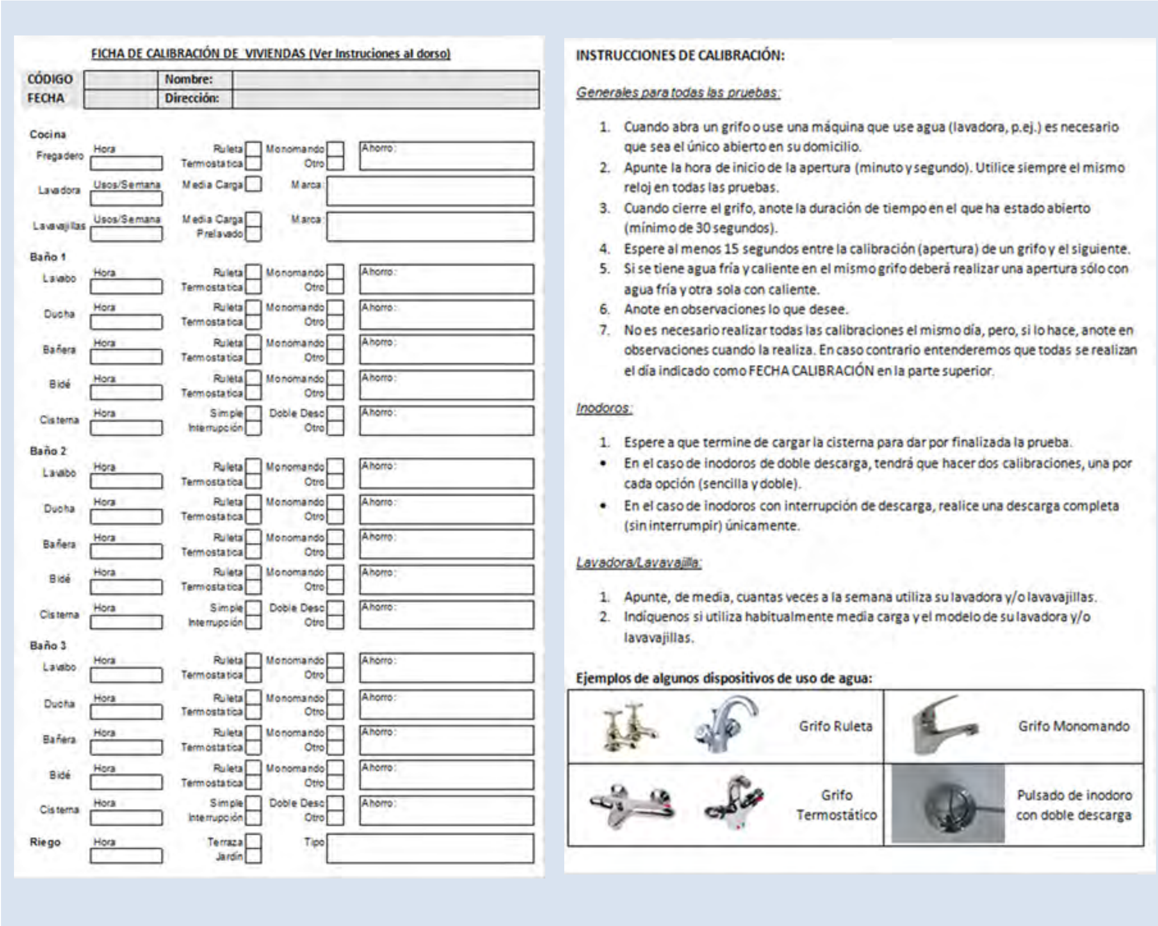
In the case of consumption habits, the answer options have been ranked in increasing or decreasing intensity regarding the point of desired information. The questions are related to the individual's concern with water problems and related consumption habits (turning off taps, irrigation methods, etc.). For the socioeconomic data, only the age and level of education are considered.

Calibration of appliances in households. Tests were conducted to characterise potential water uses in the households taking part in the *Monitoring Panel*. The tests were carried out once the meter, pulse emitter and remote station were installed, and the correct pulse reading was verified.

Calibrations consisted in recording the pulses from the various devices or water consumption points, in an individualised manner and controlled over time. Furthermore, for devices that can use hot and cold water, both consumptions were individualised, since the usage events have different characteristics.

In the sections on washing clothes and dishes (washing machines and dishwashers), given the diversity of programmes available, information has been collected regarding the main programmes used in the household and a precise communication was requested regarding when they were used (the day and hour interval) in order to characterise the events, which is complemented with bibliographic or commercial information regarding the specific brand. The data sheet used for data collections is illustrated in Figure 94.

FIGURE 94. HOUSEHOLD DATA CALIBRATION SHEET



FICHA DE CALIBRACIÓN DE VIVIENDAS (Ver Instruciones al dorso)

CÓDIGO | Nombre:
FECHA | Dirección:

Cocina
Fregadero: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Lavadora: Usos/Semana | Media Carga | Marca
Lavavajillas: Usos/Semana | Media Carga / Prelavado | Marca

Baño 1
Lavabo: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Ducha: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bañera: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bidé: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Cisterna: Hora | Simple / Interrupción | Doble Desc / Otro | Ahorro:

Baño 2
Lavabo: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Ducha: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bañera: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bidé: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Cisterna: Hora | Simple / Interrupción | Doble Desc / Otro | Ahorro:

Baño 3
Lavabo: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Ducha: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bañera: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Bidé: Hora | Ruleta / Termostatica | Monomando / Otro | Ahorro:
Cisterna: Hora | Simple / Interrupción | Doble Desc / Otro | Ahorro:

Riego: Hora | Terraza / Jardín | Tipo

INSTRUCCIONES DE CALIBRACIÓN:

Generales para todas las pruebas:

1. Cuando abra un grifo o use una máquina que use agua (lavadora, p.ej.) es necesario que sea el único abierto en su domicilio.
2. Apunte la hora de inicio de la apertura (minuto y segundo). Utilice siempre el mismo reloj en todas las pruebas.
3. Cuando cierre el grifo, anote la duración de tiempo en el que ha estado abierto (mínimo de 30 segundos).
4. Espere al menos 15 segundos entre la calibración (apertura) de un grifo y el siguiente.
5. Si se tiene agua fría y caliente en el mismo grifo deberá realizar una apertura sólo con agua fría y otra sola con caliente.
6. Anote en observaciones lo que desee.
7. No es necesario realizar todas las calibraciones el mismo día, pero, si lo hace, anote en observaciones cuando la realiza. En caso contrario entenderemos que todas se realizan el día indicado como FECHA CALIBRACIÓN en la parte superior.

Inodoros:

1. Espere a que termine de cargar la cisterna para dar por finalizada la prueba.
- En el caso de inodoros de doble descarga, tendrá que hacer dos calibraciones, una por cada opción (sencilla y doble).
- En el caso de inodoros con interrupción de descarga, realice una descarga completa (sin interrumpir) únicamente.

Lavadora/Lavavajilla:

1. Apunte, de media, cuantas veces a la semana utiliza su lavadora y/o lavavajillas.
2. Indíquenos si utiliza habitualmente media carga y el modelo de su lavadora y/o lavavajillas.

Ejemplos de algunos dispositivos de uso de agua:

Based on the calibration, examining the events from the received pulses, the technician had information about the event characteristics, such as maximum flow rate (in the case of taps, showers and bath tubes as these had hot and cold water consumption, they would have two values for each), volume associated with use (mainly in water tanks, where there may be various different ones, in cases such as dual flush mechanisms) and consumption duration (important in toilets, programmed irrigation and washing cycles). With this information, the technician carried out the assignment of uses for the training months.

Climate data. In terms of climate data, to aid the interpretation of consumption and usage results for the sample, the decision was made to collect some meteorological data in order to explain variations in the patterns (see Table 21). Accordingly, average monthly data were calculated with 10 control points, 7 of which belong to the Comunidad de Madrid (Navacerrada; Colmenar; Barajas; Madrid; Cuatro Vientos; Getafe; Torrejón) and 3 to nearby areas (Guadalajara, Cuenca and Toledo), so there were representative values in the entire area of the study.

TABLE 21. WEATHER DATA FOR WATER CONSUMPTION AND USAGE ANALYSES

T	Monthly average daily temperatures (ºC)
dT	Daily average temperature standard deviation
Tx	Monthly average of maximum daily temperatures (ºC)
Tn	Monthly average of minimum daily temperatures (ºC)
R	Accumulated rainfall during the month (millimetres)
Q	Quintile to which it belongs
nr	Number of days with rainfall >= 1 mm
Hr	Total sunshine hours during the month
%	Percentage of total sunshine hours during the month compared to normal

Data analysis

Through a series of routines, the data obtained have been processed and arranged for analysis. The pulse data have been processed not only to obtain consumption events, but also to obtain consumption histograms.

In terms of the main parameters on which the data from the tables were grouped together, with the consumption and usage data for the entire month, these were the type of day (**non-working days**, including Saturdays and Sundays; **regional non-working days** and **business days**); the time at which the consumption took place; the household occupancy and the type of household (multi-family homes, which include the categories of flats and apartments/studio; and single-family homes, which include the categories of house/detached house without a plot, semi-detached houses with a communal plot, semi-detached house with its own plot and individual houses with their own plots).

6. Study results

With the selection of households that have formed part of the study, the aim was to obtain a representativeness of the sample with regard to the explanatory water consumption variables, as well as the concordance thereof with the average values of these parameters in the Comunidad de Madrid. However, there is a series of factors that cannot be known *a priori,* which can only be identified through monitoring and by the actual progress of the measurements and detailed studies.

An analysis of the information recorded in terms of consistency must consider the differences in such variables throughout the study, therefore these differences have been analysed in the section “Sample characterisation”.

The results of the study, based on the readings of the households that formed part of the study sample are divided into consumption results and end use or micro-component results.

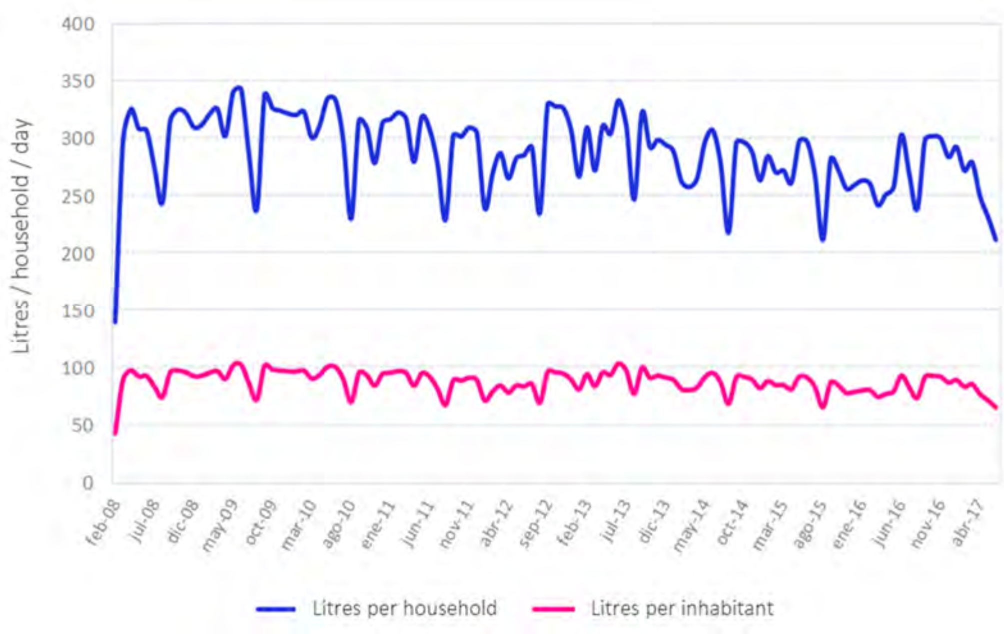
6.1. CONSUMPTION RESULTS

This section summarises the data obtained throughout the study, in terms of monthly consumptions recorded in the sample households and consumption data per household and per inhabitant.

The results are presented, taking into account both, real days with consumption, that is, days of the month on which some water consumption was recorded in the household, and calendar days, that is, every day of the month, regardless of whether or not consumption was recorded.

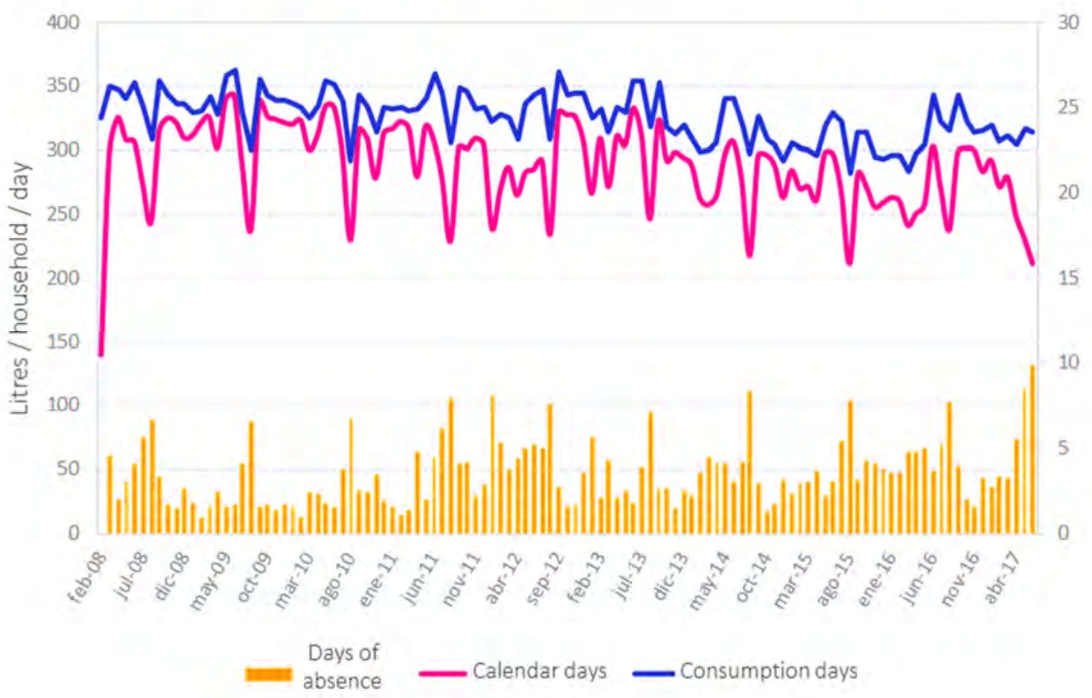
By real days, average monthly data, in litres per household, or per inhabitant and day, are illustrated in Figure 95. Both per household and per inhabitant, there is a downward trend in consumption, particularly since 2013.

FIGURE 95. CHANGES IN MONTHLY CONSUMPTION PER CALENDAR DAYS



The comparison of data per calendar day or day with consumption are shown in Figure 96, which also includes the average number of days without consumption per month (absences). The main differences between the two types of data are recorded during holiday periods. In some cases, the periods are stable from one year to another (Christmas and a significant part of summer holidays), but others are variable, depending on the day/s of the week (long weekends) or the year in which holidays fall (Easter Week and holidays that do not fall on the same day). The highest values of days without consumption are recorded every year during August, with an average of 7.3 days of absence.

FIGURE 96. CHANGES IN MONTHLY CONSUMPTION PER HOUSEHOLD



The downward trend in consumption is confirmed by observing annual data, particularly for calendar days and days within real consumption, as illustrated in Figure 97. Average consumption during the entire study period was 327.7 litres per household/day, and 99.8 litres per inhabitant/day, for real days with consumption, together with 286 litres per household/day and 87.2 litres per inhabitant/day for calendar days. The average annual rate of decline is 1.7% with regard to consumption per household, considering both calendar days and real days with consumption. The average for the last three years is 12% lower than that of the first three years of the study. The figures per inhabitant also dropped, by around 1.3% per year.

The maximum number of absence days per year in 2012 was 53 days, later stabilising at around 45 days per year. The figures for 2008 refer to the formation of the *Monitoring Panel*, in January and February, when not all users recorded complete consumption months and those for 2017 ended in June, therefore the entire summer period is not reflected.

Figure 98 illustrates the number of days without consumption in the household, by months, which almost coincides with the days on which the properties were unoccupied. It is important to bear in mind that here it does not consider properties that are partially unoccupied which may be the case on a single day, that is, it only considers periods equivalent to or exceeding 24 continuous hours without consumption. For the reasons outlined previously, the graph for the months of January and February 2008 have been eliminated.

The details in Figure 98 illustrate that the main periods per year in which households were unoccupied, normally coincide with the month of August, followed by July, and the lowest values are during the winter months.

FIGURE 97. CHANGES IN ANNUAL AVERAGE CONSUMPTION

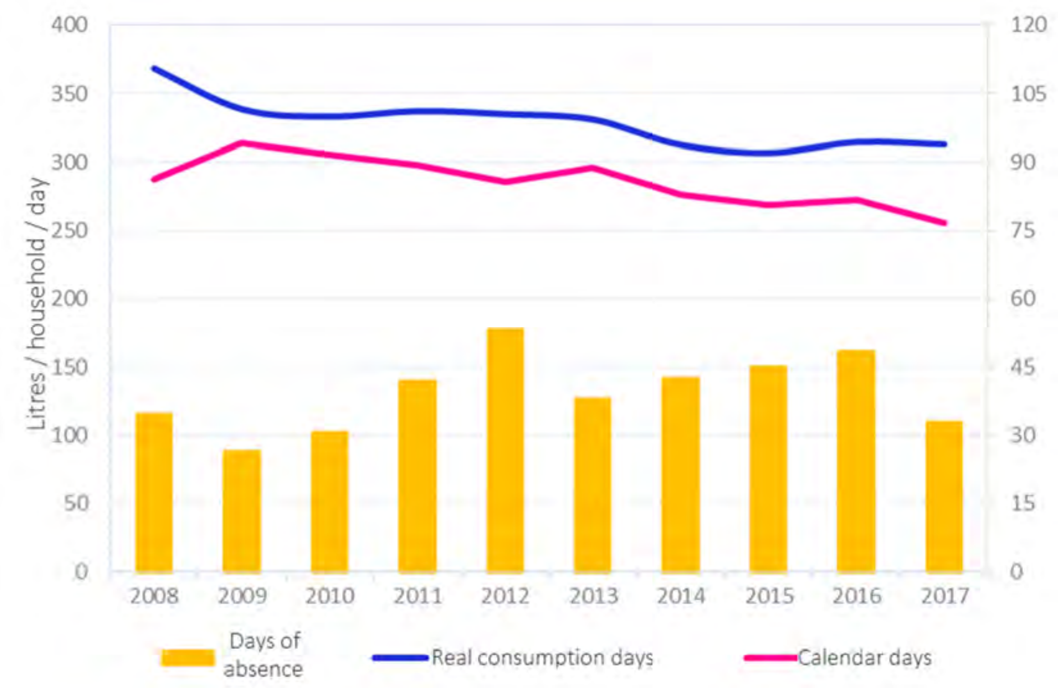
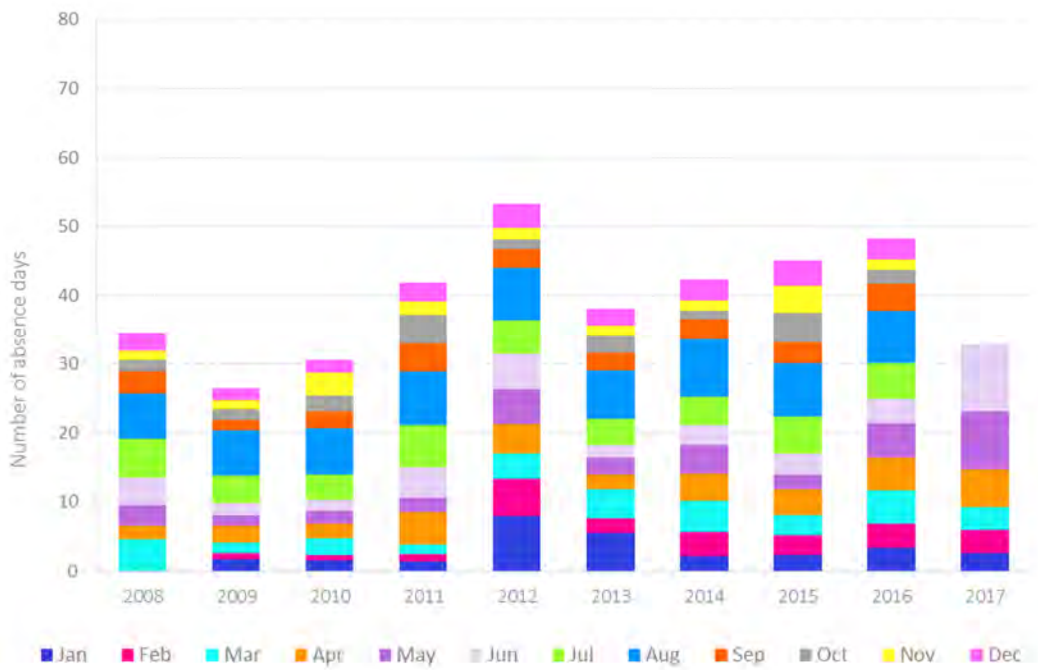
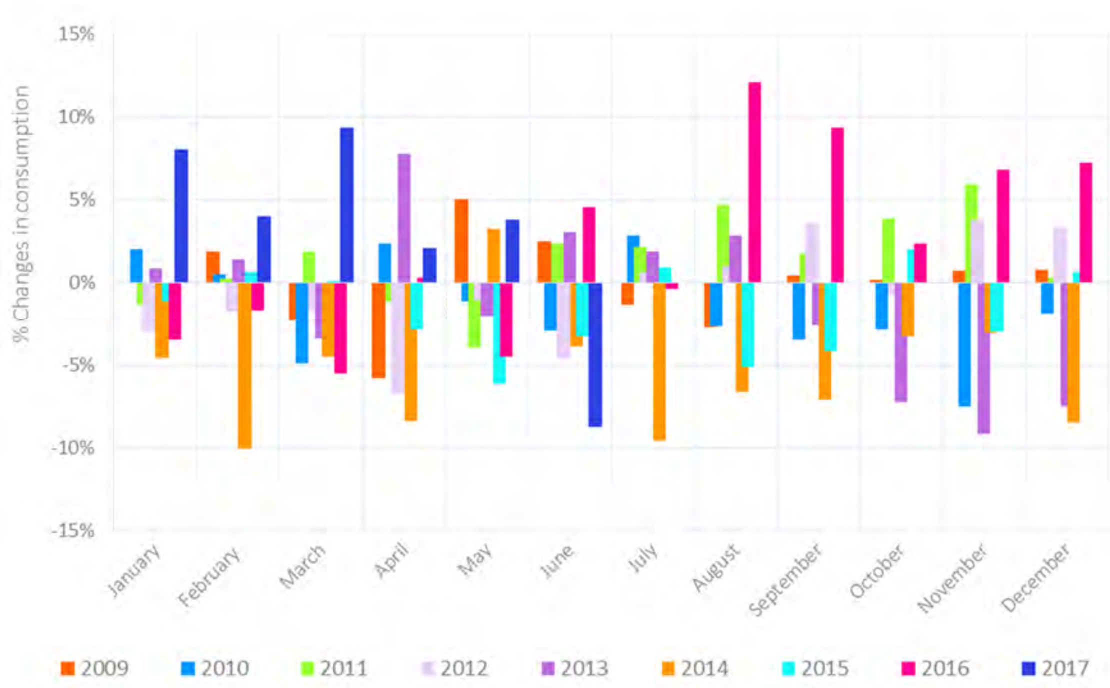


FIGURE 98. MONTHLY CONSUMPTION FIGURES FOR UNOCCUPIED HOMES DURING THE STUDY



The interannual monthly variations reflect the changes in consumption, highlighting the variability during the summer months (July and August) affected by the weather and which are also partly due to different temporal preferences for enjoying the holiday periods. The differences during March and April, in general, with the Easter Week dates (see Figure 99). The months with the fewest variations are the colder months, December and January; February is out of this group given the significant drop in consumption recorded in 2014/2013 (-10%).

FIGURE 99. INTERANNUAL VARIATIONS IN CONSUMPTION BY MONTHS (HOUSEHOLDS & REAL DAYS)



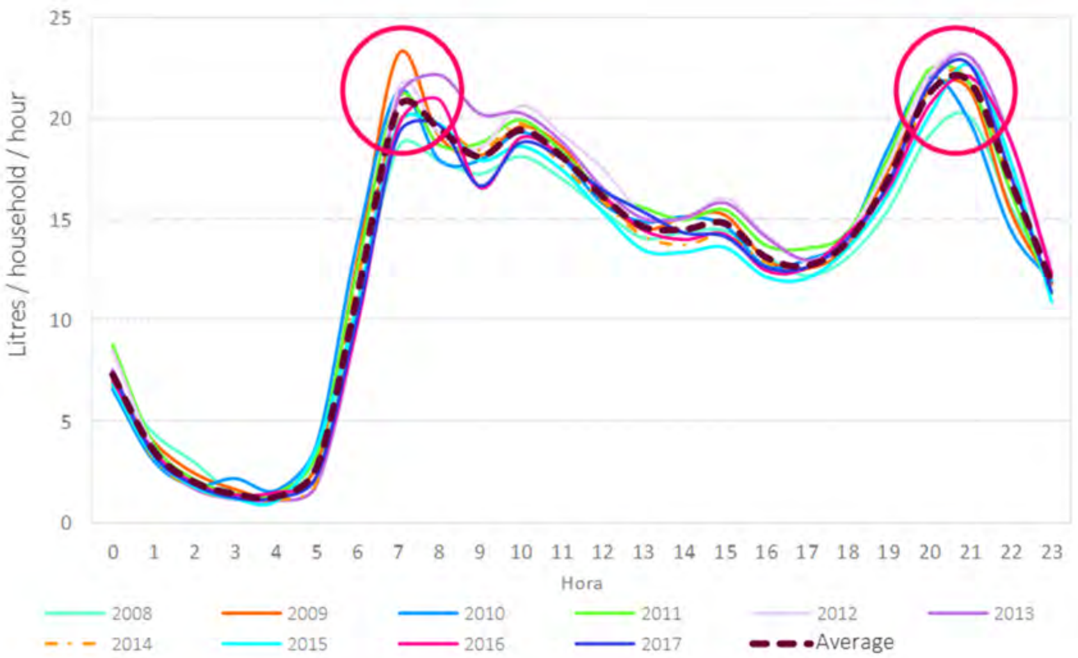
6.1.1. Hourly patterns

If hourly consumption patterns are analysed for the ten years of the project's duration, the figures show similar patterns throughout the entire study, with two consumption peaks between 7 a.m. and 8 a.m. and between 8 p.m. and 9 p.m. (see Figure 100).

Consumption is significant in both peaks, with maximum figures that gradually drop, with a slight recovery at 10 p.m. and at 3 p.m., until a minimum is reached at 5 p.m., to rise again to maximum values at the end of the afternoon. During the other times, consumption is much lower, reaching a minimum between 3 a.m. and 4 a.m.

The three main meals of the day (breakfast, lunch and dinner) are when maximum consumption figures are reached in households, since the existence of maximum figures between 7 a.m. and 8 a.m. and 10 a.m. refer to the different breakfast patterns on non-working days and business days, as illustrated in later chapters.

FIGURE 100. HOURLY CONSUMPTION



Overall, the hourly consumption distribution can be expressed in average daily consumption percentages, which, for the entire period of study, are those outlined in Table 22.

TABLE 22. HOURLY CONSUMPTION DISTRIBUTION

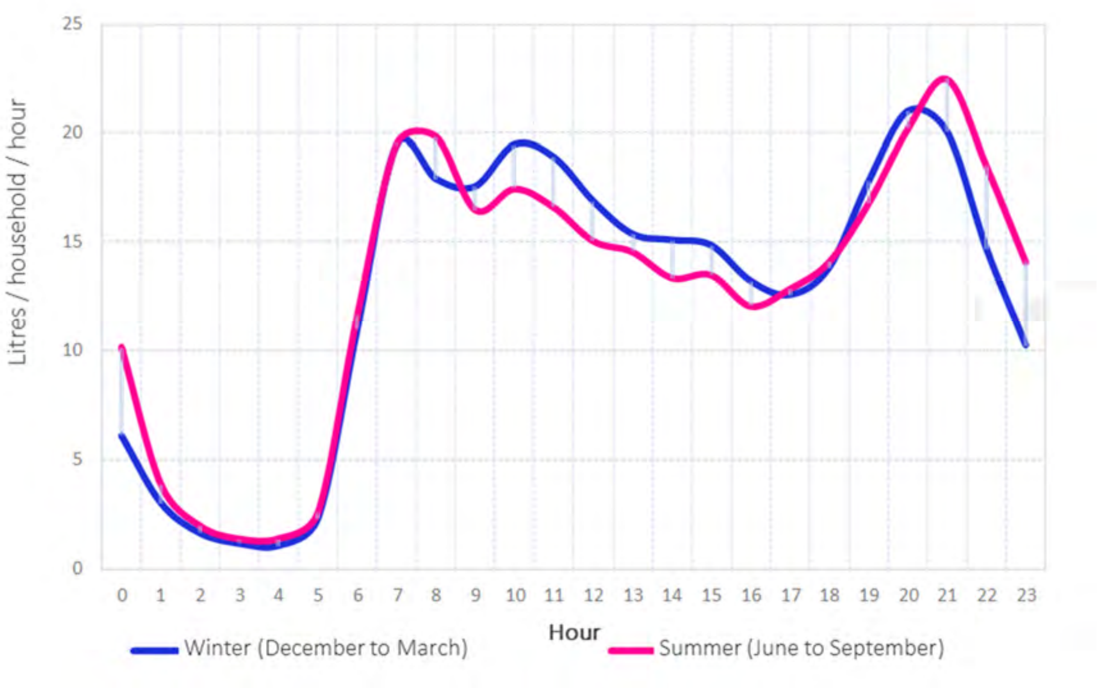
Time A.M.	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Consumption %	2.3%	1.1%	0.6%	0.4%	0.4%	0.9%	3.6%	6.6%	6.2%	5.8%	6.2%	5.8%
Time P.M.	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
Consumption %	5.1%	4.7%	4.6%	4.7%	4.2%	4.0%	4.4%	5.4%	6.8%	6.9%	5.4%	3.8%

In terms of seasonal hourly consumption, in summer there is clear upward trend in consumption during night time hours, between 9 p.m. and 2 a.m. (between 1 and 4.1 litres more), and a lower consumption in winter, between 10 a.m. and 3 p.m. and between 7 p.m. and 8 p.m. (1 to 3.5 litres less). Likewise, there is a one-hour delay in the maximum night time figures, going from 8 p.m. to 9 p.m. during summer months, as shown in Figure 101.

These patterns may be due to the fact that in winter households are occupied more, which translates into higher water consumption, and in summer watering on terraces and in gardens increases, which is normally carried out either, first time in the morning or, late in the afternoon.

Average consumption for the entire study sample in summer (June to September) is 321.7 litres per household and day, while winter consumption (December to March) is 304.8 litres per household and day, which is a difference of 17 litres. That is, average consumption in summer is only 5.5% higher than in winter.

FIGURE 101. **HOURLY CONSUMPTION IN SUMMER - WINTER**



Furthermore, two patterns can be distinguished during the summer months, in June and September water consumption reaches maximum annual figures (average obtained in the sample of 302.2 and 310.6 litres per household and day, respectively), while in August, consumption values are at annual lows (average of 231.5 litres per household and day). During July, they are around average annual figures.

It is clear that the most determining variable for residential consumption is whether the household is occupied and, as a result, although during the summer period consumption increases (May, June, September), during the hottest months (July and August), consumption drops as a result of lower occupancy levels; therefore, the summer-winter differences are lower than originally expected, since in the Comunidad de Madrid a significant number of residents leave for other areas in summer.

6.2. EFFECT OF THE DIFFERENT VARIABLES ON CONSUMPTION

Outlined below are the monthly consumption figures per household and per inhabitant, during the entire study period. It has been categorised based on whether consumption takes place on a non-working day (Saturdays, Sundays, national and regional public holidays), or if it takes place on a working day (from Monday to Friday, business days).

Subsequently, the same analysis has been carried out discriminating between type of household, multi-family or single-family homes and, likewise, based on household occupancy.

6.2.1. Effect of non-working days

Average consumption on **business days** is 321.0 litres per household and day, with variations ranging between 283.4 litres per household and day in August 2015, and 368.4 litres per household and day in June 2009.

Non-working days recorded a slightly higher than average consumption, with 330.2 litres per household and day (2.9%), with more variations than on business days, which ranged between 277.4 litres per household and day in August 2015 and 370.7 litres per household and day in June 2008.

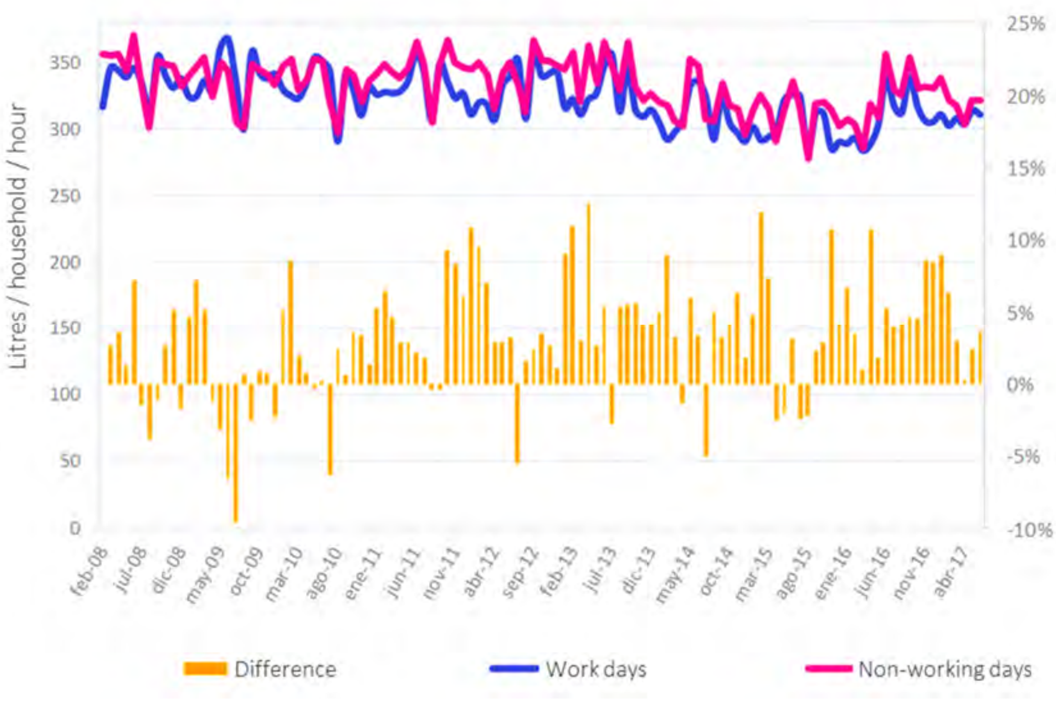
In terms of consumption per inhabitant, average consumption on **business days** stood at 97.6 litres per inhabitant and day, with variations between the 86.5 litres per inhabitant and day in August 2015 and the 121.0 litres per inhabitant and day in July 2013.

Non-working days recorded a slightly higher-than average consumption, with 100.4 litres per household and day (2.9%), with more variations than the business days, which ranged between 85.5 litres per household and day in August 2015 and 114.4 litres per household and day in June 2013.

Although the general pattern is a lower daily consumption, the drop was greater on business days compared with non-working days (-5% compared with the -4% respectively, in consumption per household and -5.3% compared with -4.4% in consumption per inhabitant).

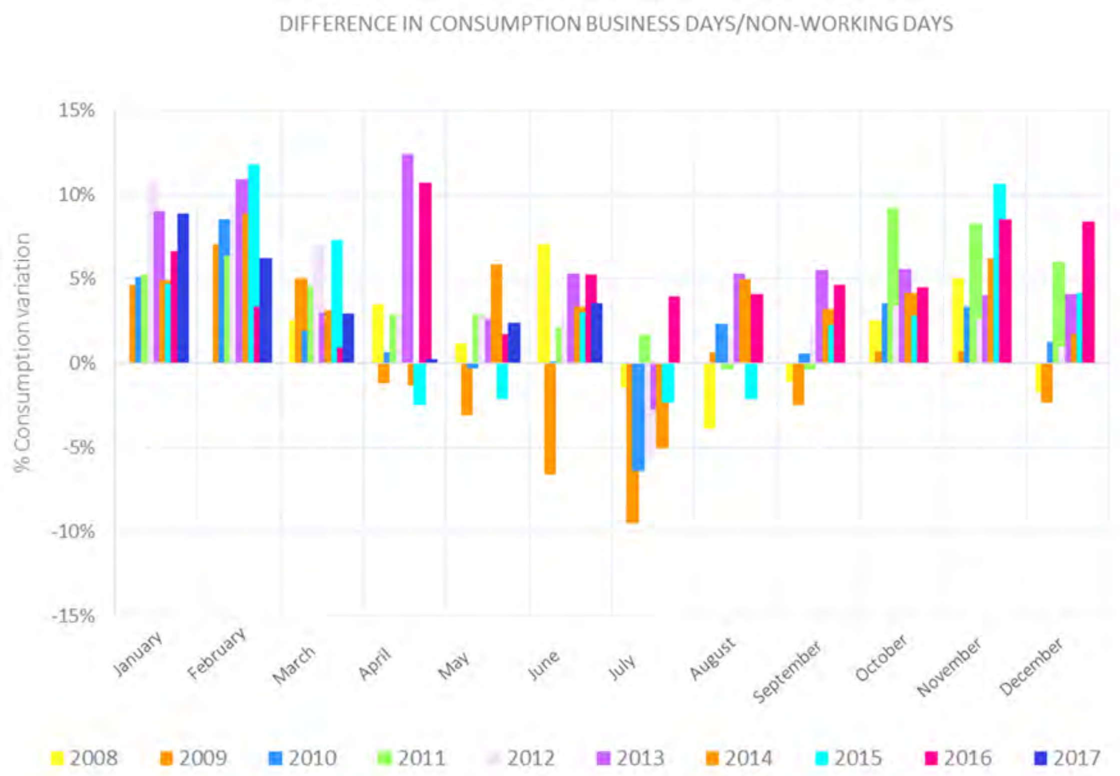
The fact that consumption is higher on non-working days is related to the weather and holiday periods, as illustrated in Figure 102. In July 2009, the greatest difference in consumption per household on business days was recorded (11.02%), and in April 2013 the greatest difference for non - working days (-11.07%).

FIGURE 102. CONSUMPTION BASED ON THE TYPE OF DAY



In general terms, it can be noted that at the start of the study (2008-2010), consumption is higher on non-working days (January to April and, in October to November), with some exceptions related to when Easter Week falls within the year. Likewise, consumption is lower from June to September, mainly due to an increase in unoccupied properties at the weekend during this period. Since 2011, the highest consumption on business days was mainly in April and from July to August. Figure 103 illustrates the consumption variation percentages by type of day. These percentages are calculated as the difference between consumption on non-working days compared with business days.

FIGURE 103. MONTHLY CONSUMPTION VARIATION BY TYPE OF DAY



Evolution of consumption per household and inhabitant, on an annual basis, is presented in Figure 104, illustrating how, on both non-working days and on business days, there is a downward trend throughout the study period.

The hourly distribution on business days and non-working days has also followed similar patterns over the ten years of the study, without visible differences between them. In the hourly analysis comparing business days and non-working days, Figure 105 reflects that the greater concentration of consumption is during the morning between 6 a.m. and 8 a.m., on business days, compared with 9 a.m. to 12 noon on non-working days. This displacement of the peak hours on non-working days and its extent, was to be expected, based on the different habits between the two types of days. Maximum night time consumption, however, took place between 8 and 9 p.m., in both types of days, although the intensity thereof on non-working days is lower. Consumption is very similar, as indicated previously, on non-working days 2.9% higher consumption was recorded on average per day.

In terms of seasonal differences, figures 106 and 107 compare winter consumption (December to March) with summer months (June to September).

On business days, the patterns are quite similar, in particular, night time consumption does change in the summer from 8 p.m. to 9 p.m., which was also seen on non-working days. On non-working days, there is also a significant difference in consumption between 10 a.m. and 4 p.m. and within this section, particularly between 10 a.m. and 1 p.m. (between 4 and 5 litres).

FIGURE 104. ANNUAL CONSUMPTION ON NON-WORKING DAYS AND BUSINESS DAYS

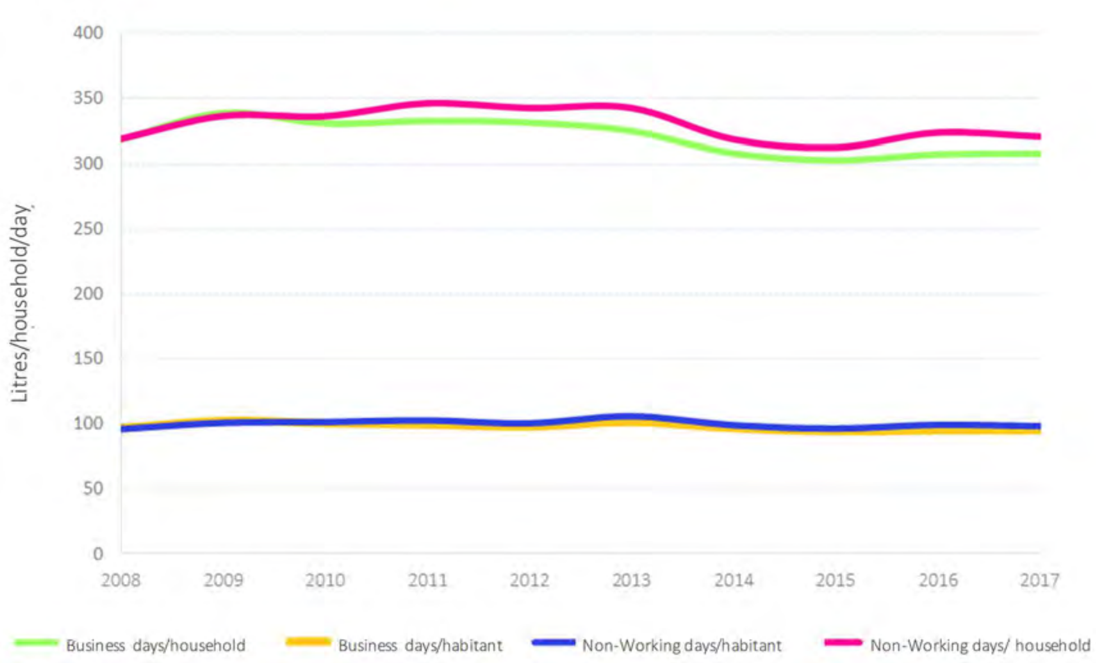


FIGURE 105. MONTHLY CONSUMPTION VARIATION BY TYPE OF DAY

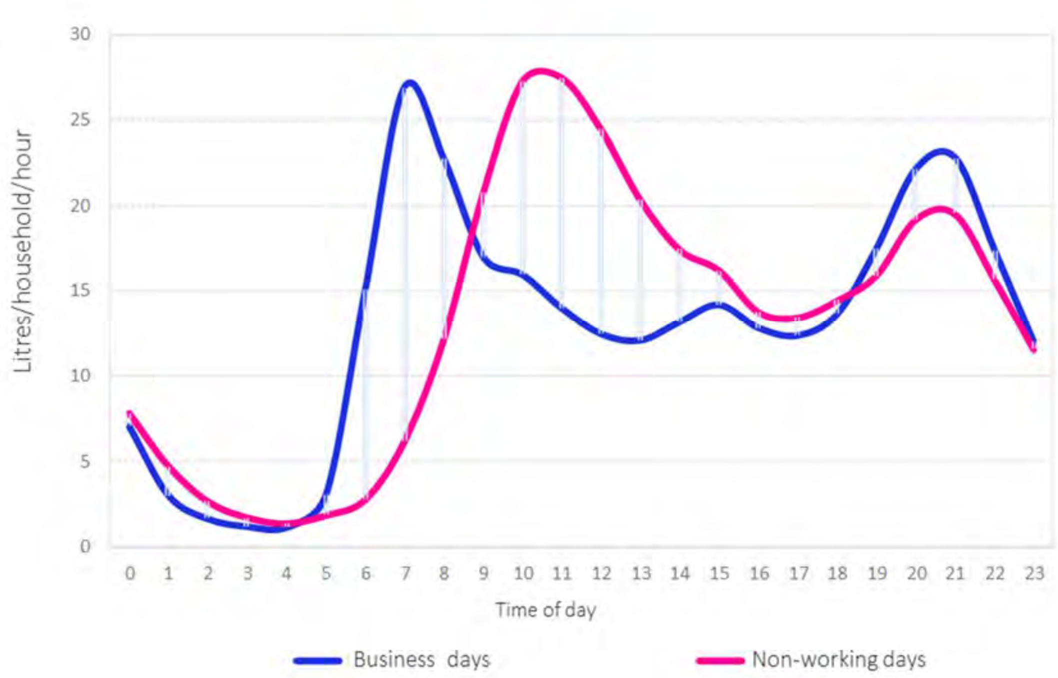
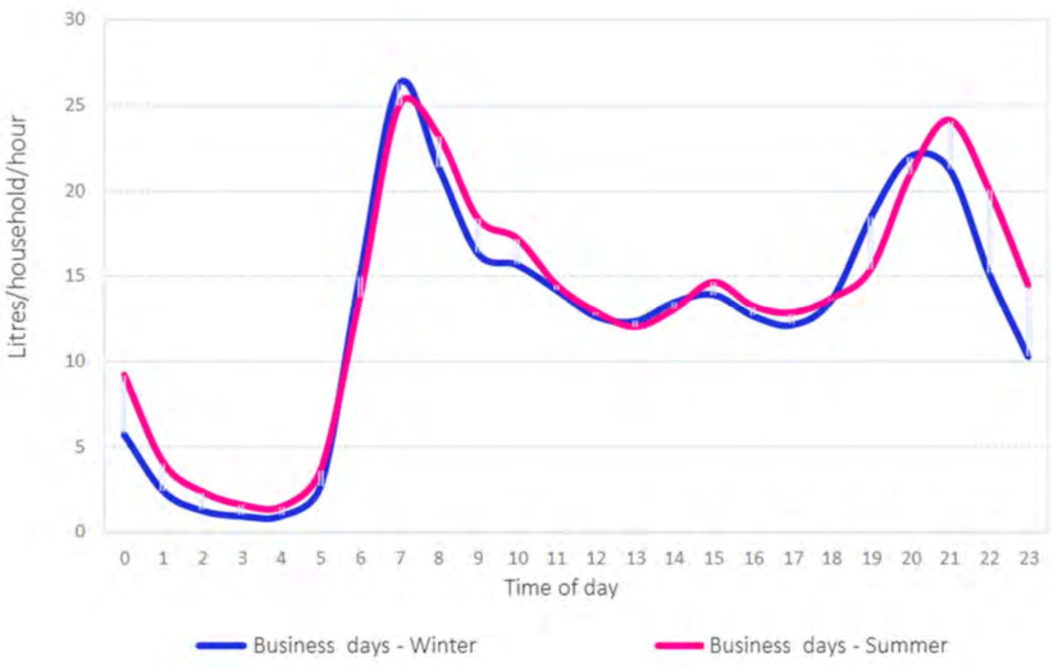


FIGURE 106. **SEASONAL DIFFERENCES IN THE HOURLY MODULATION - BUSINESS DAYS**



If we consider average consumption throughout the day, in winter consumption is 3.9% higher on non-working days, compared with business days and in summer, only 0.5% higher.

FIGURE 107. **SEASONAL DIFFERENCES IN HOURLY MODULATION - NON-WORKING DAYS**

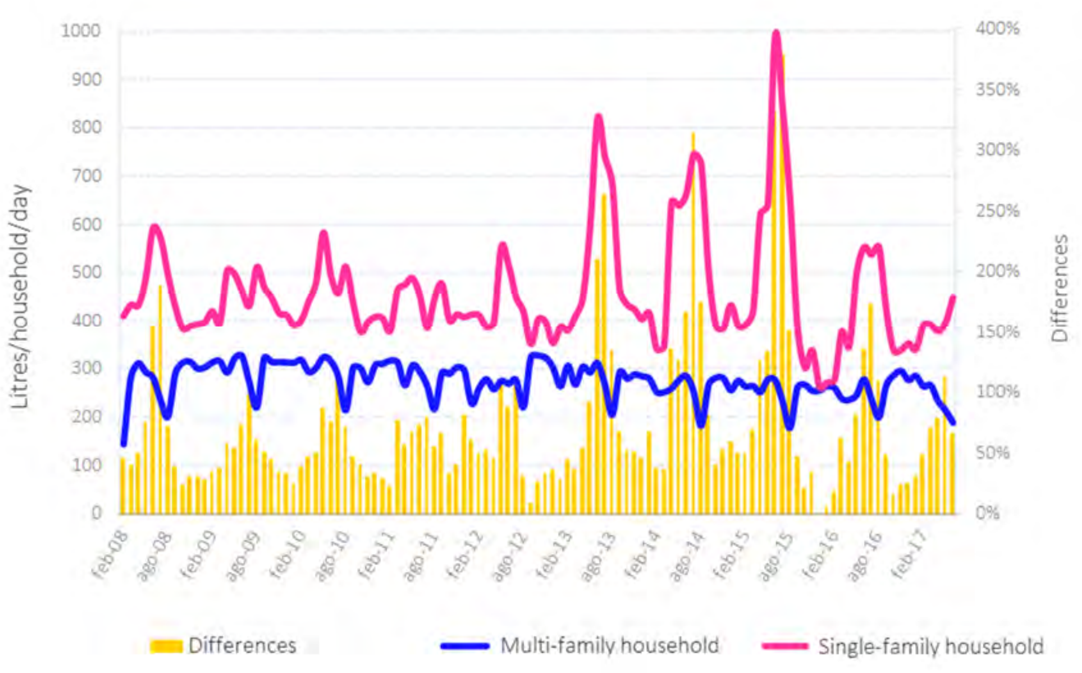
6.2.2. Effect by type of household

Below is an analysis of the consumption data based on the type of household: single-family or, multi-family homes. The percentage difference is calculated according to the difference between single-family home consumption minus the multi-family home consumption, with respect to multi-family home consumption (Figure 108).

Average consumption in multi-family homes is 271.2 litres, per household and day, with variations between 176.1 litres, per household and day in August 2015, and 325.5 litres per household and day in October 2012. Single-family homes recorded much higher average consumption figures than multi-family homes, with 449.1 litres per household and day (65.6% higher than multi-family homes), and also with greater monthly variations than in multi-family homes, between 262.3 litres per household and day in January 2016 and 993.3 litres per household and day in July 2015.

In terms of consumption per inhabitant, average consumption stood at 83.2 litres per inhabitant and day in multi-family homes, with variations between the 54.7 litres per inhabitant and day in August 2015 and the 98.6 litres per inhabitant and day in June 2009. Single-family homes recorded considerably higher average consumption figures, with 127.5 litres per inhabitant and day (53,2%), with greater variations than multi-family homes, between 74.7 litres per inhabitant and day, in January 2016, and 261.4 litres per inhabitant and day in July 2015.

FIGURE 108. MONTHLY CONSUMPTION BASED ON TYPE OF HOUSEHOLD



The general pattern throughout the ten years of the study has shown lower daily consumption in multi- family homes. In single-family homes, from 2013, there was an increase in consumption per household, particularly during the summer months, which may be due to the inclusion in the sample of households with larger gardens, a segment which was not sufficiently represented in the past.

Although consumption is always higher in single-family homes than in multi-family homes, the differences are more noticeable during the summer period and based on the weather (due to outdoor uses, in single-family homes, mainly). Particularly during July and August, when families generally go on holiday, with an increase in outdoor uses, consumption in single-family homes can be four times that of multi-family homes.

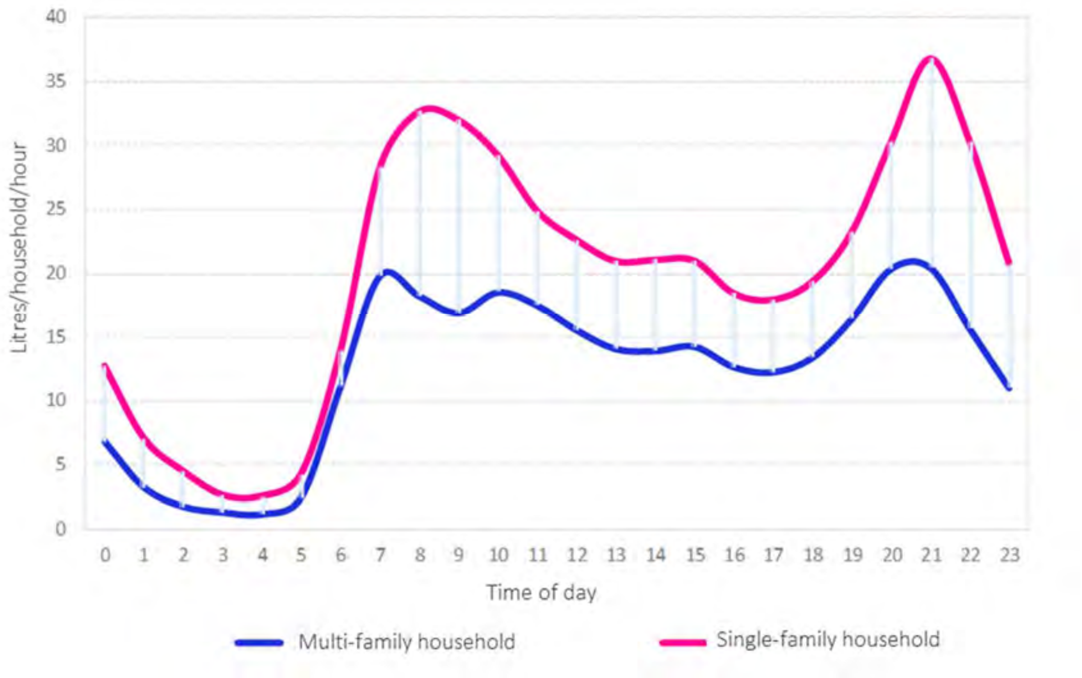
By analysing annual values (Figure 109), it appears that the difference in consumption between single-family homes and multi-family homes was not always as important every year. From 2008 to 2012, the difference in consumption dropped from 75% to 54%. From 2013, there was a noticeable increase in the consumption difference between single-family homes and multi-family homes, due, as indicated previously, to the inclusion in the sample of new single-family homes with larger gardens. In 2015, this difference exceeded 100%. The values in 2017 only included figures until June, therefore the summer months with higher consumption in these types of households have not been included.

FIGURE 109. ANNUAL CONSUMPTION BY TYPE OF HOUSEHOLD

In terms of the hourly distribution of consumption during the years of the study, it would seem that multi-family homes followed similar patterns over the seven years, without noticeable differences being identified among them. In single-family homes, there appears to be a difference between the hourly consumption distribution, due mainly to the implicit variability in the sample composition.

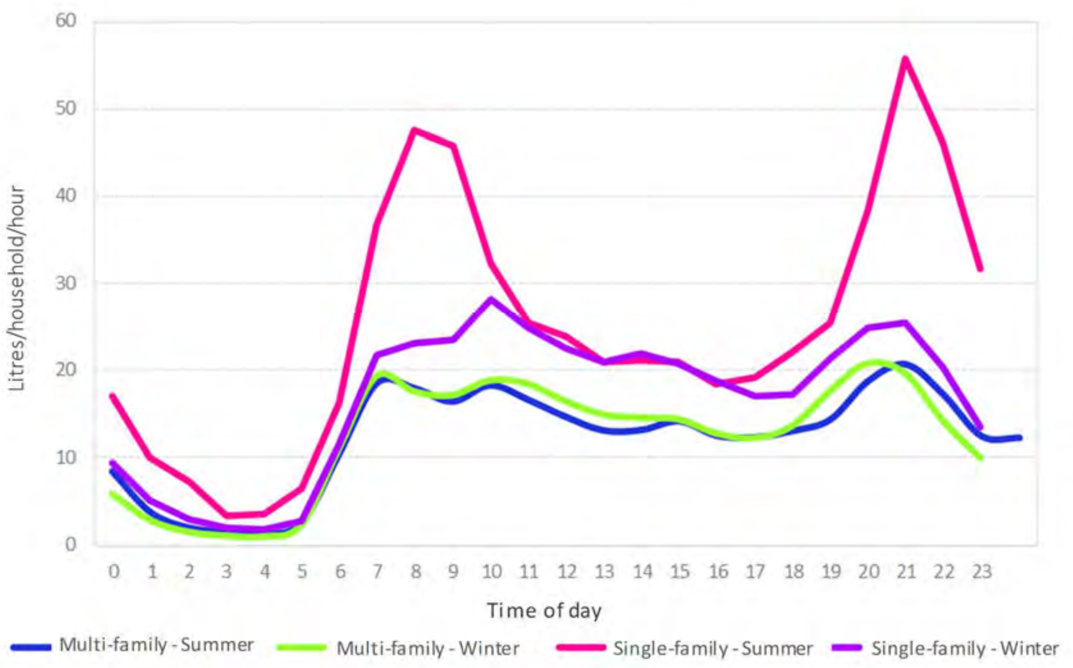
As illustrated in Figure 110, the comparison between the hourly analysis of multi-family homes and single-family homes shows a greater consumption in the latter throughout the entire day. The greatest differences are recorded between 8 p.m. and 10 p.m., with a maximum difference of 16 litres per hour at 9 p.m., and between 8 p.m. and 10 p.m. with a maximum at 9 p.m. of 15 litres per hour and household. There is also a displacement in maximum consumption time in the morning, and evening, of one hour in single-family homes from 8 p.m. to 9 p.m. and from 9 p.m. to 10 p.m.

FIGURE 110. **DIFFERENCES IN THE HOURLY MODULATION BASED ON TYPE OF HOUSEHOLD**



In terms of seasonal patterns per type of **household**, Figure 111 offers an image in which winter consumption (December to March) has been compared with summer consumption (June to September) for multi-family homes and single-family homes.

FIGURE 111. **SEASONAL DIFFERENCES IN THE HOURLY MODULATION BASED ON TYPE OF HOUSEHOLD**



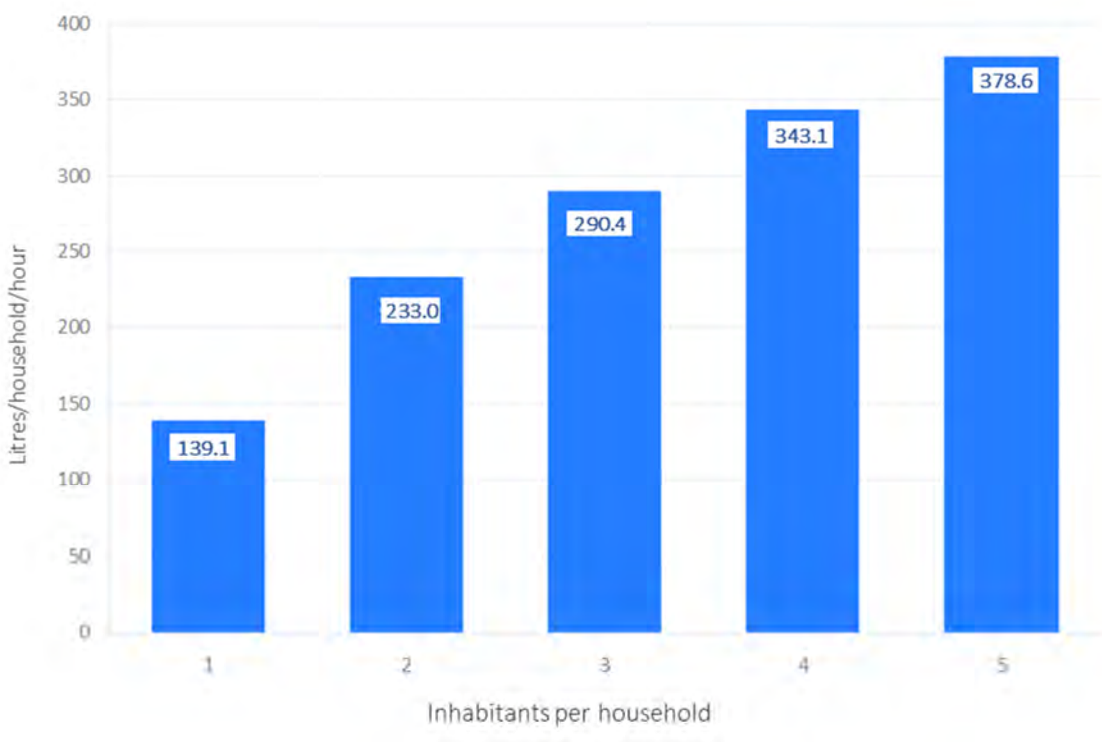
The graph in Figure 111, shows that the behaviour of multi-family homes is similar during both seasonal periods. With regard to single-family homes, the daily consumption in winter is similar, in terms of profile to that of multi-family homes, although it is more intense during the central part of the day, with the exception of the evening period; consumption in winter in single-family homes is very similar to that of the summer months for multi-family homes between 9 p.m. and 8 a.m.

Daily summer consumption in single-family homes is characterised by a much higher volume, with a marked difference compared with other consumption, particularly during the morning and evening peaks and until 3 a.m. Single-family homes show similar consumption during the central part of the day (between 12 noon and 6 p.m.) in summer and in winter.

6.2.3. Effect of household occupancy

Household occupancy is one of the characteristics that is more closely related to water consumption in properties. It is clear that consumption increase with the higher the number of people living in the household (Figure 112), but there are other factors that affect this growth not being linear.

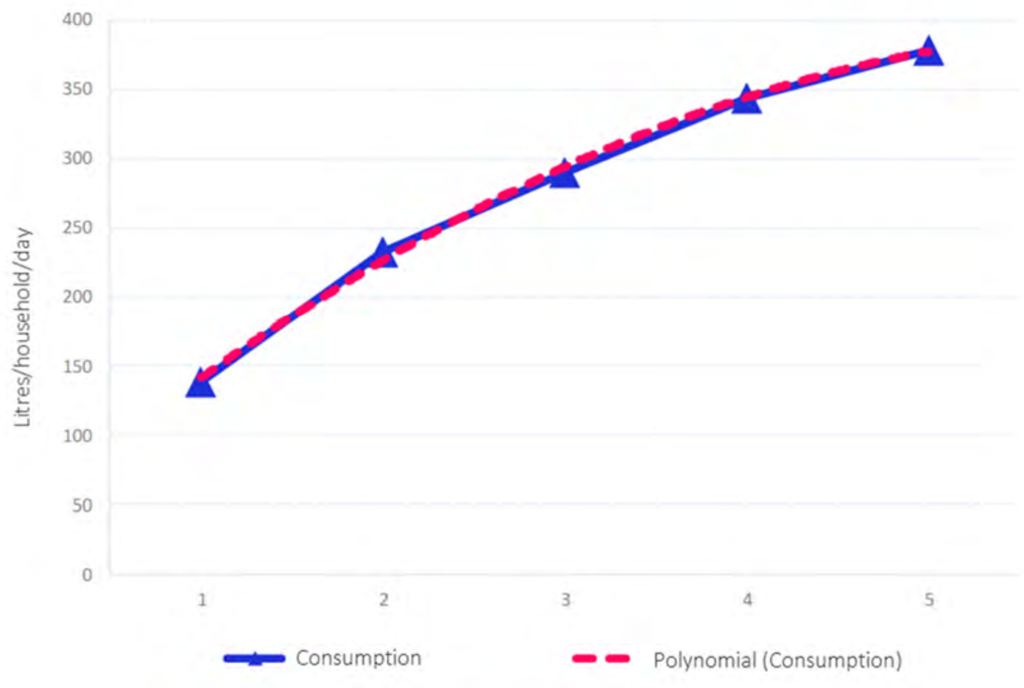
FIGURE 112. CONSUMPTION AVERAGES BASED ON HOUSEHOLD OCCUPANCY



The statistical analysis of this variable in the study shows a significant relationship between the number of occupants and residential consumption, with a high Pearson correlation (0.984), with 99% confidence. The model obtained is shown below and in the chart in Figure 113.

Consumption per household = -12,957 **x** *inhabitants*^{2} *+ 139,219* **x** *inhabitants*

FIGURE 113. **CONSUMPTION AVERAGES BASED ON HOUSEHOLD OCCUPANCY**

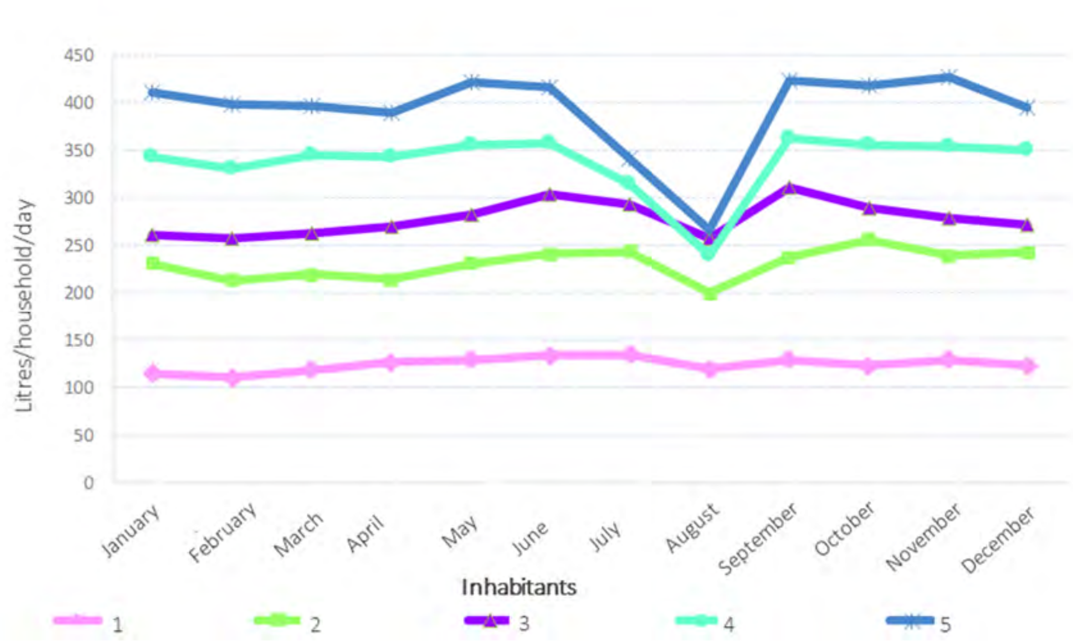


If the progress of annual consumption in households is analysed, based on occupancy, there is a drop in consumption for households with between one and four occupants (Figure 114), as opposed to households with five inhabitants, which show a clear tendency to increase consumption (with increases of 24% between 2008 and 2016).

FIGURE 114. **ANNUAL CONSUMPTION BASED ON OCCUPANCY**

If the monthly progress of consumption is analysed, it reveals that the greatest consumption variations throughout the year are in the drop in consumption, which is typical of the summer period. In households with higher occupancy rates, this drop in consumption is more noticeable, while in those with fewer numbers of inhabitants, the effect of the summer is barely noticeable.

FIGURE 115. MONTHLY CONSUMPTION BASED ON OCCUPANCY (PER HOUSEHOLD)



Another way of analysing consumption is per inhabitant, instead of per household. Figure 116 reflects the monthly figures of the entire study period, with the graph clearly showing the drop in consumption per person, with the increased occupancy in households and vice versa, as the number of inhabitants drops per household, the variability of consumption recorded increases.

If the evolution of annual residential consumption is analysed, based on occupancy rates, Figures 117 and 118 show how consumption drops per inhabitant as the occupancy rate increases, reaching a 37% lower figure in households with 5 inhabitants than in those with just one person.

FIGURE 116. EVOLUTION OF MONTHLY CONSUMPTION PER INHABITANT BASED ON OCCUPANCY

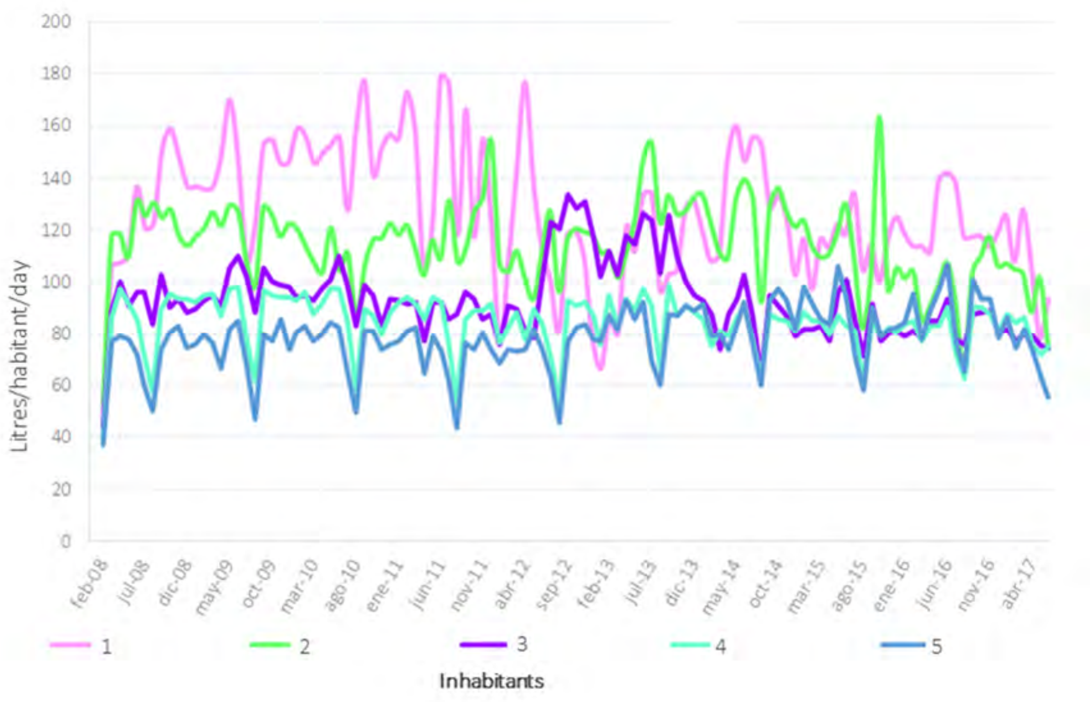


FIGURE 117. ANNUAL CONSUMPTION PER INHABITANT BASED ON HOUSEHOLD OCCUPANCY

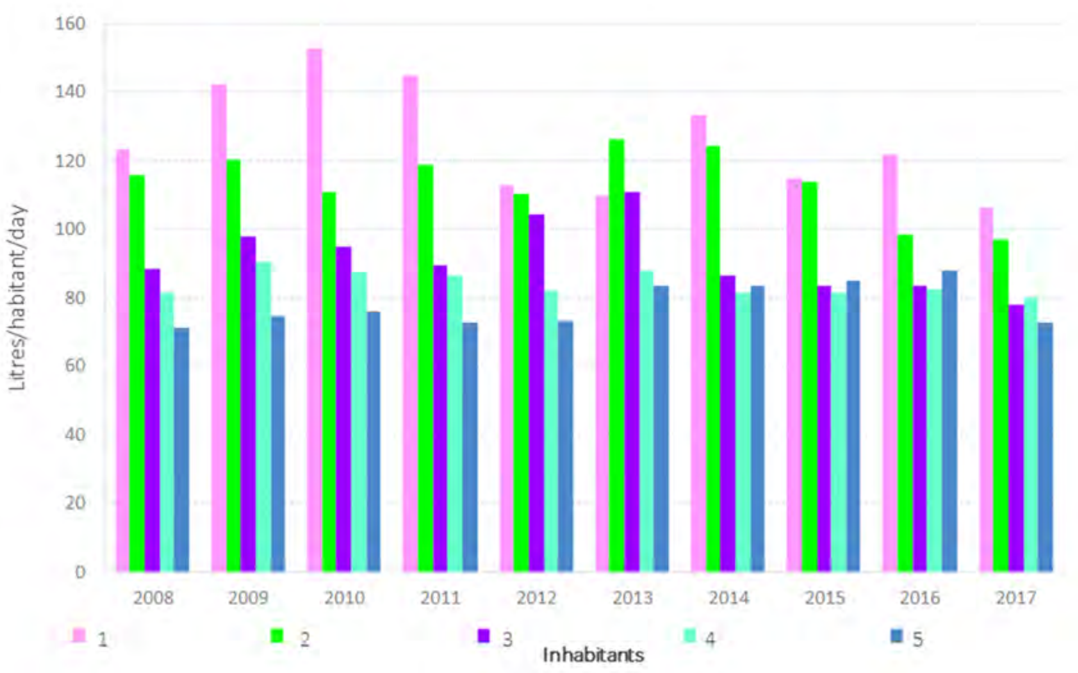
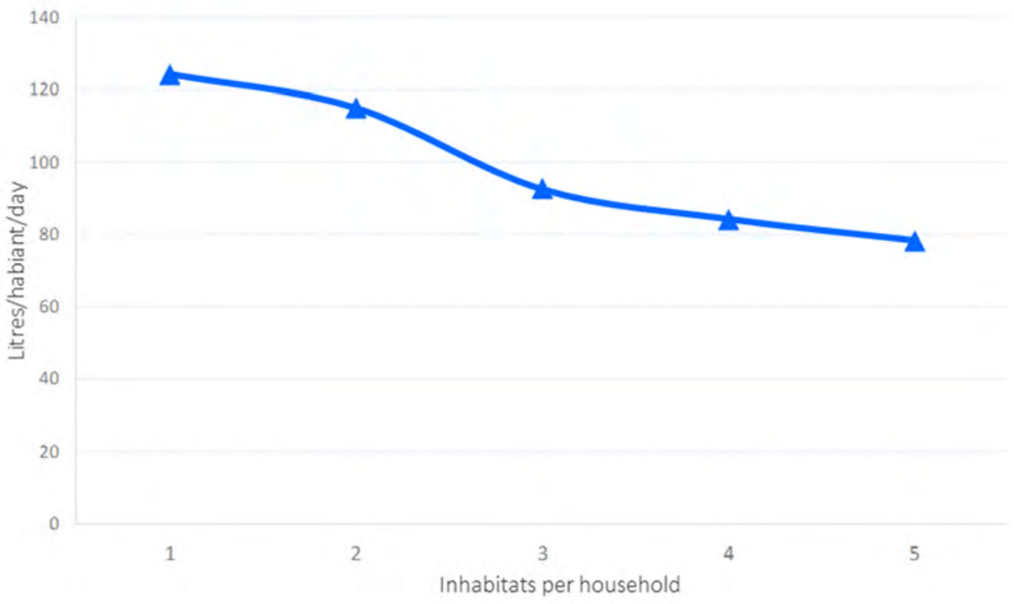


FIGURE 118. AVERAGE ANNUAL CONSUMPTION BASED ON OCCUPANCY



6.3. CHARACTERISATION OF NIGHT-TIME MINIMUM CONSUMPTION

In order to characterise night-time consumption figures, the average consumption between 2 a.m. and 5 a.m. has been taken into account in the sample households (Figure 119). During this period, hourly consumption was less than 1% of the daily consumption, which, on average, is 328 litres per household for the entire study period.

The minimum night-time consumption, in all cases, takes place at 4 a.m. but on business days, consumption is lower, except at 5 a.m. when activity begins in some households. On the other hand, on non-working days, the rest period is later, with the highest night-time consumption recorded at 2 a.m.

When analysing consumption by type of household, consumption is much higher in single-family homes compared with multi-family homes, particularly at 2 a.m., as shown in Figure 120. Outdoor use for irrigation is one of the main contributing factors to the difference in consumption.

The monthly analysis of nocturnal consumption shows that, in general terms, it is higher during holiday periods, and specifically on non-working days, such as the Christmas period, in which there are days with very long evenings. Particularly noteworthy is the increase in consumption at the end of spring and summer, simultaneously with the growth in nocturnal activities at the weekend and on non-working days (Figure 121).

By type of property, single-family homes (Figure 122) begin watering in spring, and this goes on until September, with particularly significant figures during the summer months. Campaigns concerning the most suitable watering times, together with irrigation programming options, have resulted in consumption values increasing during the night time, also affected by leaks in outdoor networks which are closed during the rest of the year.

FIGURE 119. AVERAGE NIGHT-TIME CONSUMPTION, BY HOURS AND TYPE OF DAY

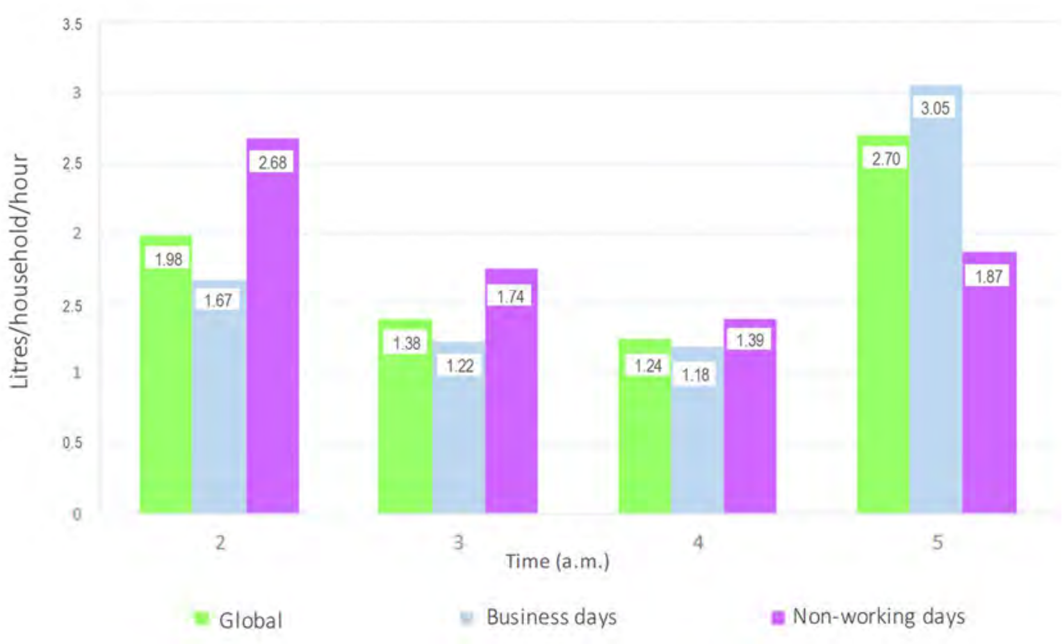


FIGURE 120. AVERAGE NIGHT-TIME CONSUMPTION, BY HOURS AND TYPE OF HOUSEHOLD

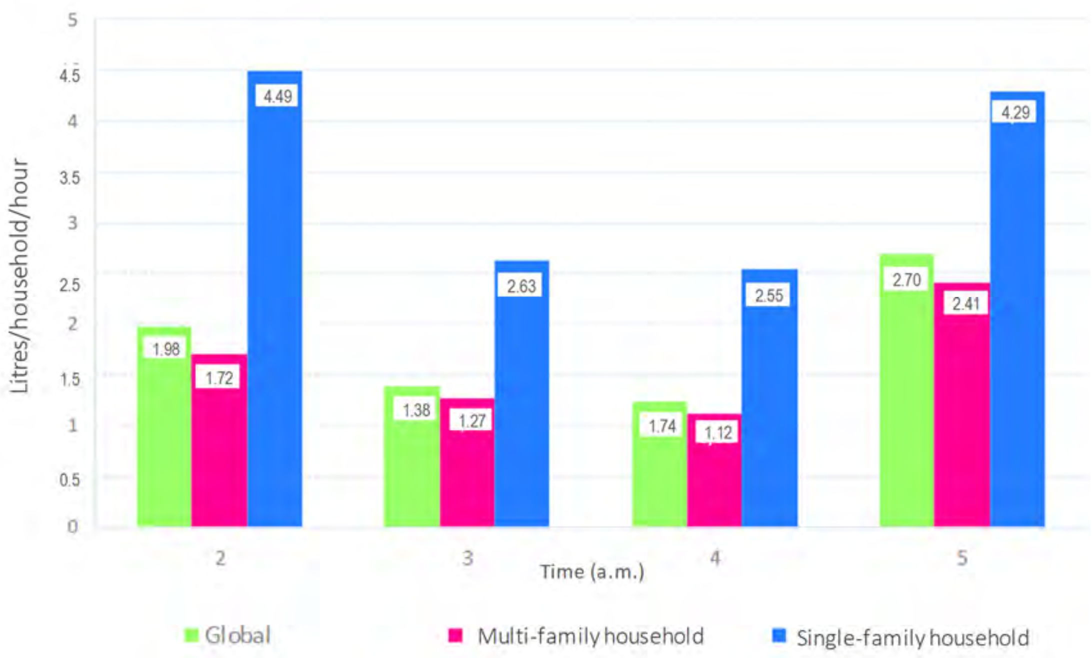
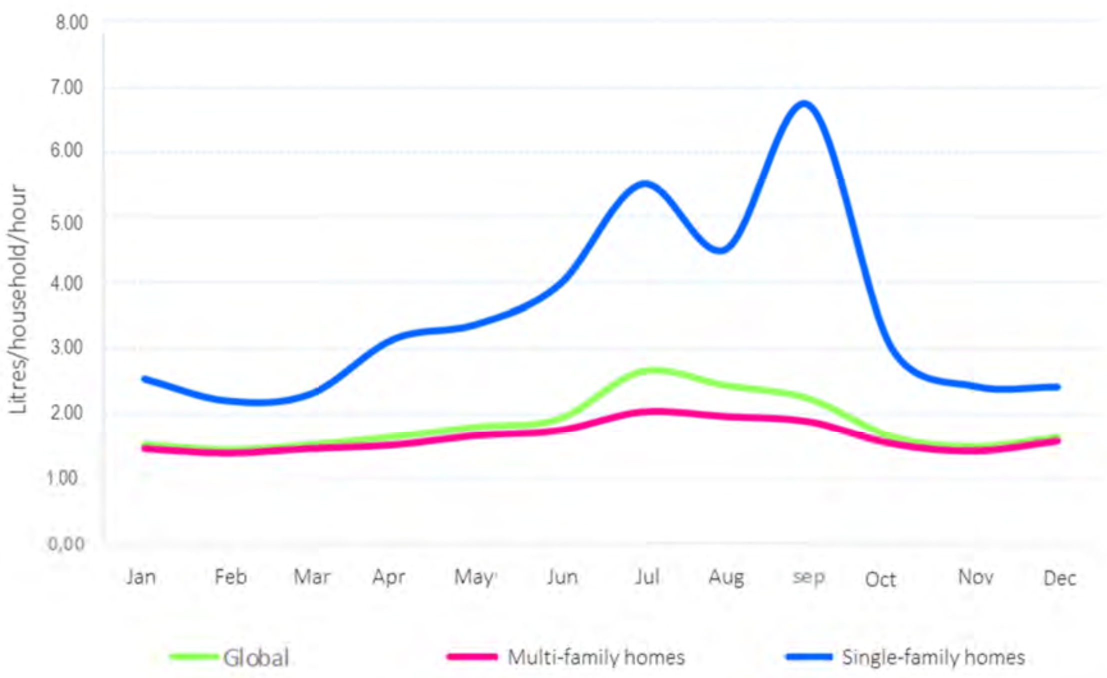


FIGURE 121. **AVERAGE NIGHT-TIME CONSUMPTION, BY HOURS AND TYPE OF DAY**

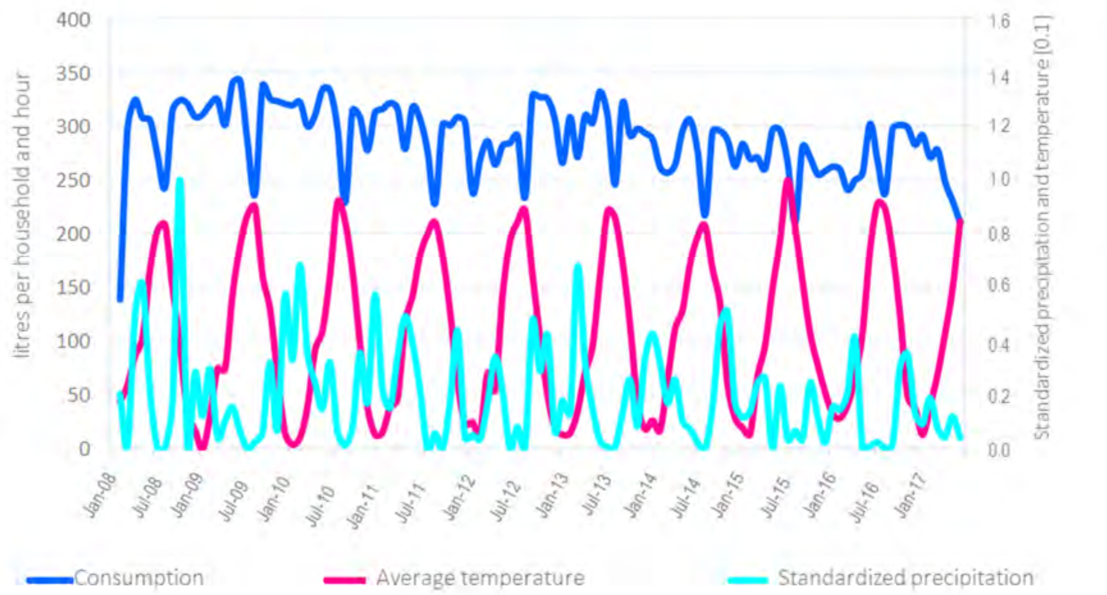
FIGURE 122. **AVERAGE MONTHLY NIGHT-TIME CONSUMPTION, BY TYPE OF HOUSEHOLD**



6.4. IMPACT OF METEOROLOGICAL VARIABLES ON CONSUMPTION

The effect of the weather on consumption increases, and decreases is clear, as shown in Figure 123. Representing the values of a specific population study, a recurring pattern has been noticed: when the temperature begins to rise, and rainfall drops, consumption begins to increase and when rainfall increases, and the temperature begins to drop, there is a drop in consumption.

FIGURE 123. MONTHLY CONSUMPTION, RELATED TO WEATHER CONDITIONS



However, making a model and specifying that the total consumption depends on the temperature or rainfall is complicated, since they are not correlated.

The weather variables shown in Figure 123 are the normalised rainfall and normalised temperature, which means they have undergone a linear transformation, and this is done to eliminate their dependence with regard to the measurement units. The formula used is as follows:

$$z_i = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)}$$

In order to try to determine the climate effects, the effects between consumption and consumption variations on non-working days and business days, and for single-family homes and multi-family homes have been studied, with regard to the temperature, rainfall, days of rainfall and sunshine. All these variables have been studied with regard to the entire temporal period considered (113 moths) and with regard to average monthly figures for the period (12 months). Bearing in mind that the representativeness of single-family homes is limited, this chapter offers results of interest from the analysis carried out.

6.4.1. Analysis of the whole period

Only reportable relationships were found with regard to the temperature. In all cases it is noticed a dispersion of data as the temperature increases, which causes the coefficient of determination to worsen noticeably.

Relationship between the consumption differences of single-family homes and multi-family homes with respect to temperature. The analysis of the data reveals a significant relationship between the variables, with a modest Pearson correlation (0.678). The model obtained has a coefficient of determination $R^2 = 0.46$, with a confidence level of 99%:

Difference single-family home - multi-family home = 0.040 x Temperature

As shown in Figure 124, the increase in temperature explains 46% of the difference in consumption between single-family homes and multi-family homes.

Relationship between single-family home consumption and temperature. The aim has been to model the increase mainly of outdoor water uses with weather variables. In terms of the normalised temperature, the analysis of the data reveals a significant relationship between the variables, with a Pearson correlation coefficient of 0.693. A significant model is obtained with a coefficient of determination of $R^2=0.48$.

$$\text{Ln (Single family home consumption)} = 5.866 \times e^{(0.09 \times \text{normalised temperature})}$$

As shown in Figure 125, the exponential model, explains the increase in single family home consumption in logarithms, with regard to the increase in temperature, by 48%.

FIGURE 124. REGRESSION DIFFERENCE SINGLE-FAMILY HOMES AND MULTI-FAMILY HOMES WITH TEMPERATURE

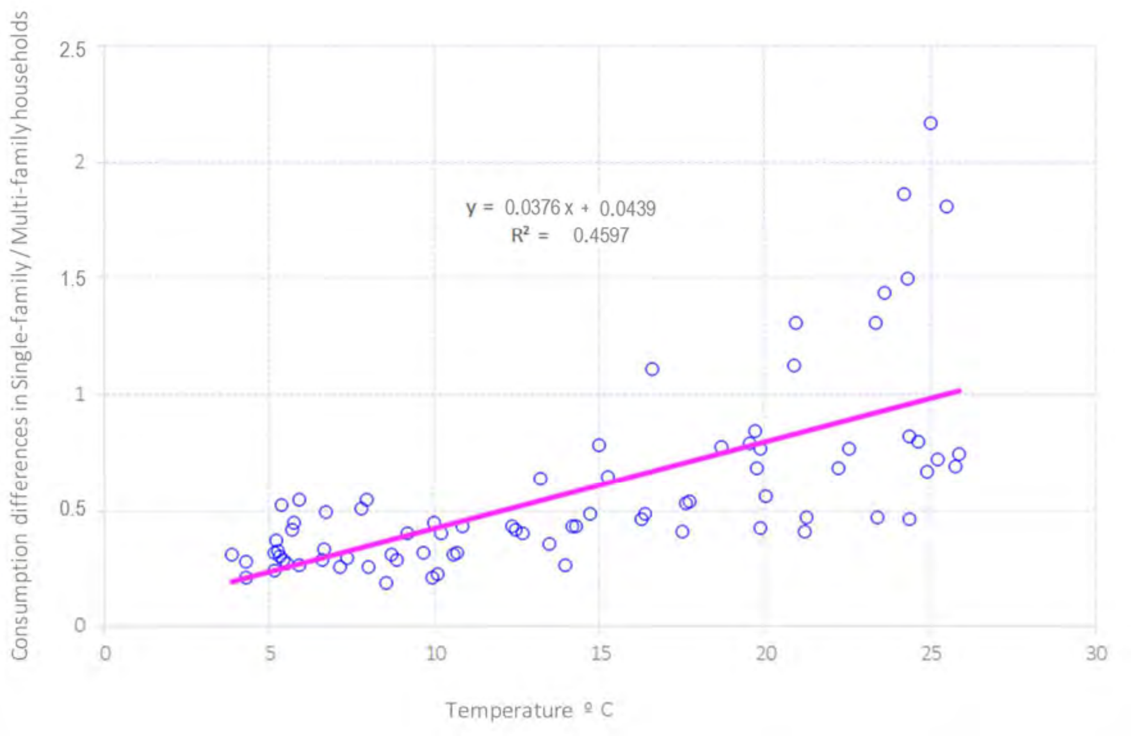
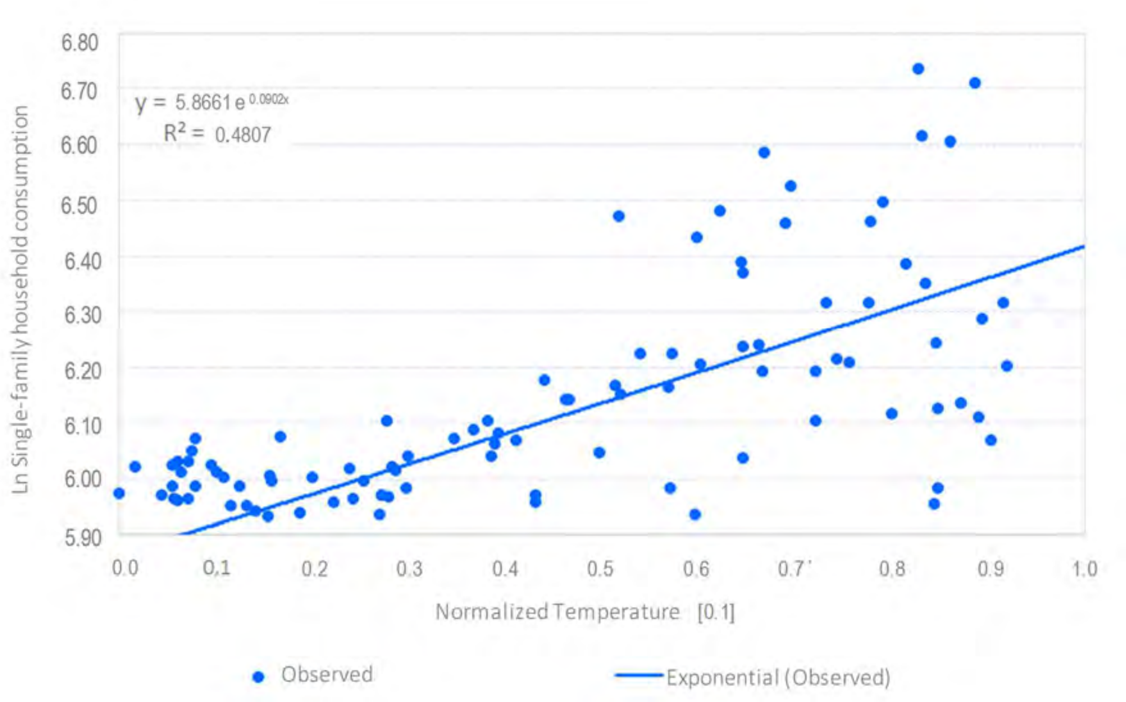


FIGURE 125. SINGLE-FAMILY HOME CONSUMPTION REGRESSION WITH NORMALISED TEMPERATURE



6.4.2. Analysis of average monthly figures

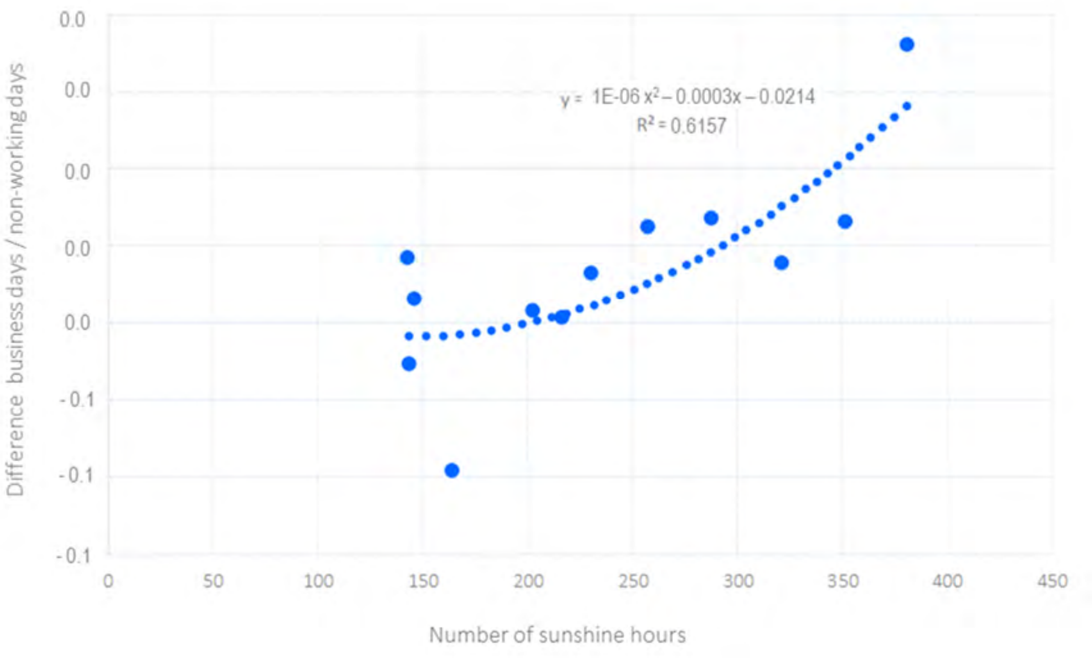
This analysis was conducted on average monthly consumption figures, that is, on the 12 average figures for each month of the year, instead of being based on the overall study data. In this case, climate variables with relationships worth mentioning are sunshine hours and days with rainfall, together with the temperature.

Relationship between the consumption differences on business days and non-working days with regard to sunshine hours (in percentage). The model that best explains the difference is the quadratic (moderate quality), with a coefficient of determination R^2=0.616). The model is significant for a 95% level of confidence and the variables are also significant for this level of confidence.

Difference in %
*non-working day and business days = - 0.021 – 3,08 x 10-4 x sunshine hours + 1.070*10^{-6} x sunshine hours^2*

As shown in the quadratic model of Figure 126, the increase in the sunshine hours explains the 61.6% increase in the consumption difference between non-working days and business days.

FIGURE 126. REGRESSION % DIFFERENCE IN NON-WORKING DAYS, AND BUSINESS DAYS, WITH SUNSHINE HOURS



Relationship between the consumption differences between single-family homes and multi-family homes with regard to the sunshine hours and days of precipitation. The analysis of these figures reveals a relationship between the significant variables, with a Pearson correlation with regard to the sunshine hours of 0.919 and with regard to days with precipitation of 0.935. The model is significant and of excellent quality, with a coefficient of determination of R^2=0.937.

Single-family - multi-family difference 0.546 - 0.063 x days with precipitation + 0.002 x sunshine hours

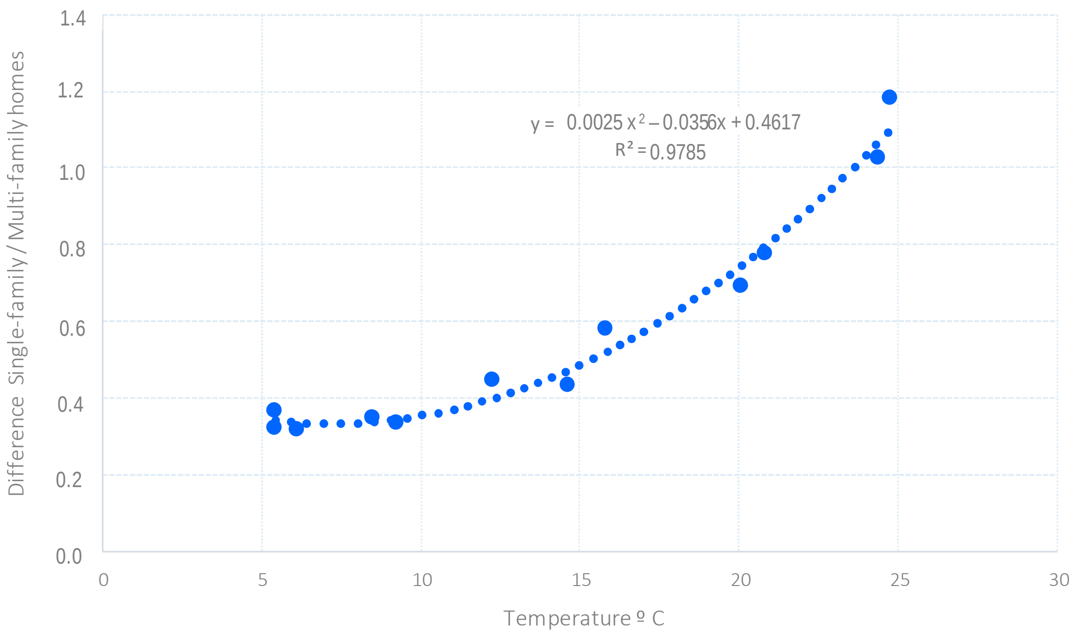
The difference in consumption between single-family homes and multi-family homes is explained 93.7% by the sunshine hours and days with precipitation. Pursuant to the result obtained, on days with precipitation, the consumption in the types of properties is similar, while during sunshine hours its difference increases.

Relationship between the differences in consumption between single-family homes and multi-family homes with regard to the temperature. The analysis of the figures reveals a significant relationship between the variables, with a Pearson correlation of 0.933. A significant model is obtained with an excellent quality, and a coefficient of determination of R^2=0.978.

Single–family - Multi-family difference = 0.0025 **x** *temperature*^{2} *- 0.0352* **x** *temperature* **+** *0.4587*

As shown in Figure 127, the increase in temperature explains the growing difference in consumption between single-family homes and multi-family homes of 97.8%.

FIGURE 127. REGRESSION DIFFERENCE, SINGLE-FAMILY HOMES AND MULTI-FAMILY HOMES WITH TEMPERATURE



6.5. IMPACT OF CERTAIN SPECIFIC EVENTS ON CONSUMPTION

Average consumption of any supply may be very different to that which takes place on specific occasions due to extraordinary events, or public holidays that fall at different times of the year, such as Easter Week. In order to assess the impact thereof on the consumption recorded in the study, some extraordinary consumption events that took place throughout these 10 years have been identified.

6.5.1. General strike 2010

The general strike held on 29 September 2010, pursuant to official records, had an uneven turnout depending on the consulted source: 70% turnout according to the syndicates; 7.5% according to State officials and 23.8% in public companies according to the Government.

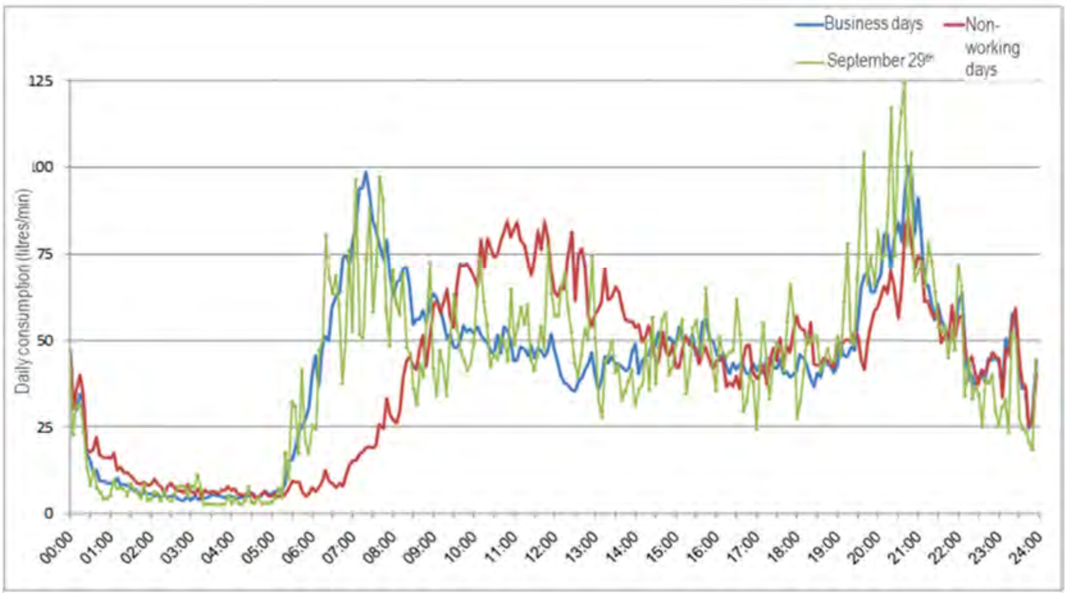
There was a 10% turnout in shops and 3% in the hotel and catering industry; the transport sector supported the strike with a 21% turnout according to Government figures. Electricity consumption dropped by 16.5%.

The data extracted for that day do not show a significant difference when compared with the two business days before and after the day of the strike (Figure 128).

Analysing the consumption curve on 29 September, it shows that the maximum morning consumption was recorded at 7.30 a.m., which is very similar to normal business days. Between 9 a.m. and 2 p.m., there was a slight increase in consumption, at around 12 noon, which is similar to the behaviour on a non-working day, although the consumption values were more similar to those of a working day. From then on, the curves on business days and non-working days were very similar and consumption on 29 September follow the same patterns.

In terms of overall consumption for all the households analysed in September 2010, average daily consumption was 344.1 litres, while on 29 September, average consumption stood at 316.3 litres, which represents an 8.1% drop.

FIGURE 128. CONSUMPTION DURING THE GENERAL STRIKE 29/09/2010



6.5.2. 2010 FIFA World Cup South Africa 2010

The FIFA World Cup was held from 11 June to 11 July 2010. The analysis of the data did not establish a clear impact of consumption associated with the games, bearing in mind that this is a study of residential consumption.

The most significant consumption was during the FIFA world cup final in South Africa (Figure 129); the analysis of data enabled the singularity of consumption to be observed. Below are the data recorded on that day.

Between 8.15 p.m. and 11 p.m., consumption was always lower than normal, except during the halftime interval, namely:

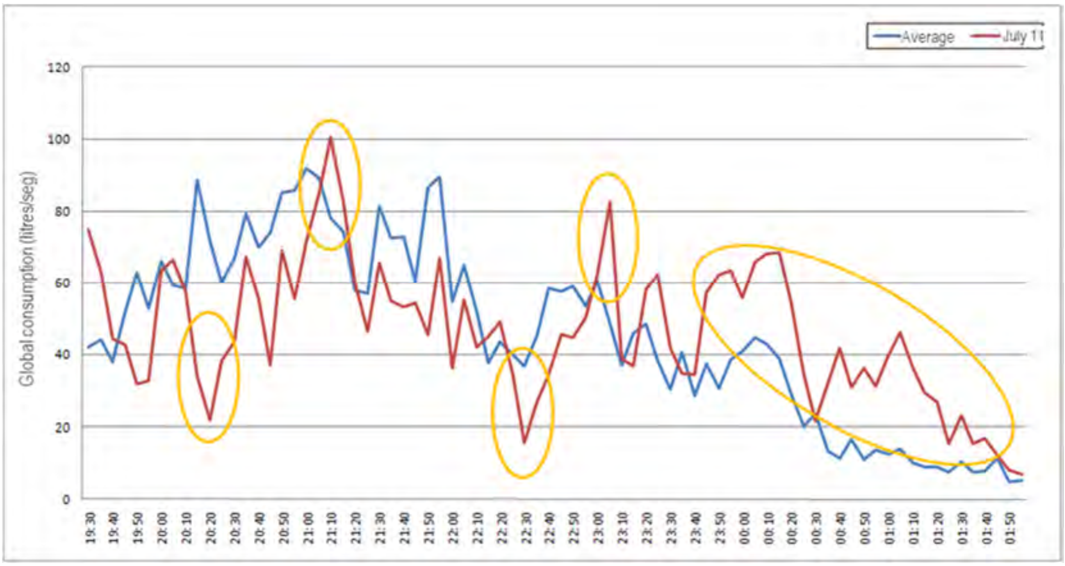
- 9:10 p.m. to 9:25 p.m. (half-time interval).
- 10:15 p.m. to 10:25 p.m. (end of the match and start of the extra time).

At the start of the match, the drop reached around 70% of the average consumption, reaching a 57% decrease at the beginning of the extra time.

Consumption between the end of the match and 2 a.m. was higher than the average, with very high peaks.

- 70% at the end of the match.
- Consumption exceeding 200% between 12:50 a.m. and 1:25 a.m.

FIGURE 129. **CONSUMPTION DURING THE FIFA WORLD CUP FINAL IN SOUTH AFRICA (11-07-2010)**



6.5.3. Easter Week

Traditionally, during Easter Week there is a noticeable drop in the population during this holiday period, since the celebration of Holy Thursday and Friday as non-working days, coincides with the school holidays.

The consumption recorded during the Easter Week periods have been analysed for all the years included in the study, with the date being variable from year to year. This difference in Easter Week dates (up to 4 weeks), together with the significant changing weather conditions at the beginning of spring, result in consumption being closely related to holidays and empty properties during these days, as reflected in Table 23.

Easter Week during the 10 years included in the study, have fallen on the following dates:

2008, from 17 to 23 March
2009 from 6 to 12 April
2010 from 30 March to 4 April
2011 from 18 to 24 April
2012 from 2 to 8 April
2013, from 25 to 31 March
2014 from 14 to 20 April
2015 from 30 March to 5 April
2016 from 21 March to 27 March
2017 from 10 April to 16 April

As reflected in Table 23, there was barely any rainfall between 2008 and 2010, and also from 2014, which increased holiday absences during these periods.

TABLE 23. **CONSUMPTION DURING EASTER WEEK**

Year	*Average temperature º C*	*Rainfall mm*	Consumption *L/Household and day*
2008	8.56	0.57	300.00
2009	11.41	0.73	287.76
2010	9.44	0.77	296.85
2011	12.95	7.39	310.07
2012	9.08	3.88	252.90
2013	10.15	6.18	274.21
2014	17.64	0.17	267.41
2015	17.98	0.00	250.30
2016	10.77	2.07	245.02
2017	20.09	0.00	265.69

In terms of temperature, the four weeks difference that may exist between the dates on which Easter Week falls, have a significant effect. Therefore, the four years in which Easter Week fell during the month of April, coincide with the highest temperatures, particularly the 20.1ºC in 2017.

In 2017, the high temperatures also coincide with the lack of rainfall, with it being the year with the third lowest consumption (265.7 litres per household and day).

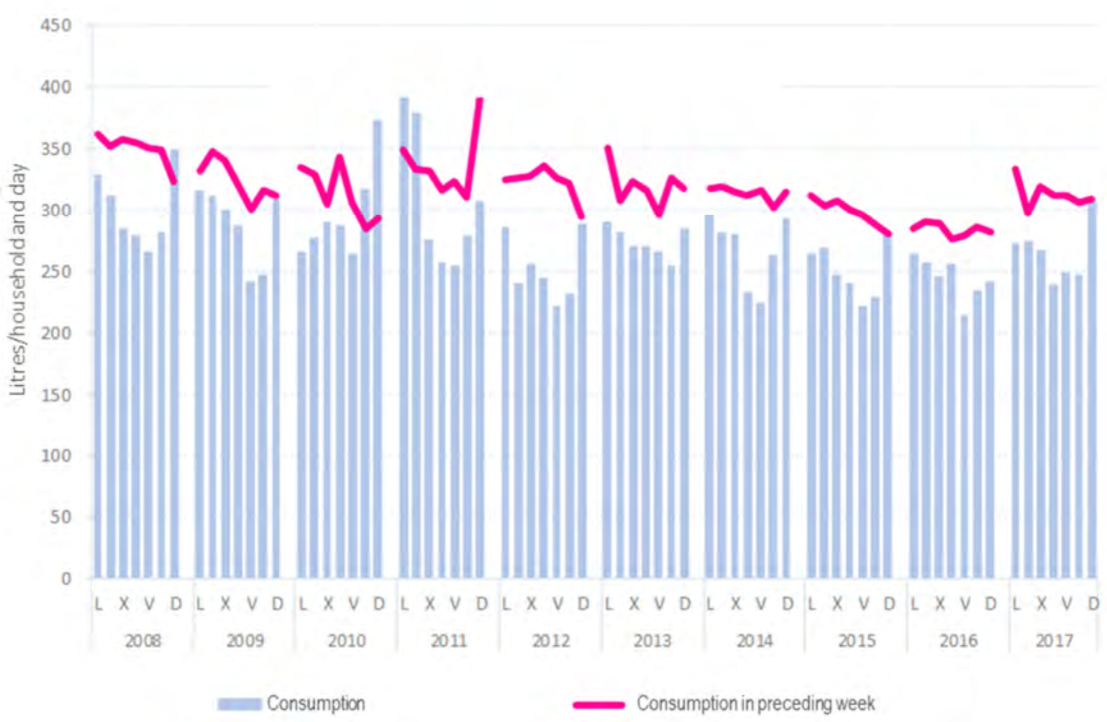
However, in 2011, with mild temperatures of 13ºC, consumption was higher, with 310.07 litres per household and day, due to the high rates of rainfall (7.39 mm, the highest recorded).

The analysis, broken down by days, is illustrated in Figure 130 and shows how, in 2013, the effect of the holiday exodus for Easter Week was not so clear on any day, and the start of the holidays coincided with low temperatures and rainfall, which occurred again on Good Friday. In 2012, the start of Easter Week was better, despite the initial rain, there was a clear pattern with the second lowest average consumption (252.90 litres per household and day).

If consumption during Easter Week is compared with the preceding week (Figure 131), it clearly shows that consumption during Easter Week was much lower, except in 2010 which was barely 6% higher during the week before Easter Week; followed by 2011, with just 9%. The year with the greatest difference was 2012, with 28% more than during Easter Week. Since 2013, the difference ranged between 16 and 10%.

FIGURE 130. METEOROLOGICAL EFFECT ON CONSUMPTION DURING EASTER WEEK

FIGURE 131. COMPARISON BETWEEN CONSUMPTION DURING EASTER WEEK AND THE PRECEDING WEEK



The comparison between the days of the week (Figure 132), shows how the lowest consumption was recorded from Wednesday to Saturday particularly on Friday, which is the lowest day (243. litres per household and day), while Sunday and Monday are the days with the highest consumption, followed by Tuesday (304, 300 and 288 litres per household and day, respectively).

If an analysis is conducted by type of day, *Non-working days-Business days* (Figure 133), we see that 2010 is the only year in which consumption was higher during non-working days, reflecting that there was not a holiday exodus that year. In 2011, the difference was 80 litres per household and day, lower on non-working days, and from then on, the difference ranges between 11 and 30 litres per day (2014).

FIGURE 132. CONSUMPTION COMPARED BY DAYS DURING EASTER WEEK

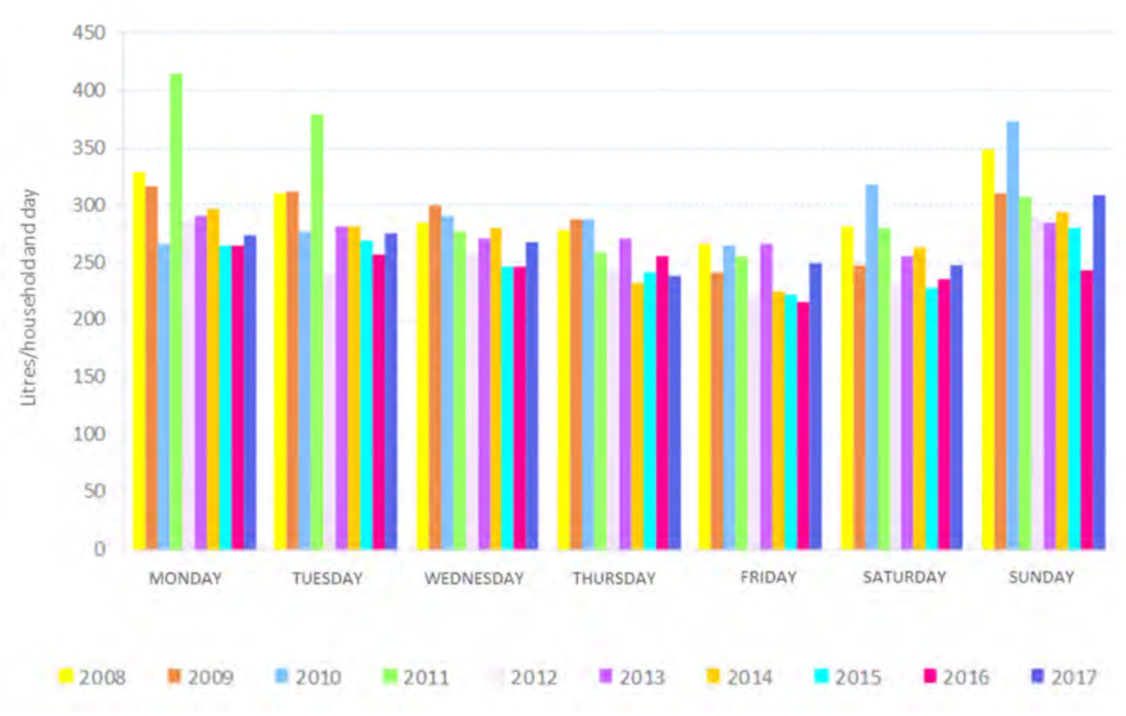


FIGURE 133. CONSUMPTION COMPARED DURING THE DIFFERENT EASTER WEEK CELEBRATIONS

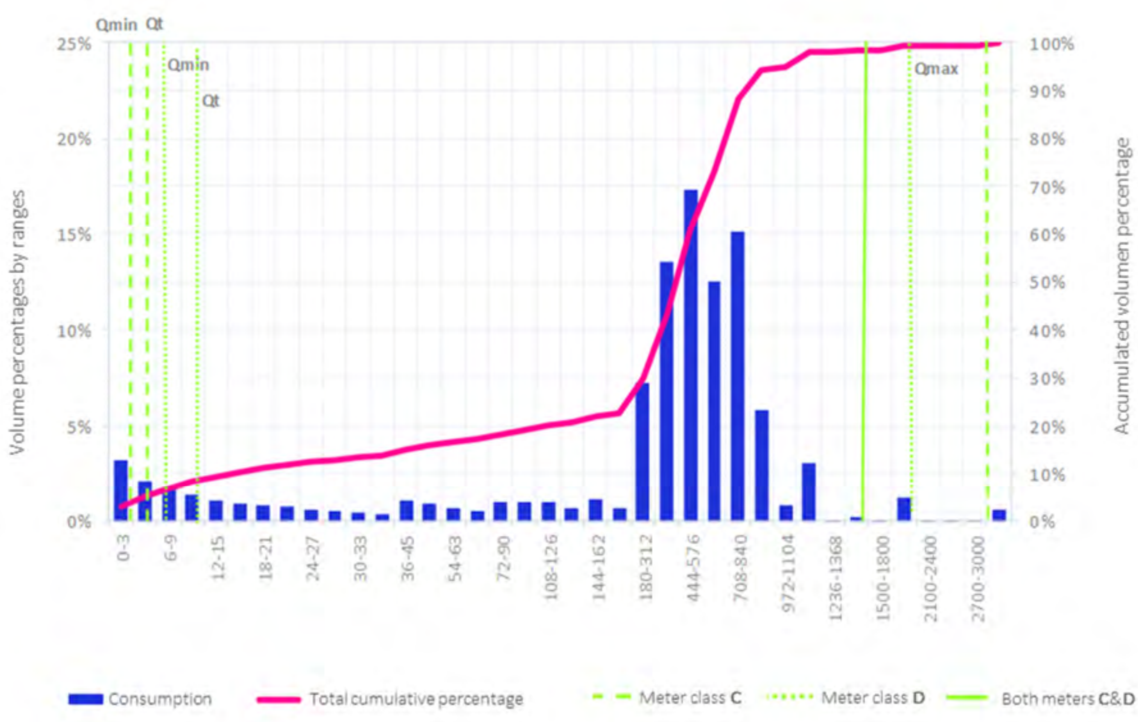
6.6. HISTOGRAMS OF CONSUMPTION

The pulses recorded in each household in the sample, have been processed to determine to which flow rate each litre or decilitre recorded has been consumed. Accordingly, a series of ranges have been determined in which to group together this volume, particularly low flow rates, with the aim of gaining a better understanding of this consumption.

6.6.1. Results obtained

Figure 134 illustrates, for the established ranges, the volume percentages consumed in each of the range, and the accumulated percentage from the lowest one. This figure includes the characteristic flow rates of the meters used in the study (Class C and D), which will subsequently be outlined in Table 24. It can be seen that the interval of ranges between the 180 litres per hour and the 972 litres per hour averages more than 70% of the total consumption and, particularly, it is in the 444 to 576 litres per hour, where the highest volume is recorded (17.4% of the total); followed by the 708 to 840 litres per hour range, with 15.2% of the total); also the 321 to 444 litres per hour interval and the 576 to 708 litres per hour interval with 13.6% and 12.5%, respectively. The volumes recorded below 180 litres per hour, only represent 22.8% of the total consumption.

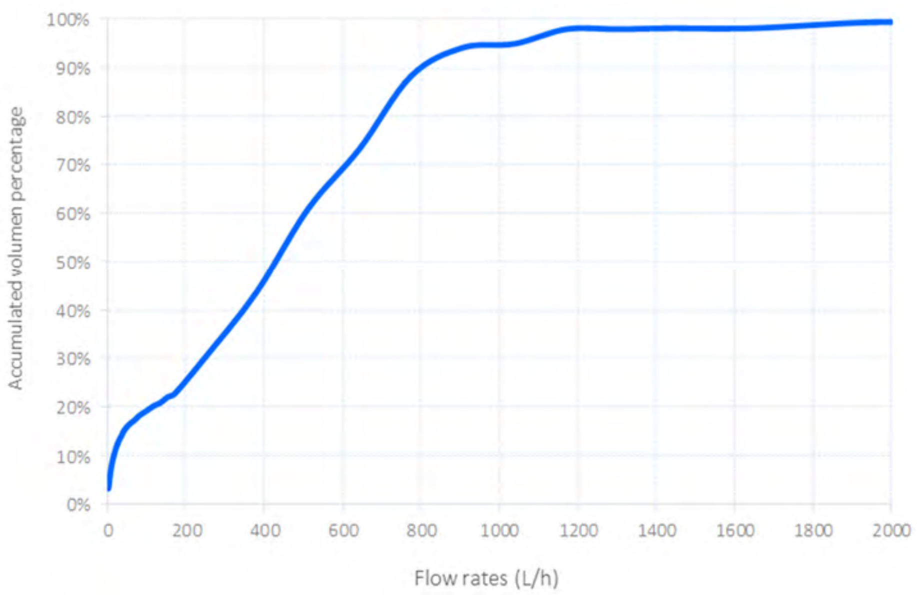
FIGURE 134. GENERAL FLOW RATE HISTOGRAM



The histogram reveals a certain volume in the highest range of 3,000 litres per hour. This volume refers to three and four users, providing 99.7% of the volume of this interval in 2013 and 98.9% in 2014, respectively. With the aim of not distorting the conclusions, these volumes have not been considered in the following analyses.

Figure 135 illustrates the accumulated frequency distribution of the volume supplied based on the flow rate.

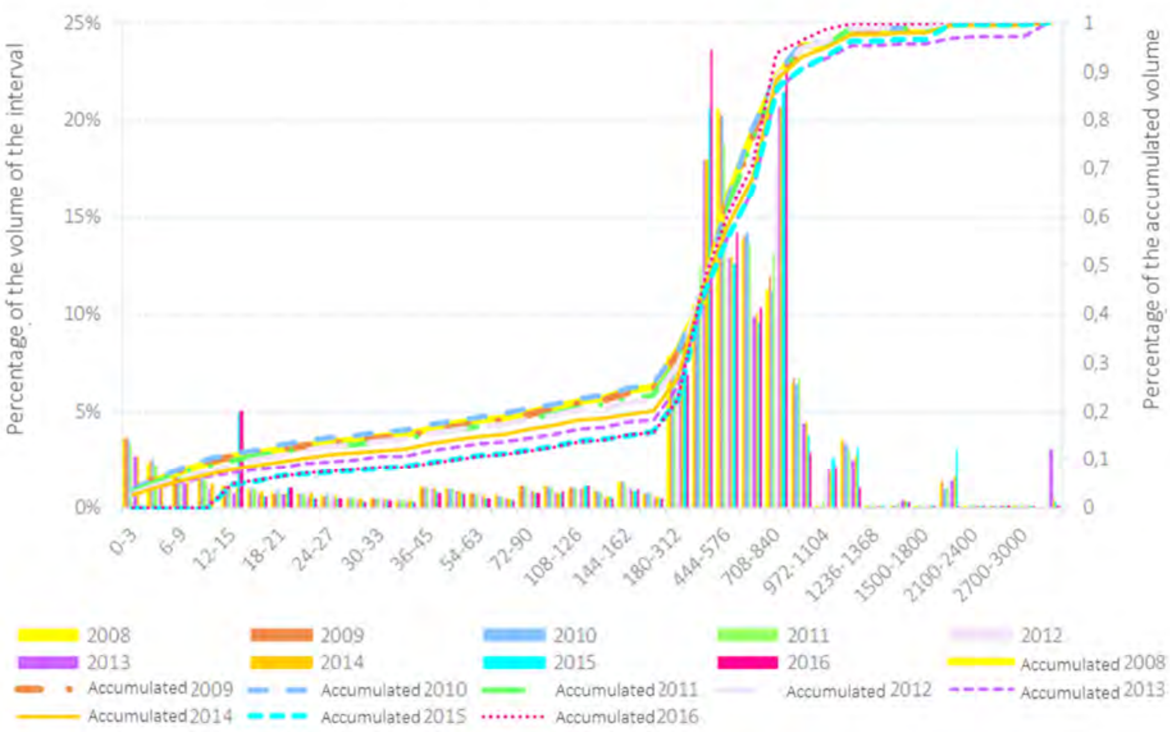
FIGURE 135. **ACCUMULATED HISTOGRAM OF CONSUMPTION**



If the overall consumption is outlined for all the years in the study, the graph shown in Figure 136, reveals a general similarity among the recorded data.

However, there is a certain difference between the accumulated consumption curves of the first years compared with the latter years. This difference may be due to the incorporation, in 2011, of class D meters.

FIGURE 136. **HISTOGRAM OF FLOW RATES PER YEARS**



6.6.2. Effect of the type of meter and data collection on the results

The use of different metrological types of meters, C and D, even when both are rotary piston volumetric type meters, reveal different characteristics in terms of flow rates, which are summarised in the following Table 24:

TABLE 24. TECHNICAL CHARACTERISTICS OF THE VOLUMETRIC METER

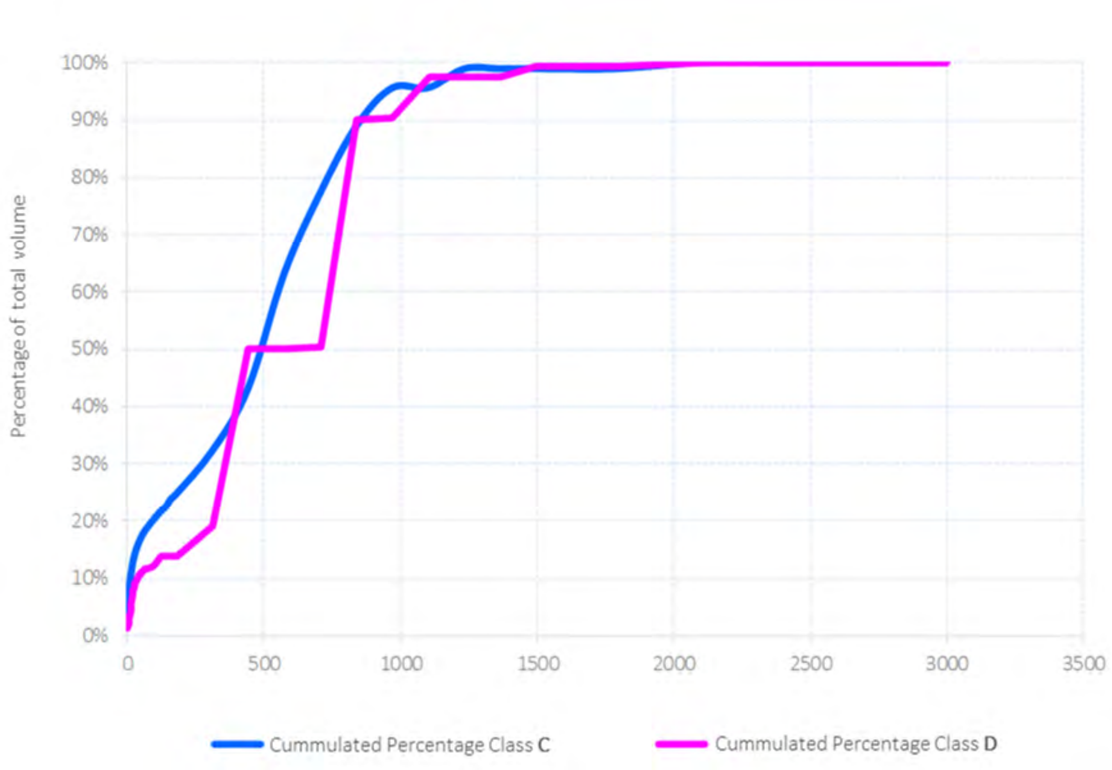
Nominal diameter (DN)	*mm*	*13/15*	*15*
Metrological class		Class C[8] all positions	Class D[9] all positions
Nominal flow rate Qn	m^3/h	1.5	1.5
Maximum flow rate Qmax	m^3/h	3	2
Minimum flow rate Qmin (Accuracy ± 5%)	l/h	3	7.5
Transition flow rate Qt (Accuracy ± 2%)	l/h	5	11.5
Start-up flow rate	l/h	<1	1
Maximum reading capacity	m^3	105	105
Minimum graduated unit	l	0.05	0.02

C[8] *Metrological class EEC*   *D[9] Pursuant to British Standard 5728/7*

An aspect to bear in mind is that the initial ***class D*** meters were installed in 2011, while the first-class ***C*** meters were installed in 2008. In order to correctly consider the possible effect of the results, some households have had these meters installed in series, so the flow rate supplied to customers is passing, through the ***class D***, ***class C*** meter and lastly, the one installed for billing purposes. An initial analysis of the data, reveals that consumption in the households considered in the study is quite constant when analysed in the 2012-2014 time series. The reading differences between the three meters are low. Only one household has differences exceeding ±2%. Overall, the current billing meter readings are slightly lower than the *class **C meters*** (-0.26%) and similar to the ***class D*** meters (-0.02%). The differences, therefore, between the class C and D meters in this sub-sample of households are very low.

By analysing the entire sample and taking into account the type of meter, we can see (Figure 137) significant differences in the lower part of the histogram, where the meter accuracy is very different. The first interval, from 0 to 3 litres per hour, includes the area with the greatest uncertainty for both meters that have a start-up flow rate of 1 litre per hour, but in the ***class C** meter* the following interval of 3 to 6 litres per hour includes the area of accuracy of ± 5% (minimum flow rate of 3 litres per hour and transitional flow rate of 5 litres per hour) but this is not the case in ***class D*** meters, which in this precision area have the following two ranges, from 6 to 9 litres per hour and from 9 to 12 litres per hour (minimum flow rate of 7.5 litres per hour and transitional flow rate of 11.5 litres per hour). Another notable difference is between the 162 and the 1,104 litres per hour, and particularly, between the 312 and the 840 litres per hour, where there are significant fluctuations between consecutive ranges for the volumes recorded in ***class D*** meters. This is because, in this range, with the meters with an accuracy of one decilitre, two pulses per second can be recorded, which is the minimum time unit used when recording data.

FIGURE 137. FLOW RATE HISTOGRAM BY TYPE OF METER (CLASSES C & D)



6.7. RESULTS OF MICRO-COMPONENTS OR END USES

The aim of this section is to analyse the water use in the different applications in households, once the consumption characteristics recorded over the ten-year study period have been outlined. It was carried out on 7 different categories: irrigation, the use of washing machines and dish washers, the use of showers or bath tubes, taps, toilet flushes, and internal leaks or losses.

6.7.1. Characterisation of the different applications

The various water uses in households have different characteristics in terms of average flow rate, peak flow rate, duration or total volume of water used, which can be used in order to classify them automatically.

The average distribution of uses in this sample is as presented in Figure 138. Showers and bath tubes, taps, toilet cisterns and washing machines account for 91% of the total consumption in a household, according to the data obtained from the sample.

Using the figures of the last complete year available (July 2016 to June 2017), the characteristics of the events assigned to these uses are summarised in Table 25.

FIGURE 138. DISTRIBUTION OF WATER END USES ON THE MONITORING PANEL 2008 – 2016

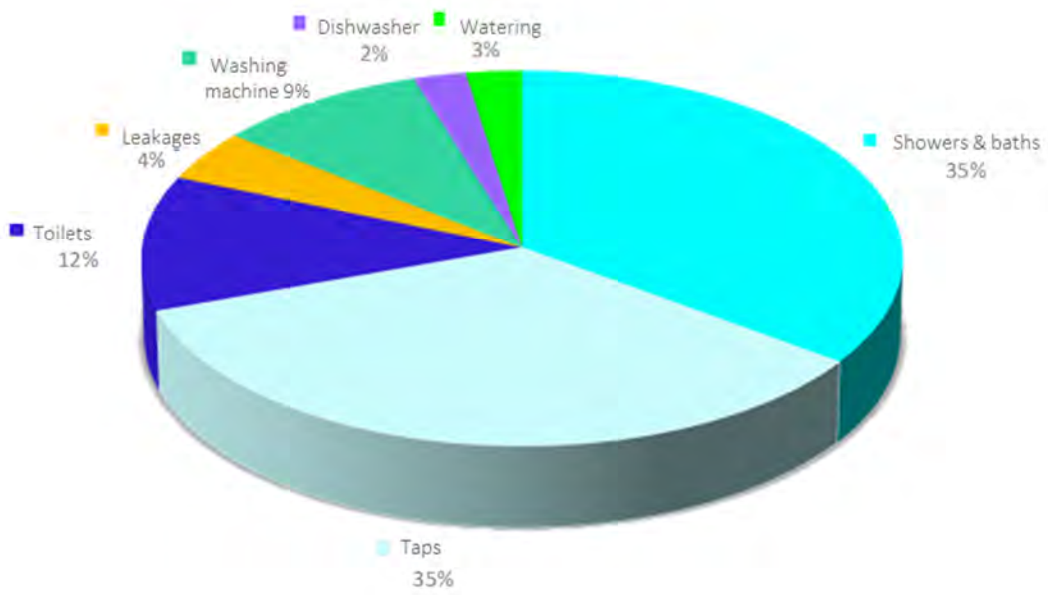


TABLE 25. DESCRIPTION OF EVENTS TYPE

Use	*No. events*	*Average duration (sec)*	*Average flow rate (l/min)*	*Average volume (litres)*	*Peak flow rate (l/min)*	*Flow rate mode (l/min)*	*Mode duration (sec)*
Showers	8,106	124.9	8.4	17.6	12.4	7.8	76.5
Toilets	125,607	34.6	8.5	4.9	11.1	8.0	22.3
Washing machines	24,728	84.1	7.5	10.5	11.3	6.7	56.2
Taps	461,476	12.2	5.5	1.1	6.5	5.8	10.2

The graphs in figures 139 to 142 illustrate these events, classified in accordance with the duration and average flow rate used.

The greatest data dispersion is in the events classified as "taps", given the wide variety of possible uses, which cannot be distinguished with the technique used for identifying and labelling.

Table 26 illustrates the average daily number for each type of event observed during the latter period (from July 2016 to June 2017).

FIGURE 139. **HISTOGRAM. CHARACTERISTICS OF SHOWER EVENTS**

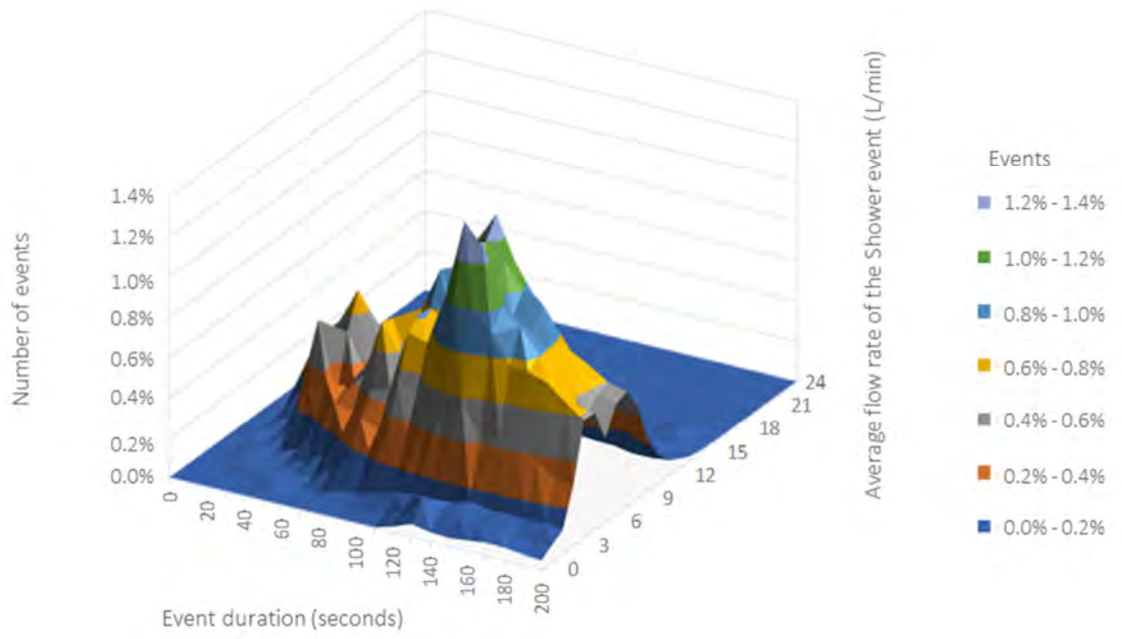


FIGURE 140. **HISTOGRAM CHARACTERISTICS OF EVENTS: TOILETS**

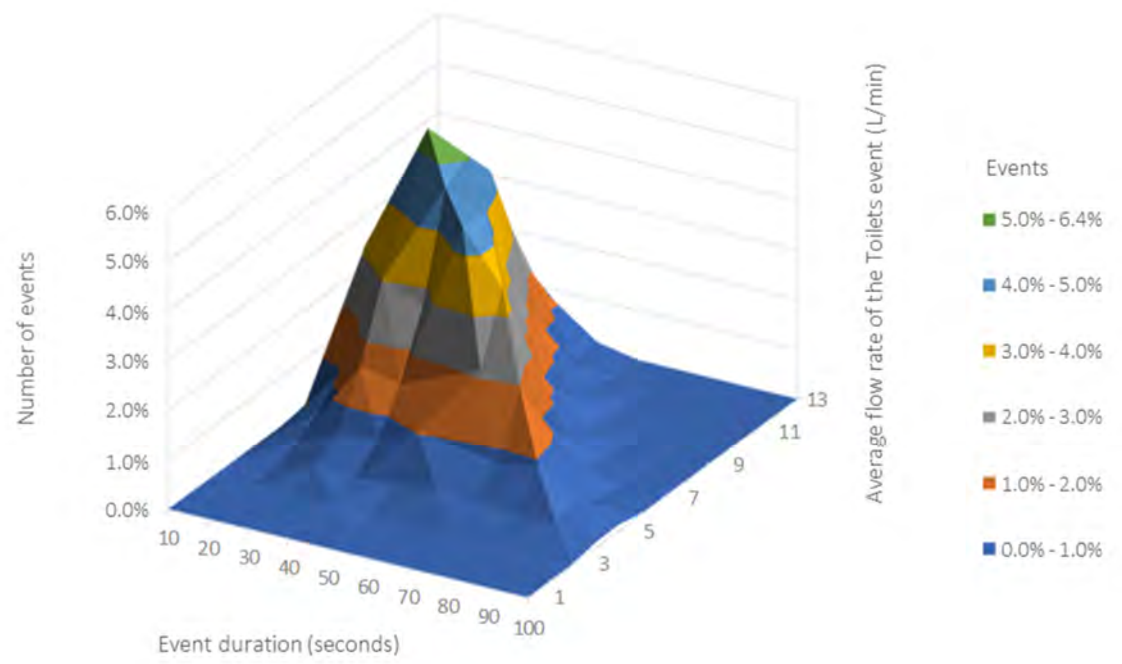


FIGURE 141. HISTOGRAM CHARACTERISTICS OF EVENTS: WASHING MACHINES

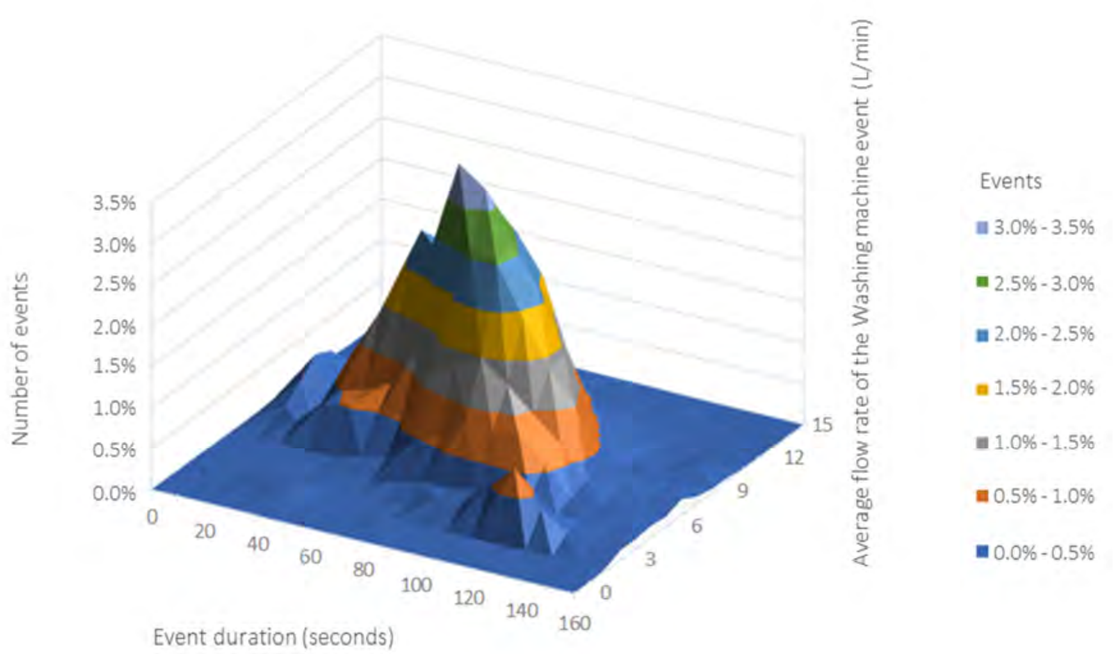


FIGURE 142. HISTOGRAM CHARACTERISTICS OF EVENTS: TAPS

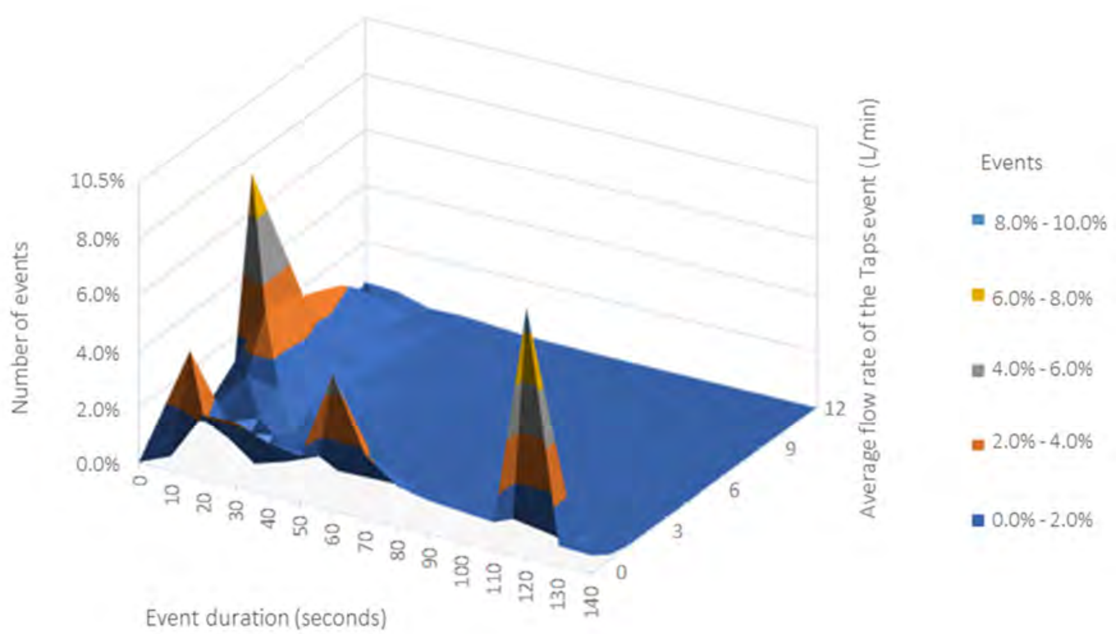


TABLE 26. AVERAGE NUMBER OF DAILY EVENTS, PER HOUSEHOLD

Use	*Average number of daily events, per household*
Showers	1.7
Cisterns	6.0
Washing machines	2.1
Taps	18.8

6.7.2. Overall results regarding use of appliances

Throughout the study, the usage results obtained, in litres per household and real day, are reflected in Figure 143.

Figure 144 outlines the trends in the pattern of uses in the sample. As shown in the graph, uses with the greatest variability are *showers and bath tubes*, together with *taps*. With regard to *showers and bath tubes,* the difference between the maximum monthly value (October 2012) and the minimum monthly value (August 2013) was 94%, and in the use of *taps*, the biggest difference (May 2014 and August 2011) was 111%.

For the rest of the uses, the patterns remained quite stable, except for *leaks,* which dropped noticeably from 2011.

FIGURE 143. AVERAGE END USES THROUGHOUT THE STUDY (LITRES PER HOUSEHOLD AND DAY)

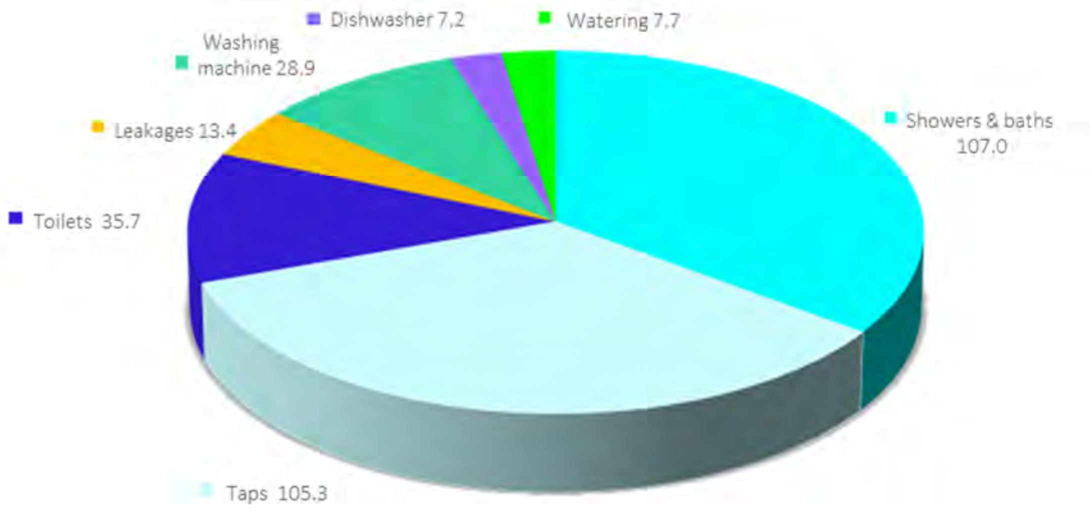


FIGURE 144. **CHANGES IN THE VOLUME OF EACH USE DURING THE STUDY**

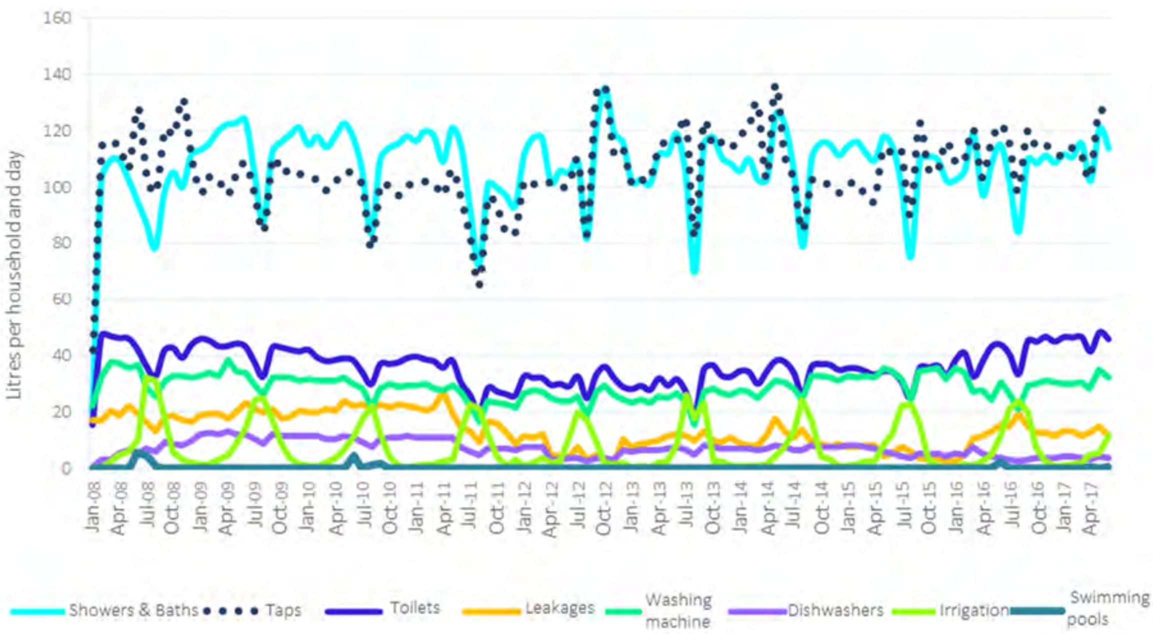
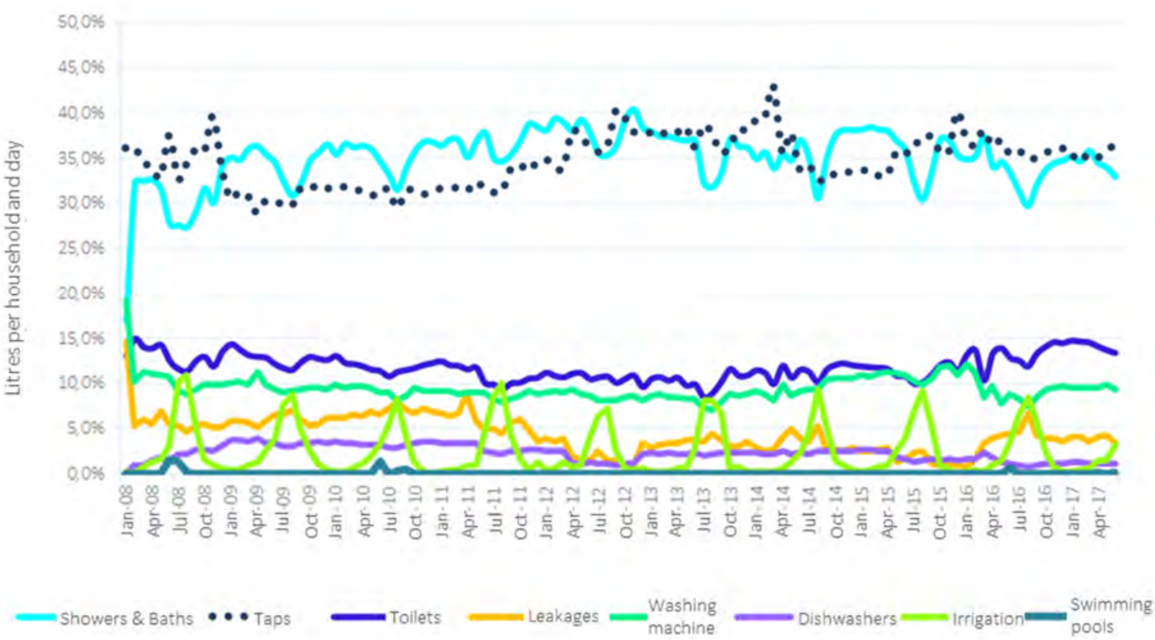


Figure 145 illustrates the evolution in percentages, where it can be seen usage patterns, with fewer fluctuations than in the previous figure. There was a significant increase in the use of *taps* from 2012, and this trend was reversed when it reached its highest peak (March 2014) throughout the entire study. This is the use in which the difference in summer is the highest (9.8%). The next significant difference is in *showers and bath tubes* (8.6%).

FIGURE 145. **EVOLUTION OF THE PERCENTAGE OF EACH USE DURING THE STUDY**



As indicated previously (Figure 138), the use of *Showers & bath tubes* and *Taps*, are the most important and account for 69.9% of residential consumption, with 35.1% and 34.5%, respectively. After these, the most important uses, according to the users in the sample, are *Toilets* (12%) and *Washing machines* (9%).

The use of *Dishwashers* and *Irrigation* account for 2.4% and 2.5% of consumption, respectively. In the case of *Irrigation*, this value is so low because it is not applicable to all the properties and given its marked seasonal nature. In terms of *Leaks*, although the average is 4%, there are continuous decreases from 2012 onwards in the annual progress. Figure 146 illustrates the annual progress of usage averages.

With the exception of *irrigation,* the monthly values in the sample remain very stable throughout the year, as shown in the graph in Figure 147, where the only drop during the summer months is for *Showers and bath tubes* and *Taps*, when households are empty during holiday periods. *Irrigation*, as expected, has the reverse behaviour and reaches maximum values during July and August.

In the monthly percentage variations, we can see how, during the irrigation season, the associated consumption is considerable, particularly during the summer and spring months (Figure 148). In households were this use is common (mainly single-family homes), during July, August and even September, consumption in irrigation sometimes exceeds that for *Taps* and *Showers and bath tubes*, with an average of 132.6 litres per household and day. During the winter months, consumption in *irrigation* drops considerably, below 1% of the total consumption. The rest of uses remain quite stable throughout the year.

The type of property is also an important factor in the distribution of uses, not only in terms of outdoor uses, such as *Irrigation* and *Swimming pools*, but also in terms of the higher number of *Leaks*, since pipes are usually longer and partly located outdoors, leading to a higher probability of breaks and small water leaks, as shown in Figure 149.

FIGURE 146. **AVERAGE ANNUAL VOLUME FOR DIFFERENT USES**

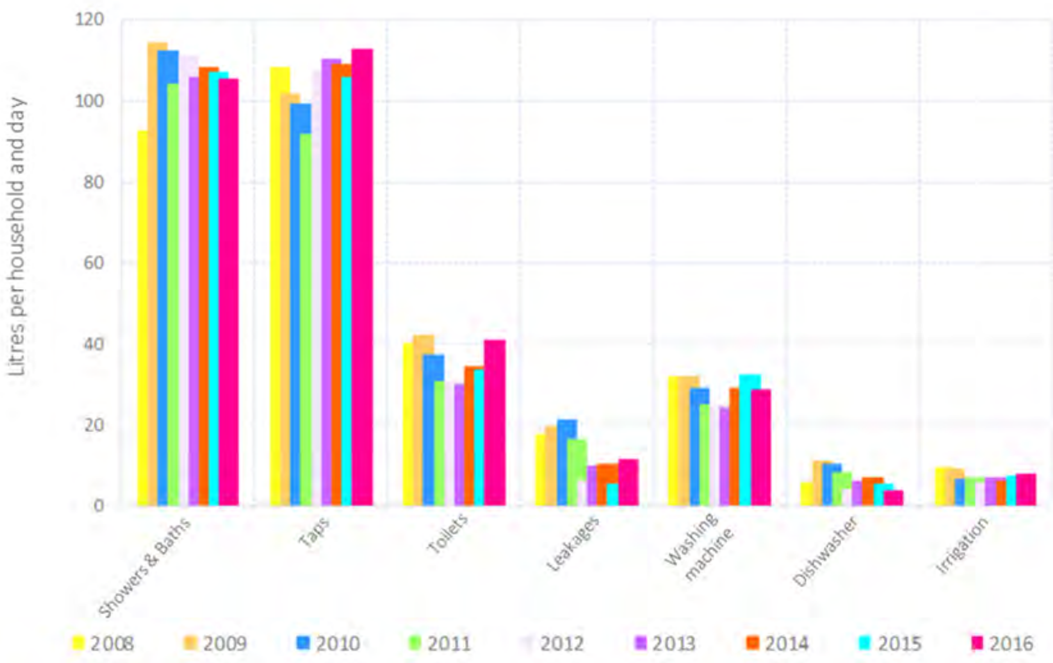


FIGURE 147. MONTHLY AVERAGE FOR DIFFERENT USES

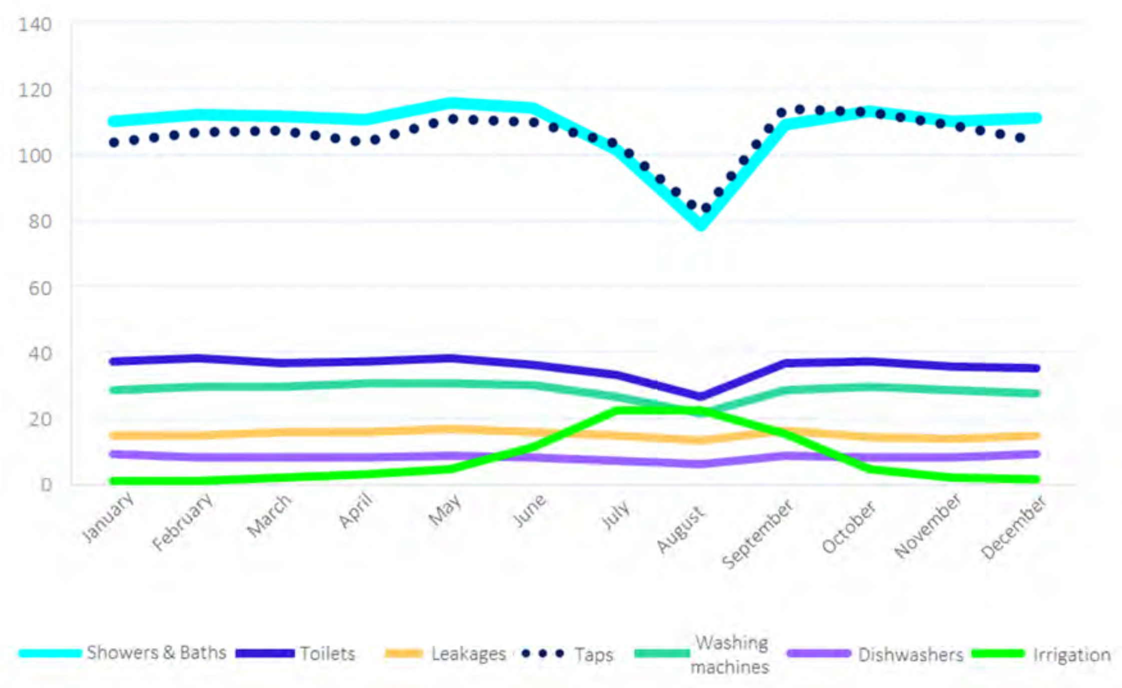


FIGURE 148. MONTHLY USAGE PERCENTAGE

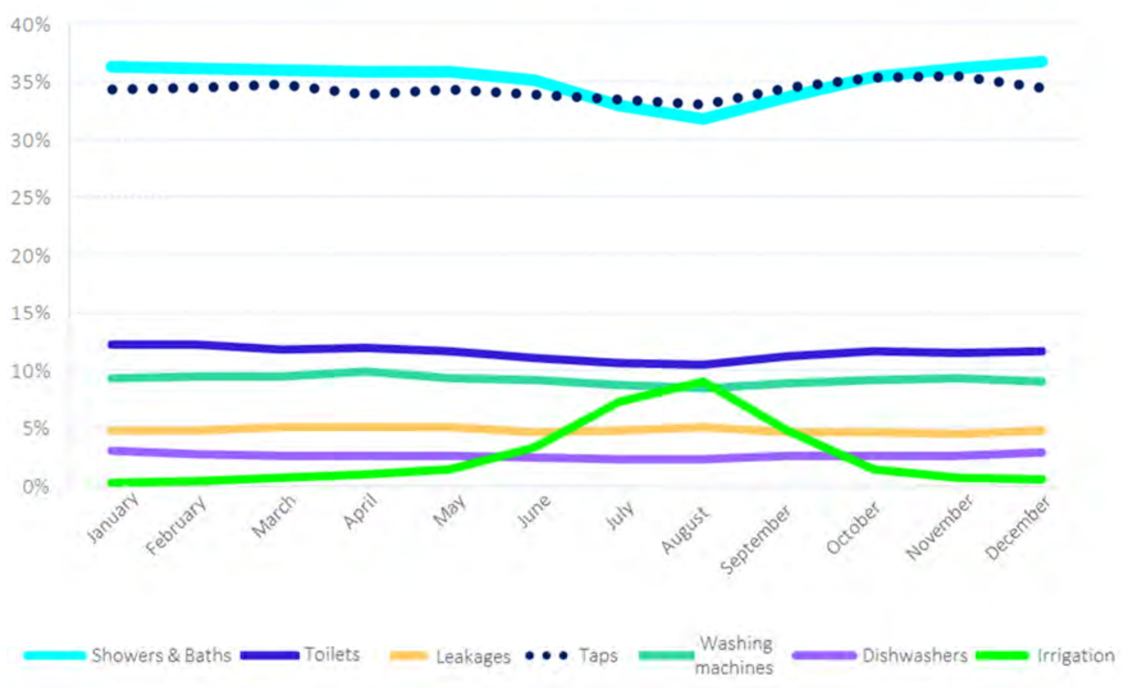
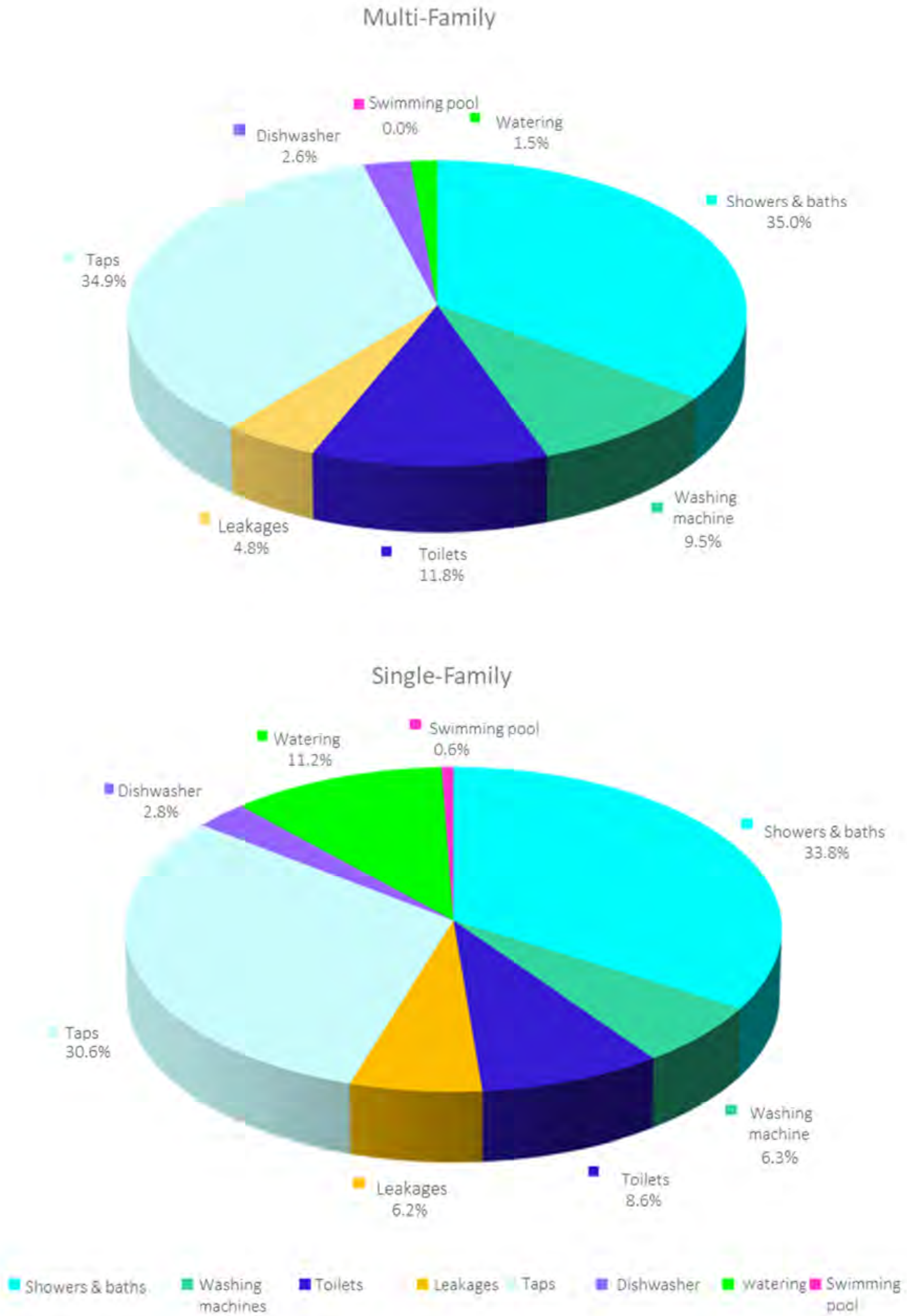


FIGURE 149. DISTRIBUTION OF USES BASED ON TYPE OF HOUSEHOLD, SINGLE_FAMILY OR MULTI_FAMILY HOMES



6.8. SPECIFIC ANALYSIS FOR EACH TYPE OF APPLIANCE

6.8.1. Type of use *showers and bath tubes*

Changes in consumption per years for *showers and bath tubes* are reflected in Figure 150. In general terms, there is a downward trend, with ups and downs on the equator of the study. Annual usage, based on the type of property, is shown in Figure 151. It can be seen that consumption in single-family homes is higher (53.8% higher in average) and the difference reached 74.8% with regard to multi-family homes in 2014, followed by 2010, with 62%.

FIGURE 150. ANNUAL AVERAGE FOR SHOWERS AND BATH TUBES

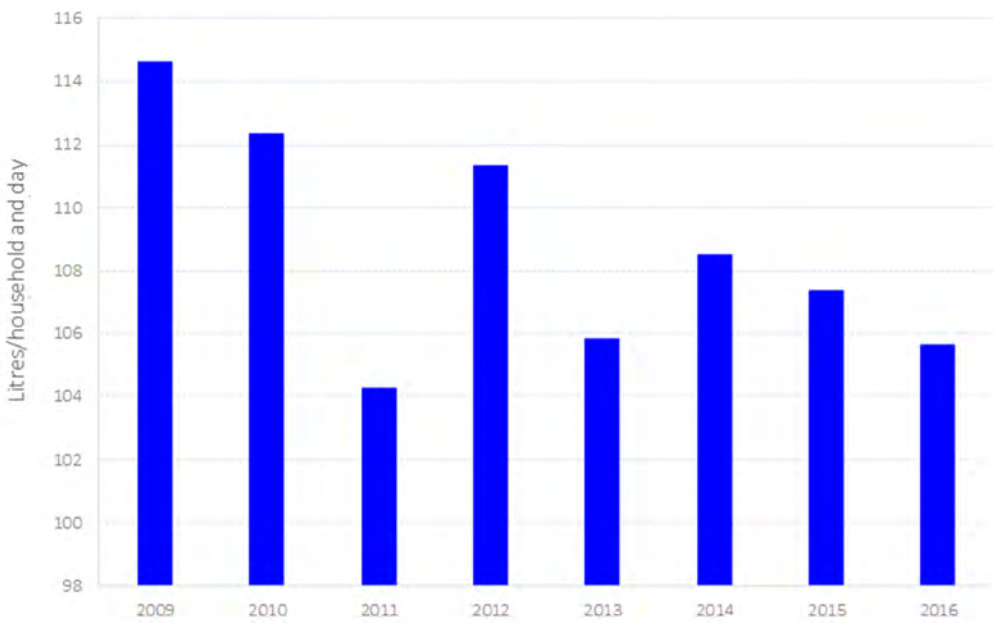


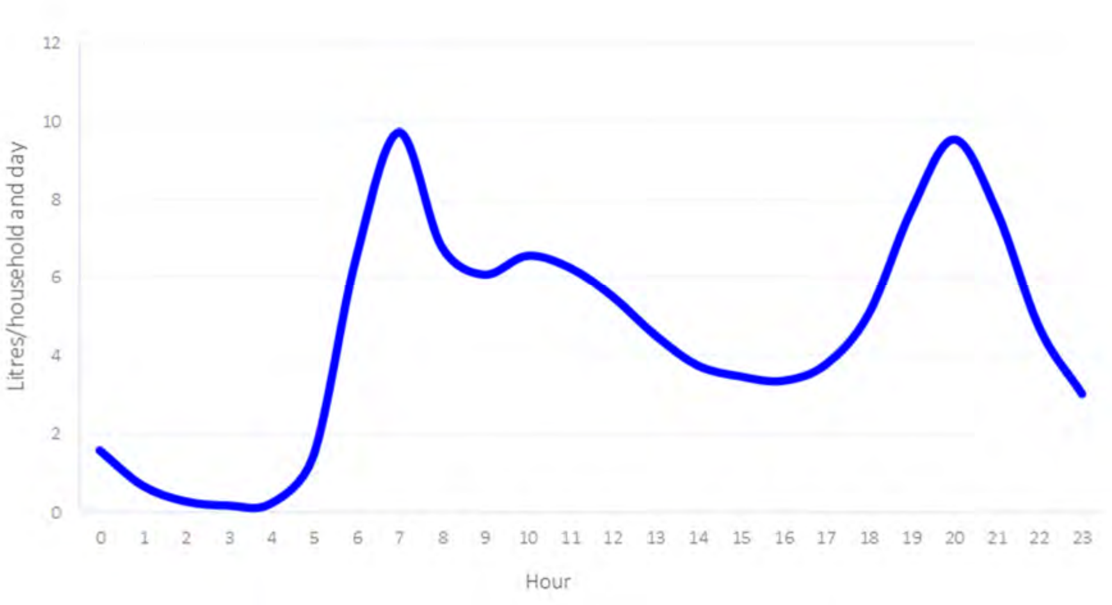
FIGURE 151. USE OF SHOWERS AND BATH TUBES PER TYPE OF HOUSEHOLD

Within each type of property, in multi-family homes, there is a significant increase in the use of *Showers and bath tubes* in 2009 (15.3% more than in 2008).

For single-family homes, there was a significant increase in 2009 (31.9% more than in 2008), and from 2010, there was a downward trend, maintained over time (around -7% compared with the preceding year. In 2014, consumption recovered, with a 23.3% increase, the difference between the maximum in 2014 and the minimum in 2008 was 41%, for single-family homes.

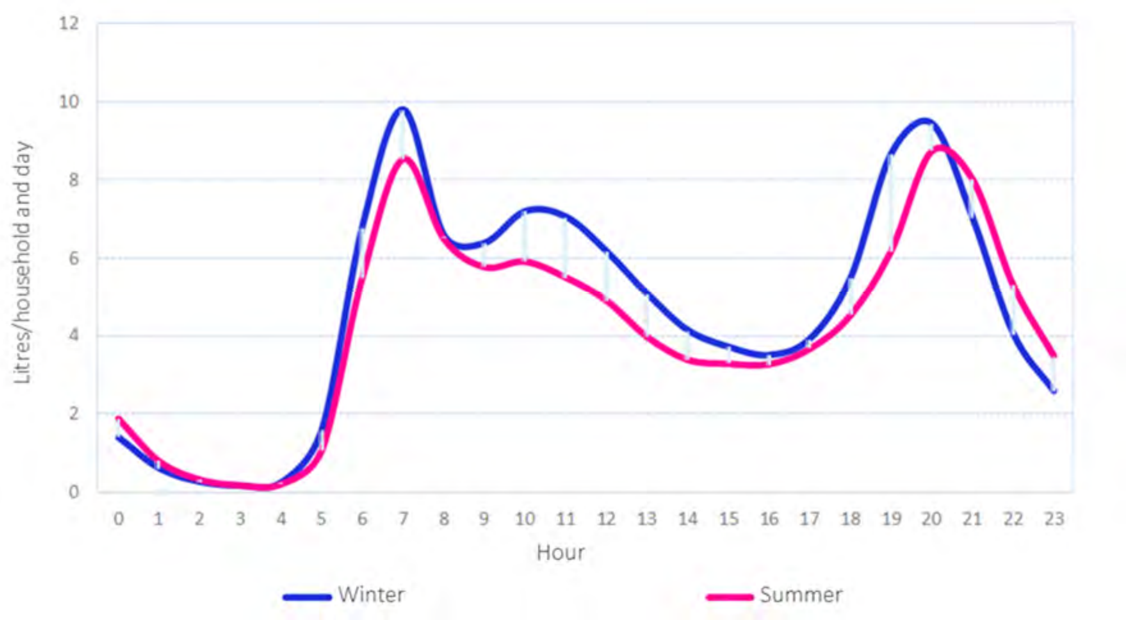
Figure 152 shows the overall hourly modulation for *Showers and bath tubes*; it can be seen that it concentrates around the initial and last hours of the day, associated with hygiene related activities. Therefore, traditionally, consumption is at a high between 6 a.m. and 8 a.m. and between 7 p.m. and 9 p.m. Peak consumption times are at 8 p.m., representing 14.1% of the average monthly consumption for this use and at 7 a.m., which represents 11.9%.

FIGURE 152. HOURLY MODULATION FOR SHOWERS AND BATH TUBES



In seasonal terms, during the winter season, consumption is higher, practically throughout the entire day compared with consumption in summer. The most significant differences are during the morning, between 10 - 11 a.m. and in the afternoon between 6 p.m. and 7 p.m. From 8 p.m. the use of *Showers and bath tubes* is slightly higher during the summer than in the winter (see Figure 153).

FIGURE 153. **SEASONAL DIFFERENCES FOR SHOWERS AND BATH TUBES**



6.8.2. Type of use *Washing machine*

In terms of the use of these appliances, there is a negative trend over the years, with it changing in 2014, when there is a slight recovery, reaching the 2009 levels, Figure 154 reflects the annual averages.

If this trend is analysed, based on the type of property, it can be seen that during the 2009 to 2014 period, the use of washing machines in multi-family homes was higher than in single-family homes; this trend was reversed in 2014, when the use in multi-family homes was 35.2% lower (Figure 155). The overall average during the entire period is 9% less in multi-family homes than in single-family homes.

The increased use of *Washing machines* in single-family homes during 2014, compared with 2013, was 78.7% and for multi-family homes, 11.3%.

This increase broke the downward trend of previous annual records. It dropped again in 2016. The difference in use in multi-family homes between the first year of the study and the last year is 27.4%

Figure 156 represents the hourly profile for the use of *Washing machines*, with consumption at its highest level between 10 a.m. and 11 a.m., dropping later until 5 p.m. and experiencing an upturn, with a maximum (much lower than daytime hours) between 8 p.m. and 9 p.m. Morning consumption, between 9 a.m. and 1 p.m. accounts for 32% of the entire daily consumption.

In terms of seasonal uses, the graph in Figure 157 reflects a 6% higher use in *Washing machines* in winter than in summer. In the profile for usage time and the relationship thereof with the time of the year, there is an increase in use between 1 p.m. and 2 p.m., 13% more in winter, nearer midnight the use of washing machines is much lower (-21%). In summer, usage is higher than in winter from 9 p.m. Even so, the same hourly behaviour can be seen.

FIGURE 154. **ANNUAL AVERAGES FOR WASHING MACHINES**

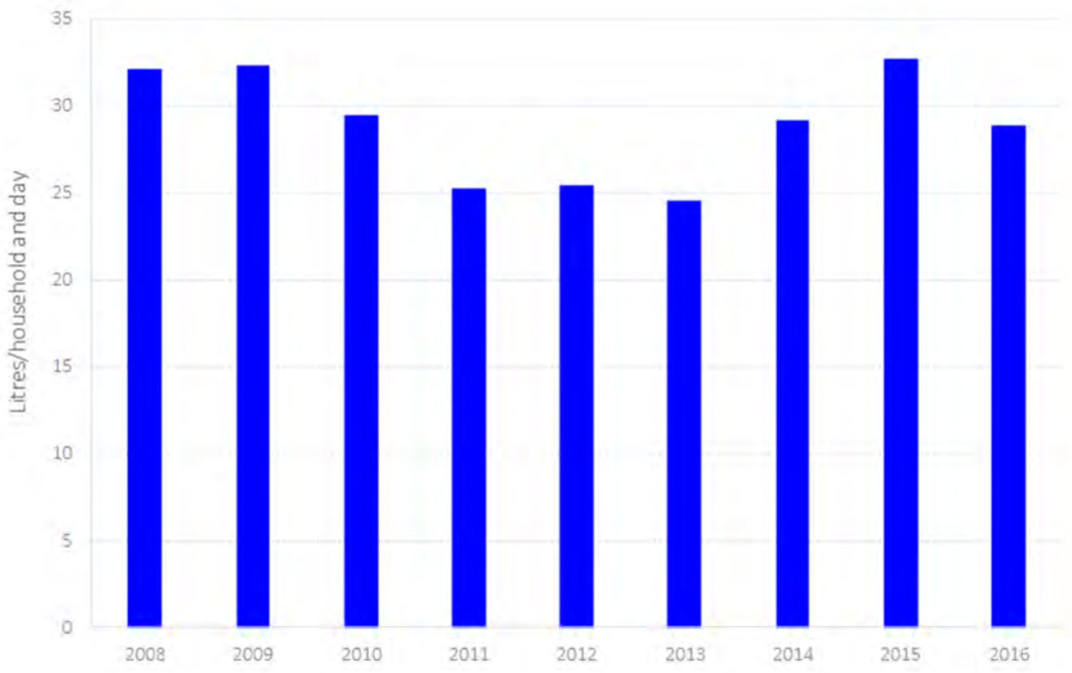


FIGURE 155. **USE OF WASHING MACHINES BY TYPE OF HOUSEHOLD**

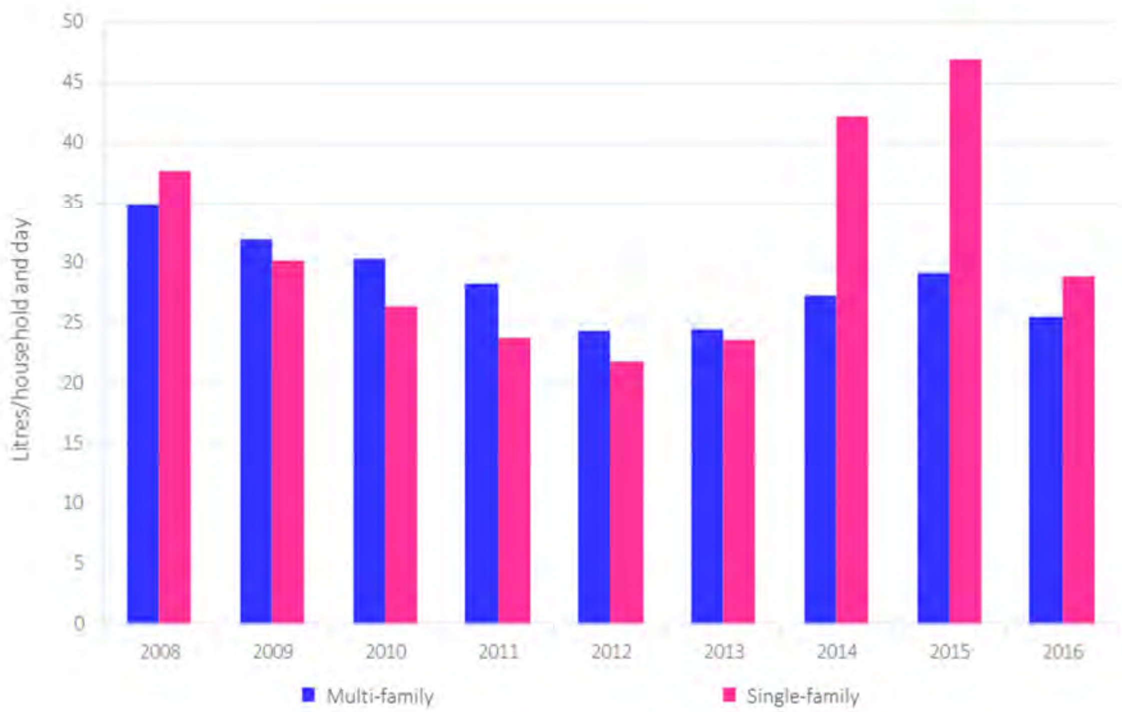


FIGURE 156. **HOURLY PATTERNS FOR WASHING MACHINES**

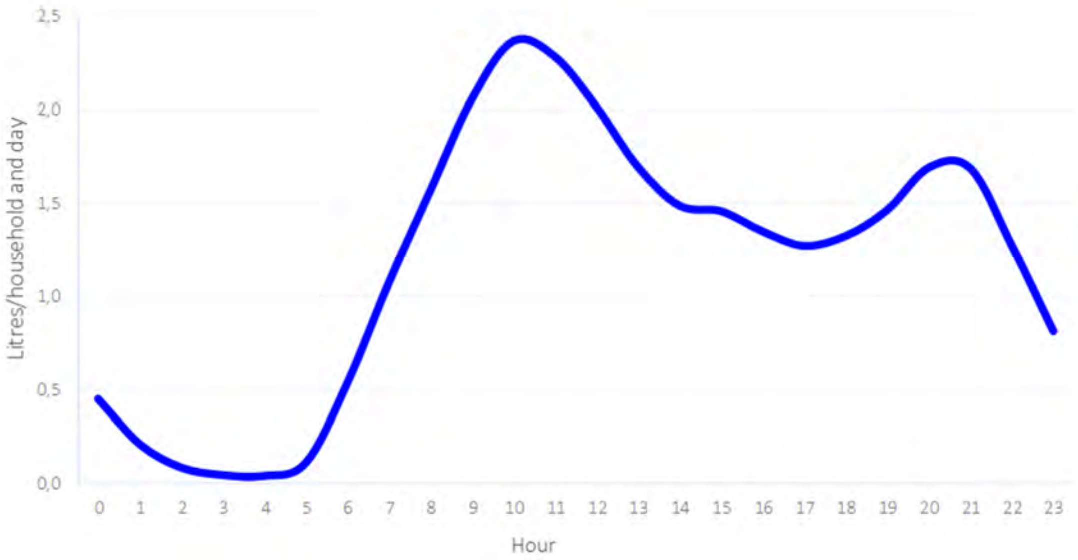
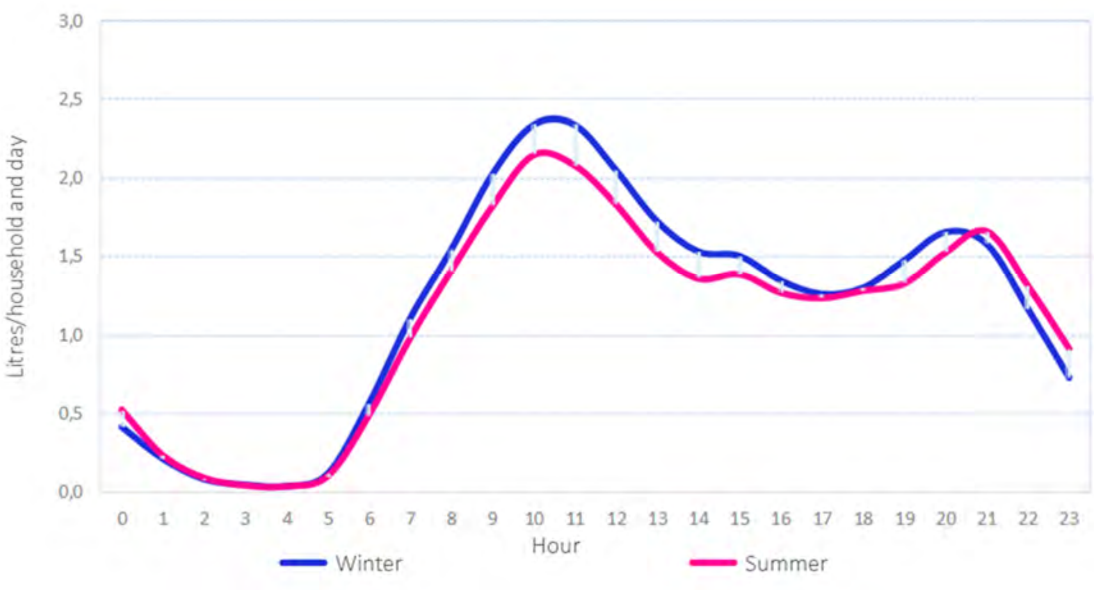


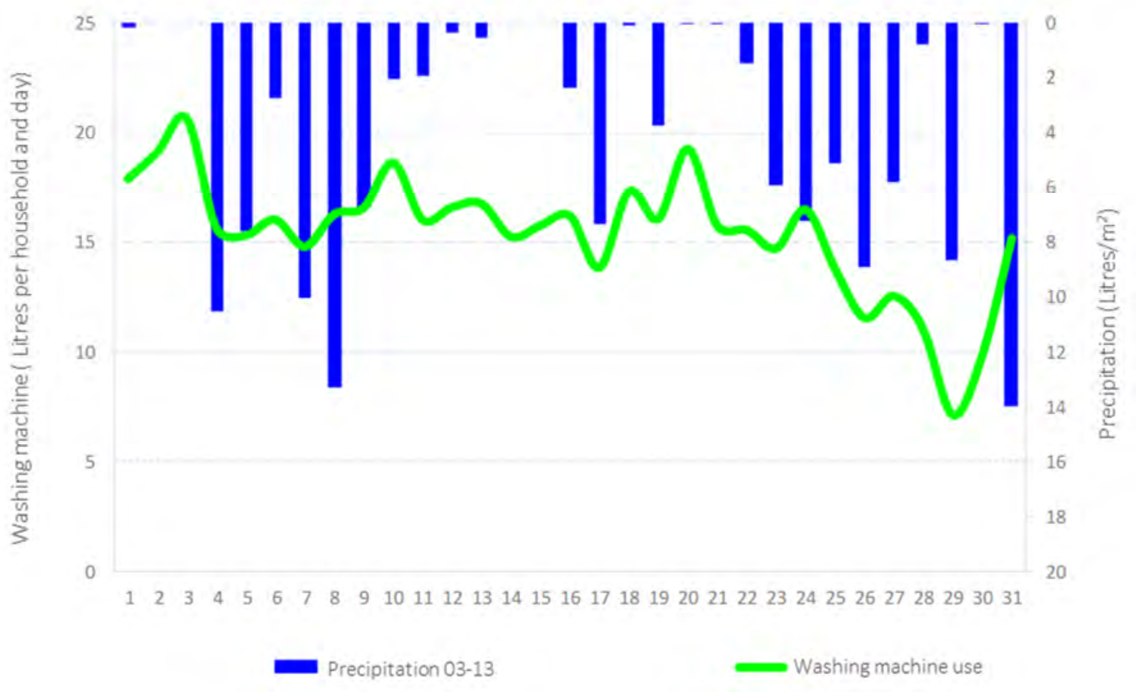
FIGURE 157. **SEASONAL DIFFERENCES FOR WASHING MACHINES**



For washing machines, an analysis of the relationship between the weather, particularly rainfall, and the use of the appliance has been carried out. To do so, the month of March 2013 was chosen, since it was the month with the most rainfall during the entire study period and therefore it was the best time to contrast the theory, which is shown in Figure 158.

Days with the most rainfall do coincide to a certain extent with a drop in water consumption in terms of *Washing machines*, although a statistically significant correlation could not be determined. The last days of March coincided with Easter Week, therefore there are other factors involved in the drop in consumption, apart from the weather.

FIGURE 158. **RELATIONSHIP BETWEEN RAINFALL AND THE USE OF WASHING MACHINES**



6.8.3. Type of use *Dishwasher*

In the analysis by years for the use of *Dishwashers*, there is a downward trend, which goes from 2009 to 2012 and, from then on, consumption begins to increase in 2013 and 2014, subsequently continuing (Figure 159) with a downward trend in the use of *Dishwashers.* The values for 2008 are conditioned by the fact that a large part of the sample during this period participated in the study on the use of dishwashers for washing up, with an initial period of two months in 2008 **without using dishwashers**, then followed by the use of dishwashers with water saving programmes.

Another aspect that conditions the results for this use, was the variation in the percentage of households with dishwashers which, overall, was 73% in the entire study period. Initially (2008 to 2009 period), it was around 84% - 85%. In 2012, it dropped to an average of 65%. During the final period of the study (2013 to 2016), the use of dishwashers reached 71%.

By type of property, it can be seen that the use of dishwashers was higher in single-family homes than in multi-family homes, an average of 82%, as shown in Figure 160.

The difference gradually increased in later years. The most significant contrast was in 2014, where the use was 202% higher in single-family homes than in multi-family homes, followed by 2015 and 2013, where the use in single-family homes was 191% higher and 139% higher, respectively.

FIGURE 159. ANNUAL AVERAGE CONSUMPTION FOR DISHWASHERS

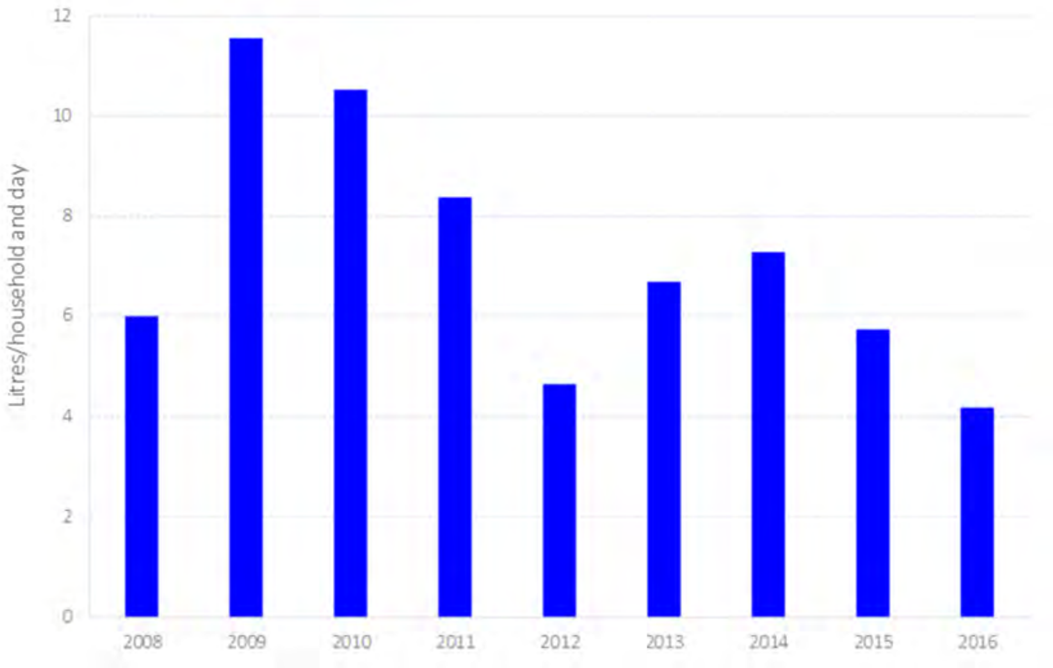
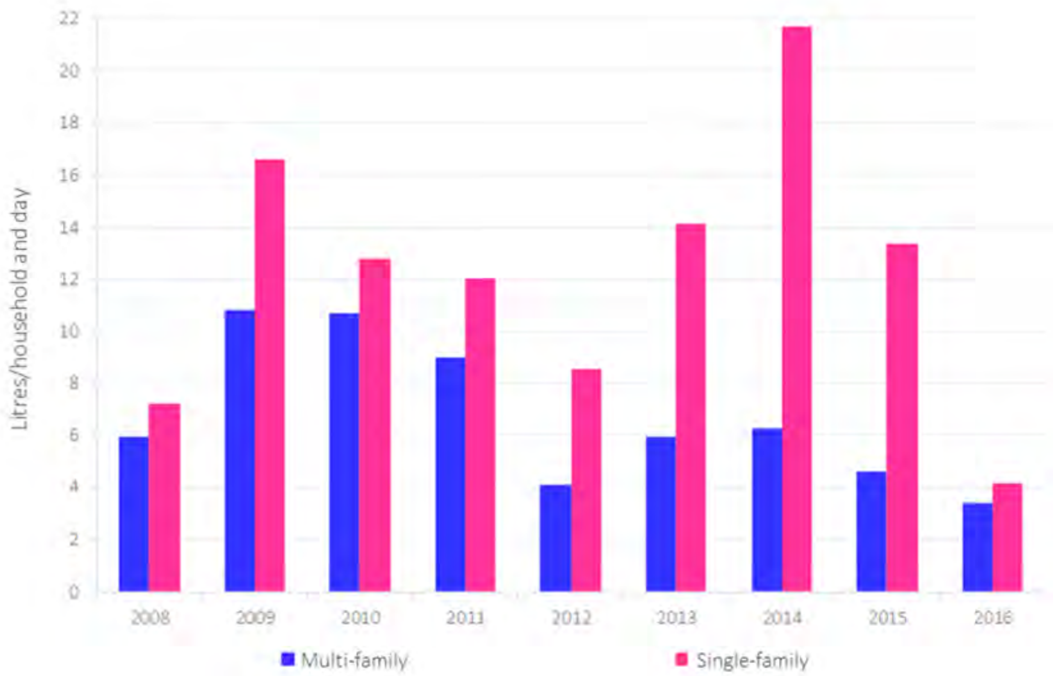
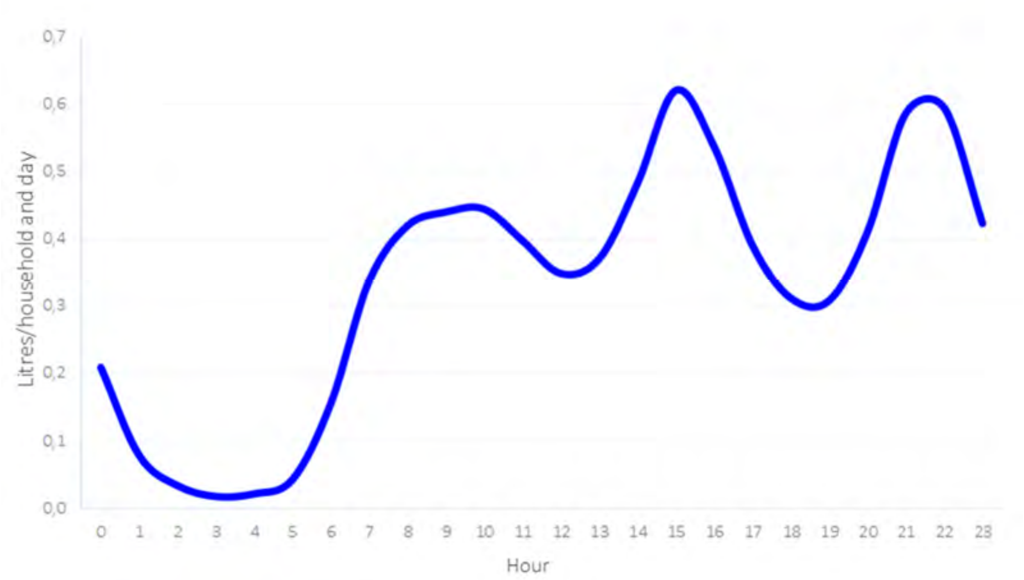


FIGURE 160. USE OF DISHWASHERS BY TYPE OF HOUSEHOLD



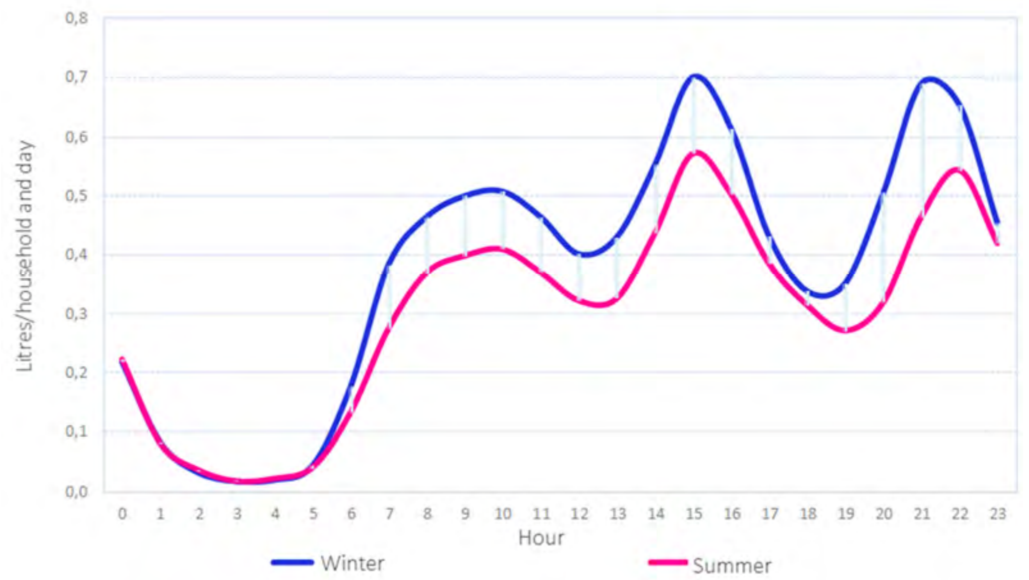
The patterns in multi-family homes reveal that in the latter years, 2013-2014, consumption values were similar to those at the beginning of 2008. The patterns in single-family homes are completely different, with an important increase in 2013 and decrease in 2016. The hourly use of dishwashers follows a pattern related to normal main meal times as illustrated in Figure 161.

FIGURE 161. **TIME MODULATION OF DISHWASHERS**



The time distribution of consumption with *Dishwasher* clearly indicates the peaks during the hours after the main meals of the day, with maximum values reached after lunch, at 3 p.m., which represents 7.79% and after dinner, between 9 p.m. and 10 p.m., which represents 7.41% of the total daily use. The increase recorded after breakfast, between 9 a.m. and 10 a.m., represents 5.55% and is clearly lower. The seasonal difference is reflected in Figure 162.

FIGURE 162. **SEASONAL DIFFERENCES FOR DISHWASHERS**

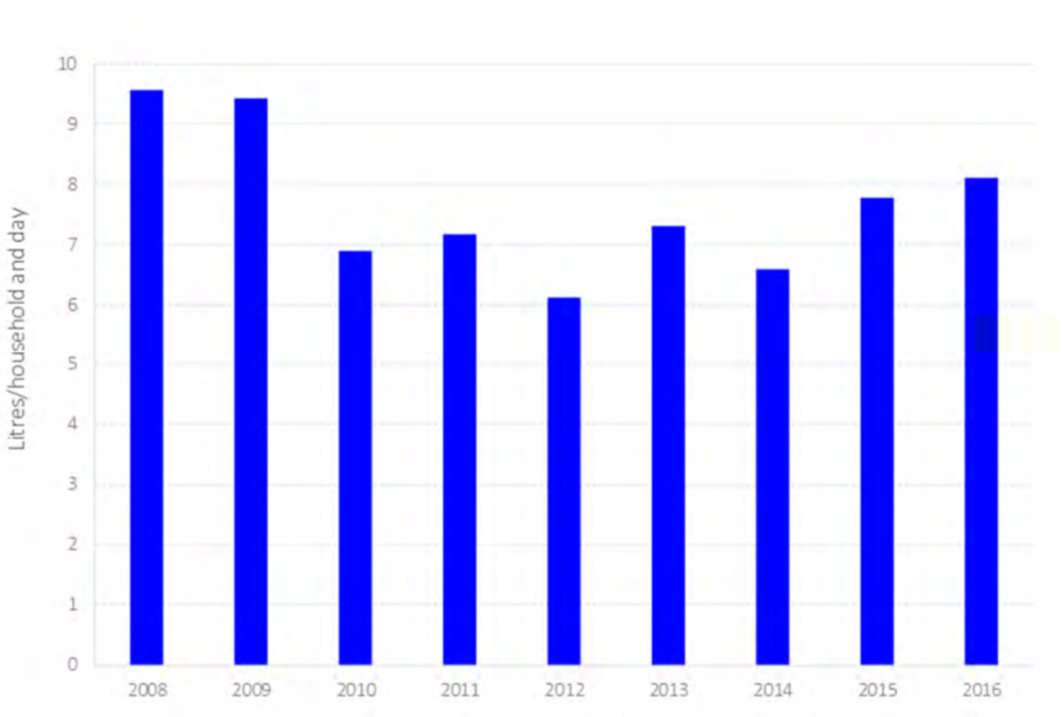


The section on seasonal use reflects higher consumption figures in winter (24.8% more) than in summer. The most significant differences are those at 8 p.m., 9 p.m. and 7 a.m., with 58.5%, 48.3% and 39.9%, respectively. During the summer months, the daytime hours are extended, and the nocturnal use of the *Dishwasher* goes from 9 p.m. to 10 p.m.

6.8.4. Type of use: *Irrigation*

Irrigation is one of the uses that is most related to the type of property and weather or climate conditions. In terms of the data collected, there were years in which irrigation values were lower: 2010, 2012 and 2014, with 2010 being the year with the highest rainfall (499 litres per m^2). In 2015 and 2016, there was an increase in consumption and at the same time, an increase in average temperatures was recorded, which is reflected in Figure 163.

FIGURE 163. AVERAGE ANNUAL CONSUMPTION FOR IRRIGATION



In terms of differences, based on the type of property, there is clearly a greater use of *Irrigation* in single-family homes than in multi-family homes, as reflected in Figure 164.

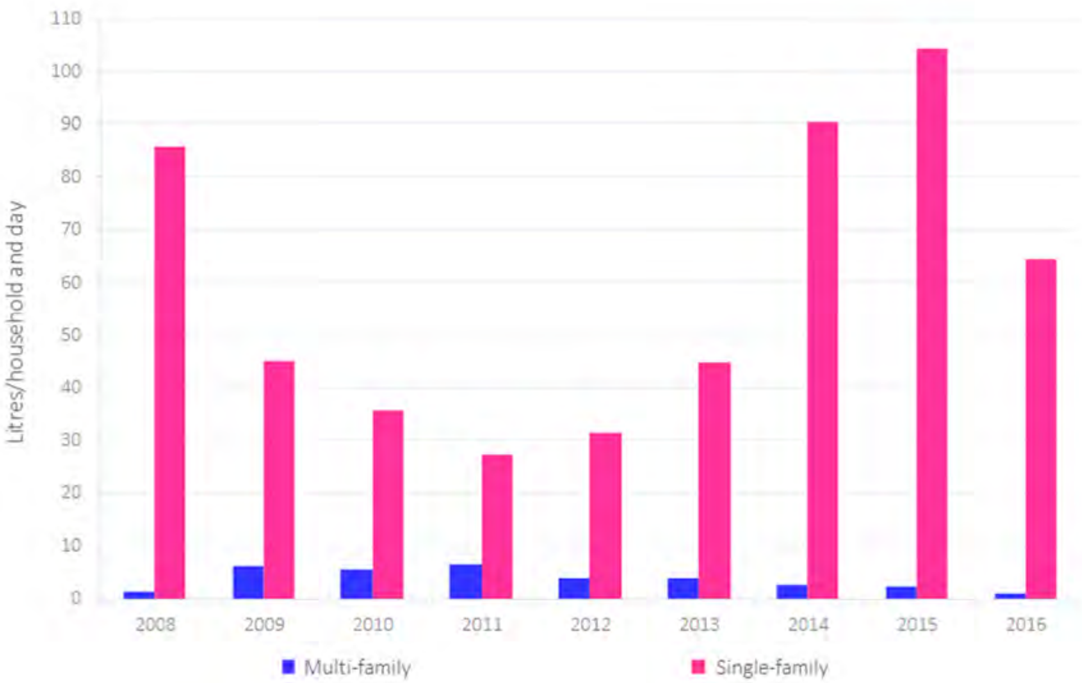
On average, consumption in single-family homes is noticeably higher (1,496%) compared with that of multi-family homes. The main differences in this use were recorded in 2008 (6,092% higher) and in 2016 (7,471% higher), with regard to consumption in multi-family homes.

Irrigation in multi-family homes reached maximum figures in 2011, and from then on, usage in this category dropped each year, until reaching similar levels to those of 2008. In these types of properties, average consumption in *Irrigation* is 3.7 litres per household and day.

It can be seen that the use of *Irrigation* has a convex form in the annual distribution for single-family homes, with its maximum levels reached in 2008 and 2015, and its minimum in 2011. Average consumption for *Irrigation* was 58.8 litres per day, during the entire period, with a maximum of 104.3 litres per day in 2015.

In terms of the daily time modulation for *Irrigation,* the average obtained during the entire period of study is represented in Figure 165. The time analysis for *Irrigation* reveals, in general, suitable habits and adapted to the advice given in this regard, since, generally, the central hours of the day are avoided (from 10 a.m. to 6 p.m.) and it is mainly carried out during the early morning hours and last evening hours, with maximum daily levels reached between 7 a.m. and 8 a.m. and between 8 p.m. and 10 p.m., respectively. Night time usage is also quite significant, with the exception of 4 a.m., when minimum consumption levels were recorded. *Irrigation* between 7 a.m. and 8 a.m. represented 10.7% of the total consumption and, in turn, irrigation carried out between 8 p.m. and 10 p.m., represented 10.6% of the total consumption.

FIGURE 164. USE OF IRRIGATION BY TYPE OF HOUSEHOLD



Seasonal usage reveals enormous differences, with a considerable increase during the summer months. Consumption peaks for winter and summer are also at 7 a.m. and 9 p.m. and the difference reaches 84.5% and 90.5% less usage in winter, compared with summer. Also notable is the use of night-time irrigation in summer (Figure 166).

As indicated at the beginning of this section, it would seem that weather conditions may be related to irrigation, for example, in March 2013, there was a considerable amount of rainfall, which has resulted in patterns with lower levels of irrigation. In terms of rainfall, there is a certain coincidence between days with rainfall and a notable reduction in irrigation, although the relationship is less clear, given that, when it begins to rain, temperatures tend to drop as well. Whether it is only the result of rainfall or a combination of rainfall and temperature, three is a change in the use of irrigation.

FIGURE 165. TIME MODULATION FOR IRRIGATION

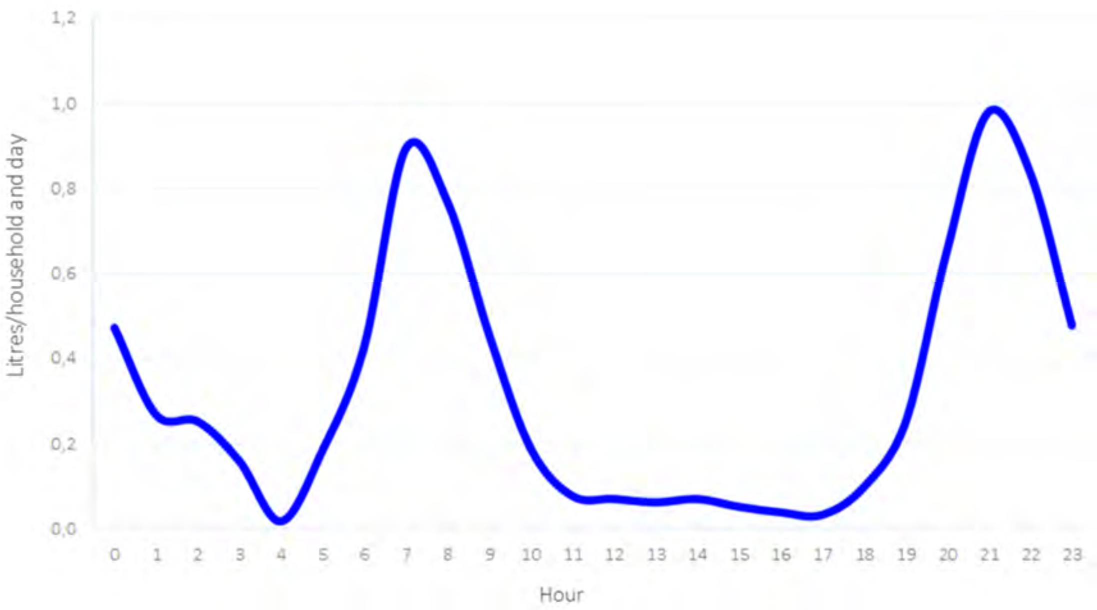


FIGURE 166. SEASONAL DIFFERENCES FOR THE USE OF IRRIGATION

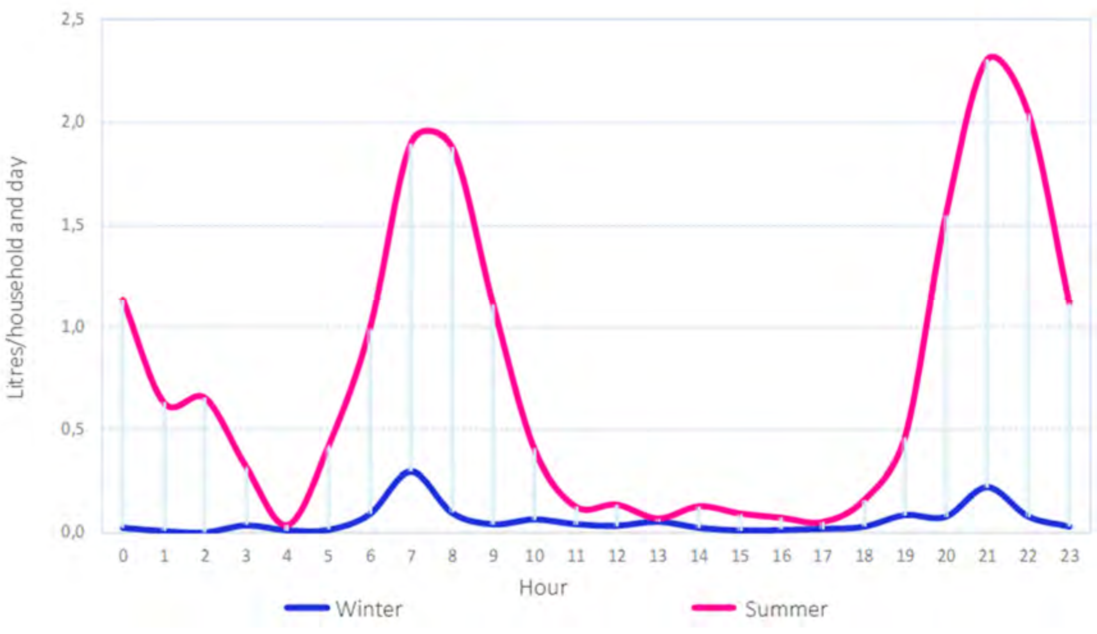
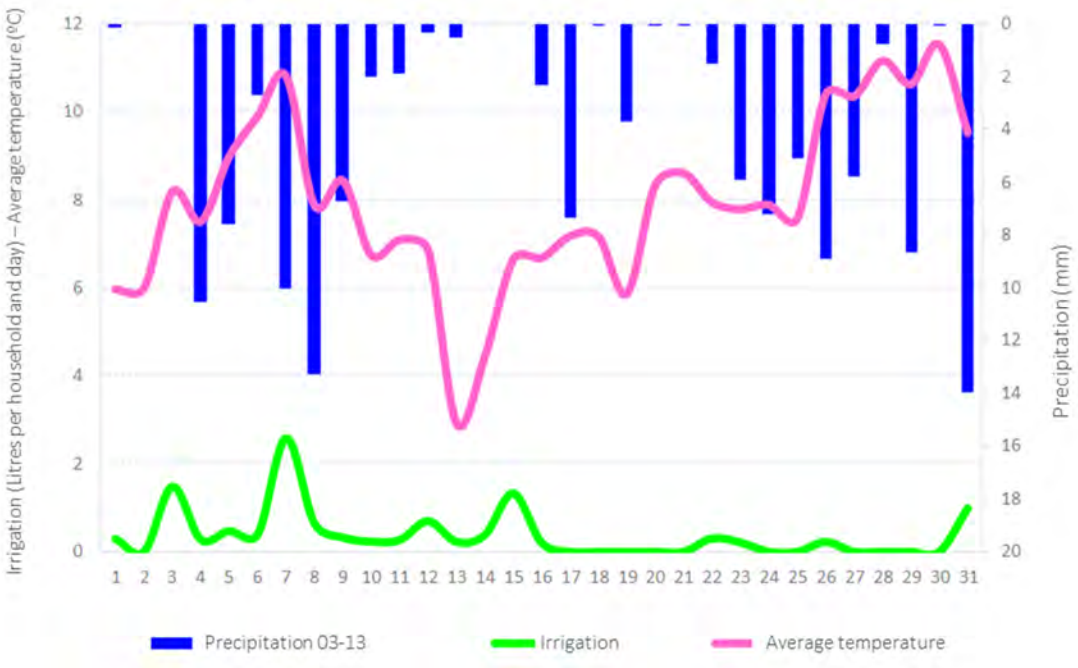


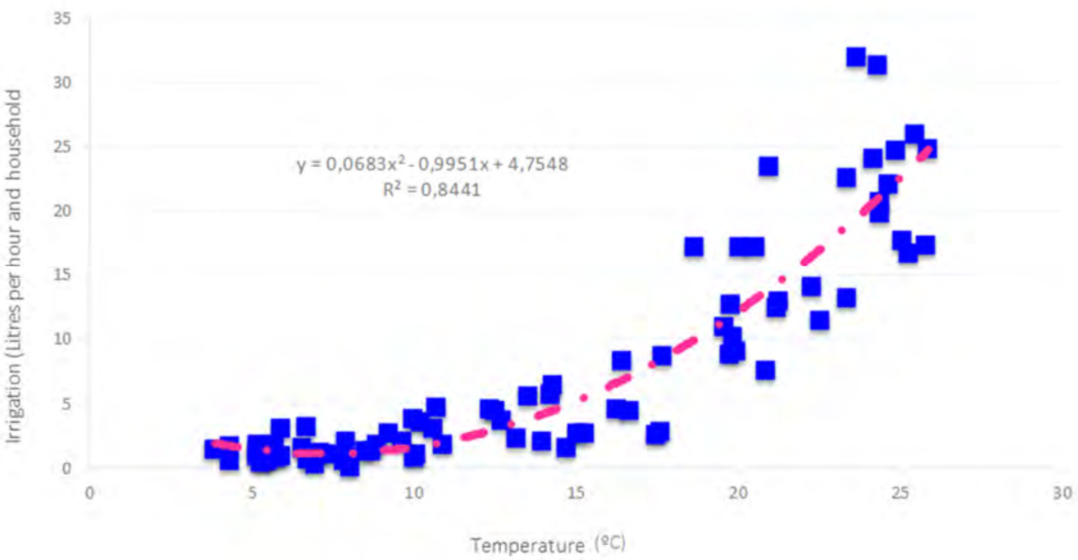
Figure 167 represents the apparent relationship between average temperatures and the use of *Irrigation.* It can be seen that, during the first half of March 2013, there was simultaneously, an increase in temperature and a greater use of irrigation and in the central part of the month, the opposite occurs. During the second half of this month, as shown, despite temperatures increases, during these days there was a considerable amount of rainfall, therefore the use of irrigation changed, in this case it decreased.

FIGURE 167. **SEASONAL DIFFERENCES FOR IRRIGATION WATER USE**



Finally, an analysis was conducted to establish this relationship between irrigation and temperature and rainfall meteorological variables. With the monthly data for the entire study period, a quadratic model was obtained, where average temperatures explain 84.4% of the variance in the use of irrigation. Figure 168 illustrates the relationship between the volume used for irrigation and the temperature. The relationship between rainfall and irrigation does not reveal such a clear correlation, with a coefficient of determination $r^2 = 0.44$.

FIGURE 168. **RELATIONSHIP BETWEEN TEMPERATURE AND IRRIGATION**



7. Comparison with other similar studies

This study was carried out over a period of almost ten years (from 2008 to 2017), and data was collected from around 211 households, with over 200 million litres of water monitored and an exact record of the time at which each litre or decilitre of water was consumed (depending on the control meter used).

Below is a comparison with other studies with similar objectives; these studies have not analysed the same amount of data. There are studies with a large number of households and comparable durations, but with less accuracy in measurements; others have been carried out with a very high accuracy in terms of measurements, but only on a small sample and comparatively, over short periods of just a few days.

Below are some of the documented works on the analysis of micro-components for residential water consumption in different parts of the world.

7.1. RESIDENTIAL END USES OF WATER (REUW 1999)[8]

This study addresses residential water use in 12 towns in North America. It was conducted using magnetic meters and it recorded consumption at 10-second intervals (which can produce imprecise results given the lower pulse definition).

The sample included one hundred households and was conducted over a period of approximately four weeks, obtaining a total of 28,015 days of measurements.

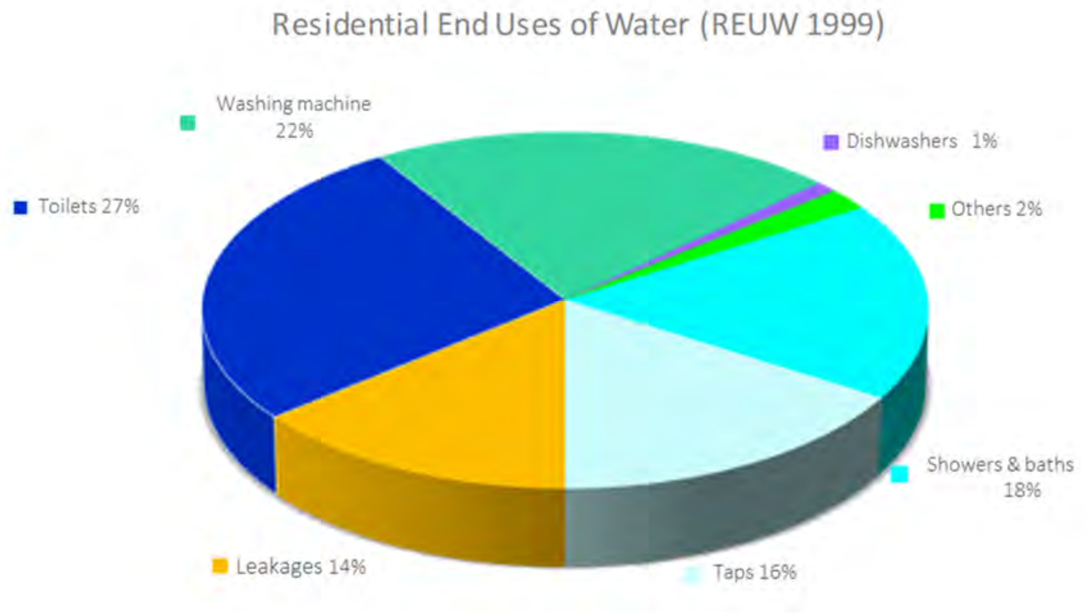
The consumption values of this study are much higher than the consumption figures in Spain. Averages per inhabitant and day were 262.3 litres, while in the work carried out by Canal de Isabel II, the figure obtained was, approximately, 103 litres per inhabitant and day. This figure already indicates that the consumption differences are so extensive, that their results are hardly comparable.

The main differences relate to the use of *Washing machines* and *Toilet flushes*, which in the case of REUW reveal much higher values than those obtained in the study presented herein, probably due to the design differences of the actual appliances (the volume of discharge of the tanks and the volume of water per wash in the actual washing machines).

The percentage of *Leaks* is also remarkable, which reached 14% of the entire internal consumption, almost three times that recorded in the Canal de Isabel II study. The values are outlined in Figure 169.

[8] Mayer, P. W., Deoreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W., Dziegielewski, B., Nelson, J. O. (1999). Residential End Uses of Water. U.S.A. American Water Works Association Research Foundation

FIGURE 169. **REUW - DISTRIBUTION OF USES**



Source: Own creation of the image of the work Residential End Uses of Water. USA American Water Works Association Research Foundation, by the authors Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W., Dziegielewski, B., Nelson, J. O. (1999).

7.2. RIWCS - RESIDENTIAL INDOOR WATER CONSERVATION STUDY (USA, 2002-2004)[9]

In this study, carried out between 2002 and 2004, an analysis was conducted on residential uses in three different parts of the United States (Seattle, Washington; East Bay Municipal Water District, California; and Tampa, Florida).

It is notable that in this study, the authors did not take into account outdoor uses (it included a generic category called *"other",* which perhaps included it); the samples of households in each location were small (between 26 and 37 households), and they were monitored over a short period of time, around 15 days. In terms of data recording, magnetic meters and data-loggers were used with measurements at 10-second intervals and with a meter accuracy of 300 - 450 magnetic pulses/litre.

As shown in Table 27, the usage percentages obtained are nothing like those obtained in this study. The first thing to point out is the difference in overall consumption values; in this study the average consumption per inhabitant and day, ranged between 240 and 326 litres, while the results of the Monitoring Panel from Canal de Isabel II's work presented herein, offered usage values per inhabitant and day, which ranged between 86 and 125 litres, depending on the month monitored.

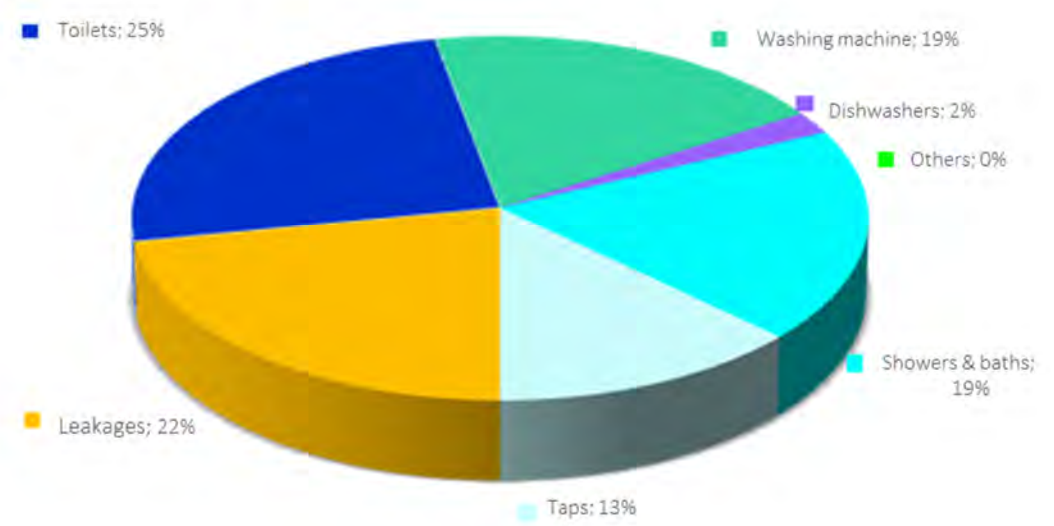
[9] Mayer, P.W., Deoreo W. B., Towler, E., Martien, L., Lewis, D. M. (2004). Tampa, Water Department Residential Water Conservation Study: The Impacts of High Efficiency Plumbing Fixture Retrofits in Single-Family Homes. Colorado: Tampa Water Department, The Unites States Environmental Protection Agency

TABLE 27. RIWCS – FIGURES FOR DISTRIBUTION OF USES

Use	*EBMWD*		*Seattle*		*Tampa*	
	Daily volume (litres/inhabitant/day)	*%*	*Daily volume (litres/inhabitant/day)*	*%*	*Daily volume (litres/inhabitant/day)*	*%*
Showers and Bath tubes	56.8	17.4%	48.1	20.0%	57.9	19.9%
Washing machine	52.6	16.1%	56.0	23.3%	55.6	19.1%
Dishwashers	3.8	1.2%	5.3	2.2%	2.3	0.8%
Taps	39.7	12.2	34.8	14.5%	35.6	12.2%
Leaks	97.3	29.8%	24.6	10.2%	71.2	24.4%
Toilets	75.3	23.1%	71.2	29.6%	67.8	23.2%
Other	0.4	0.1%	0.8	0.3%	1.1	0.4%
Total	**325.9**		**240.8**		**291.5**	

As in the REUW study, in the graph in Figure 170, it can be seen that the use of *Toilet flushes* obtained the highest value (25%), followed by *Leaks* (22%) and with the same percentage, the use of W*ashing machines* and *Showers and Bath tubes* (19%). This distribution is very different to the values obtained on the *Monitoring Panel* of this study, with the highest uses referring to *Taps and Showers and Bath tubes.*

FIGURE 170. RIWCS - DISTRIBUTION OF USES (AVERAGE FOR THE THREE LOCATIONS IN THE STUDY)



Source: Own creation based on the image of the work by Mayer, P.W., DeOreo W. B., Towler, E., Martien, L., Lewis, D. M. (2004). Tampa, Water Department Residential Water Conservation Study: The impacts of high efficiency plumbing fixture retrofits in single-family homes. Colorado: Tampa Water Department, the Unites States Environmental Protection Agency

7.3. REUMS-RESIDENTIAL END USE MEASUREMENT STUDY (YARRA VALLEY WATER, AUSTRALIA 2004)[10]

This study used DN 20 mm rotary piston water meters connected to a data logger, with an accuracy of 70 pulses/litre and with 5-second consumption measurement intervals. Measurements were taken in 81 households in winter and 93 households in summer, reaching a total of 2,394 days of measurements (around 14 days in each period).

In this work, the difference in the overall consumption between both works and areas is also notable. While in the Canal de Isabel II study, consumption values per household range between 270 and 358 litres per household and day, in the Australian study, these values are 511 litres in indoor uses, during the winter period, and 784 litres during the summer period, including outdoor uses. The values are almost twice those recorded on the *Monitoring Panel* for the Comunidad de Madrid.

The seasonal behaviour is another differential aspect, since it is the opposite to that observed on the *Monitoring Panel.* In the sample analysed over these seven years, consumption in summer dropped, due to holiday absences, while in the Australian study, consumption is clearly higher in summer (December to February).

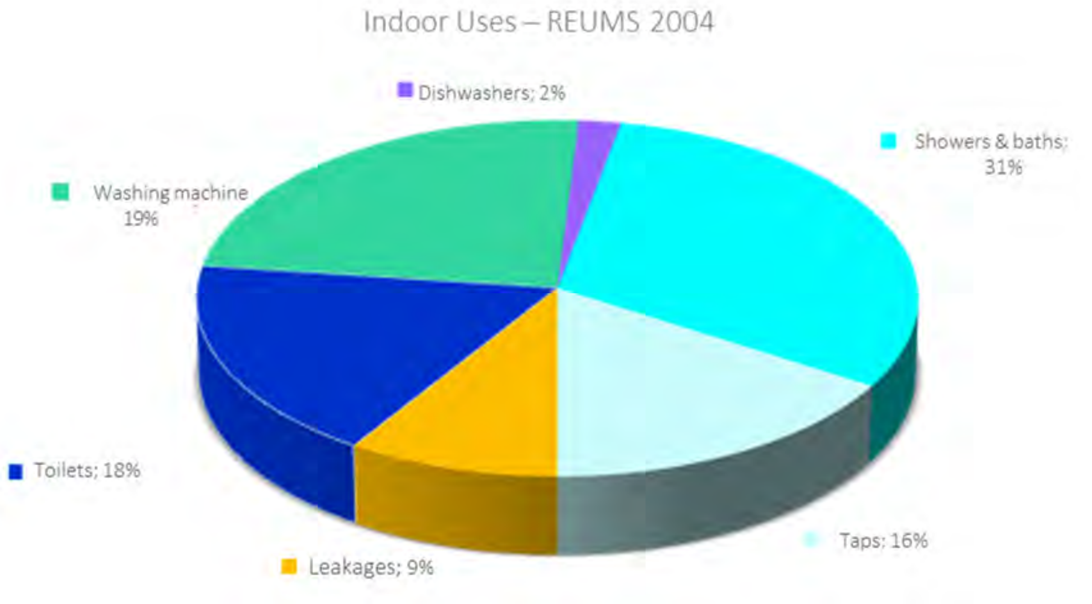
In terms of distribution of uses and values, Figure 171 illustrates the coincidence in the use of *showers and bath tubes*, since in the Australian study, it is the highest, except when *Outdoor* uses are taken into account in summer. In the Canal de Isabel II study, the use of *Showers and bath tubes* is also the highest, with percentages ranging between 30% and 35%, depending on the time of the year.

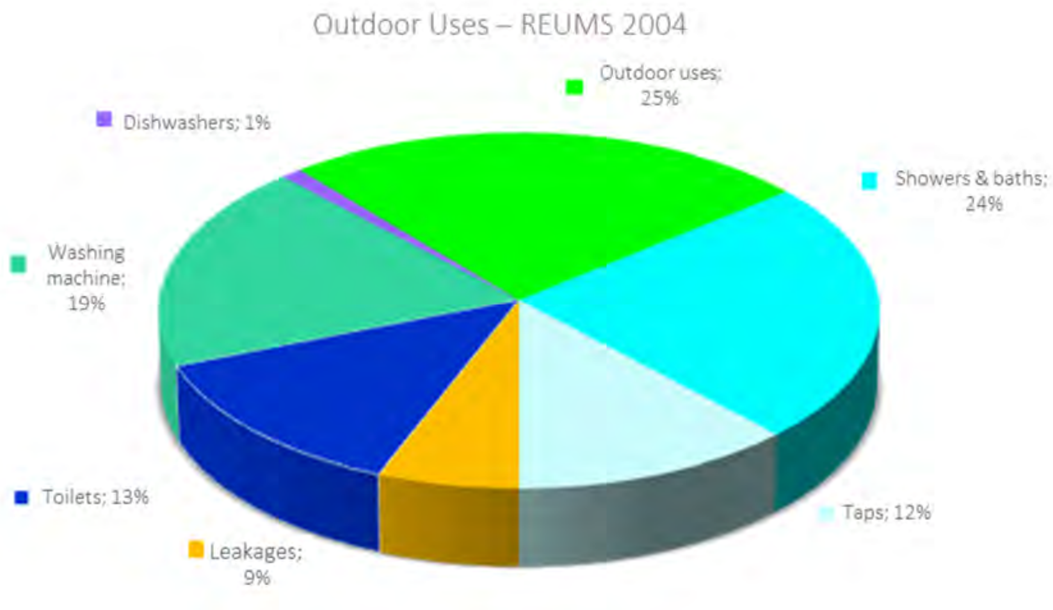
In *Outdoor* uses, the percentage is 25%, very different to the August values in the Comunidad de Madrid, where up to 11% of the total consumption was recorded. In terms of single-family homes, however, the average value of consumption in *irrigation* during July, August and September, over the nine years of study, is 23%, similar therefore to the values recorded in the Australian study.

This is followed by *Washing machines and Toilets*, offering higher values than those in this study, and *Taps*, which is clearly lower than the values in the Comunidad de Madrid. In terms of the values for¡’0*Leaks*, these reached a percentage interval similar to that of the Canal de Isabel II results.

[10] Roberts, P. (2005). 2004 Residential End Use Measurement Study. Victoria: Demand Forecasting Section, Yarra Valley Water

FIGURE 171. **REUMS - DISTRIBUTION OF USES**





7.4. STUDY OF MICRO-COMPONENTS AND EXPLANATORY FACTORS FOR WATER CONSUMPTION IN THE COMUNIDAD DE MADRID (CANAL DE ISABEL II, 2003)[11]

It was conducted in two phases (the first between 2002 and 2003 and a second phase in 2006). During the first phase, 292 households were analysed, with measurements every 15 seconds over an average of 12 months and continuous measurements were also taken (2 households simultaneously and rotating the households). During the second phase, 698 households were controlled over one year, with measurements every hour for indoor uses and every 24 hours for outdoor uses.

The consumption results, which are shown in Table 28, are quite similar to the those from the present work. In consumption per inhabitant, 84.9 litres were recorded in multi-family homes, compared with the 99.8 litres (ranging from 79.5 to 110.3 litres) in this study. In single-family homes, the values obtained were 151.4 litres, compared with the 133.8 litres per day (between 75.9 and 263.2 litres) in this study. The values are comparable, although in this study the differences between the type of property are fewer (with 78% higher consumption in single-family homes in the 2003 study, consumption was 25% higher in the work being presented herein for the 2007-2017 *Monitoring Panel*).

TABLE 28. DISTRIBUTION OF USES IN CANAL DE ISABEL II (2003-2006)

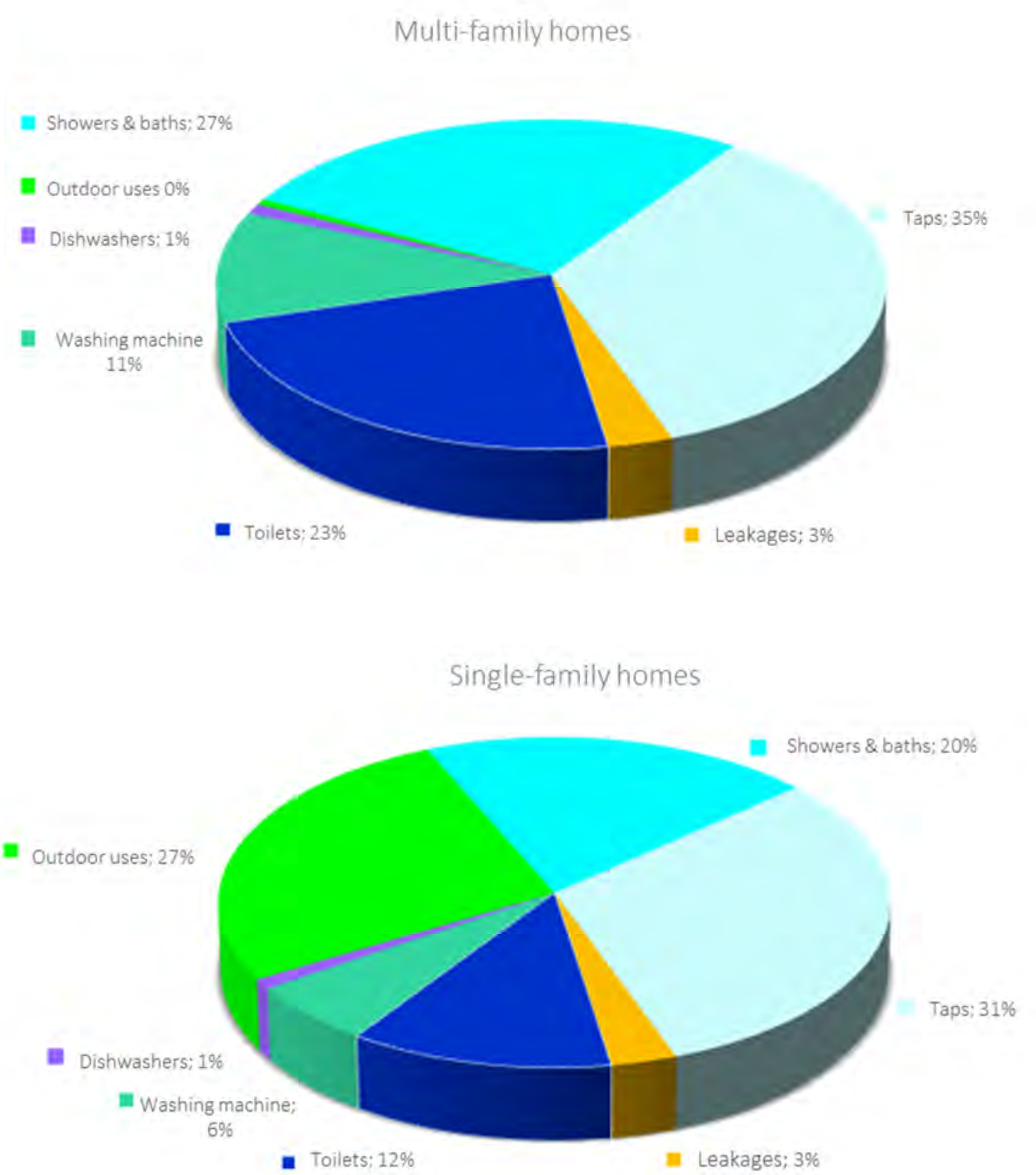
Use	*multi-family homes*				*Single-family homes*			
	Daily volume (L/house/day)	*%*	*Daily volume (L/inhab/day)*	*%*	*Daily volume (L/house/day)*	*%*	*Daily volume (L/inhab/day)*	*%*
Showers and Bath tubes	77.2	26.5	22.5	26.5	124.9	19,7	30.1	19.9
Washing machine	32.9	11.3	9.6	11.3	40	6.3	9.6	6.3
Dishwashers	3.1	1.1	0.9	1.1	4.7	0.7	0.3	0.2
Taps	103.1	35.4	30.1	35.5	194.4	30.7	46.8	30.9
Leaks	8.3	2.9	2.4	2.8	18.9	3.0	4.5	3.0
Toilets	66.5	22.8	19.4	22.9	78.9	12.5	18.9	12.5
Outdoor					171.4	27.1	41.2	27.2
Total	291.1		84.9		633.2		151.4	

In terms of the distribution of uses, as illustrated in Figure 172, the differences in *Outdoor* uses are particularly notable, accounting, in the previous study, for 27% of consumption in single-family homes, while in this study it only accounts for 11.2%, or 23% if only the summer months from June to September are considered.

[11] Cubillo, F., Moreno, T., Ortega, S. (2008). RDI Booklets No. 4. Micro-Components and Explanatory Factors for Residential Water Consumption In The Comunidad De Madrid, Canal De Isabel II.

Another difference is in the use of *Toilets*, in the previous Canal de Isabel II study (2003-2006), the results were 23.26 litres per inhabitant and day. In this study, obtained from the *Monitoring Panel*, an average of 10.96 litres per inhabitant and day was recorded. Also notable is the similarity in the value of *Taps* (35% and 31% for multi-family homes and single-family homes, respectively.

FIGURE 172. CANAL DE ISABEL II 2003-2006. DISTRIBUTION OF USES IN MULTI-FAMILY AND SINGLE-FAMILY HOMES



7.5. CALIFORNIA SINGLE FAMILY WATER USE EFFICIENCY STUDY (AQUACRAFT, 2011-12-06)[12]

The main aim of this study for California was to reduce water consumption by 20% per capita, for 2020. Data were collected from 2005 to 2008, and the total period of study was from 2005 to 2010; using a sample of around 700 households distributed, through 10 water agencies, across the entire State of California.

This study was conducted with magnetic meters and consumption readings were taken every 10 seconds, generating between 80 and 100 pulses per gallon. The 10 water agencies that took part in the study served a total of 1.3 million households during that period. A total of 735 households were included in the indoor analysis.

The total average annual water consumption in these households was 132 kilogallons per year, which is equivalent to 499,674 litres per year, or 362 gallons per household and day (around 1,370 litres per household and day). Average indoor water consumption was 62.4 kilogallons per year, equivalent to 236,210 litres per year, or 171 gallons per household and day, around 647.31 litres per household and day. Approximately 53% of the annual use appears to refer to outdoor uses and 47% to indoor uses.

7.6. MELBOURNE RESIDENTIAL WATER USE STUDIES (SMART WATER FUND, 2013-06)[13]

This study was conducted in the city of Melbourne, on a sample with the following distribution of properties: 77% individual single-family homes, 9% semi-detached single-family homes and 14% multi-family homes.

The average consumption per inhabitant between 2000 and 2001 was 247 litres per day and from 2011 to 2012 it was 149 litres per day, which suggests that consumption followed a notable downward trend. In terms of consumption per household, average consumption in winter, in this study, stood at 352 litres per day and in summer 442 litres per day.

Various consumption models were sought in this study. Among the main results is a daily linear consumption model, in litres, based on household occupancy.

Average consumption (litres) = 93.60 x occupancy + 145.18

One of the models was designed to determine the relationship between the use of washing appliances and occupancy.

Wash loads in washing machines per week = 1.13 x occupancy + 1.21

Use of dishwasher per week = 2.05 x occupancy 0.58

In terms of the use of *Shower,* the average usage time by Melbourne residents was 6.1 minutes with an average frequency of 6.3 times per week. Showers are the main use in the households.

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[12] Deoreo, W. B., Martien, L., Mayer P. W., Hayden, M., Funk, A., Kramer-Duffield, M., Davis, R. (2011). California Single-Family Water Use Efficiency Study. Colorado. Aquacraft Inc. Water Engineering and Management
[13] Gan, K., Redhead, M., Smart Water Fund. (2013). Melbourne Residential Water Use Studies. Recovered From: Http://Www.Yvw.Com.Au/Yvw/Groups/Public/Documents/Document/Yvw1004065.Pdf

Some of the differential characteristics of the households and the potential uses, compared with the study carried out by Canal de Isabel II, referring to the *Monitoring Panel,* are outlined below:

- A high percentage of the households (82%) has *gardens.*
- *Irrigation* is carried out on average once a week.
- 28% of the households have rainwater collection deposits installed.
- 8% of the households in Melbourne have swimming pools, of which 36% use rainwater, 41% use drinking water and 23% use both.
- 89% of the households in the sample have bath tubes and on average, these are used between 3 and 4 times per week.

7.7. REPORT ON *IN-HOME WATER USE PATTERNS IN SINGLE FAMILY HOMES FROM JORDAN* (AQUACRAFT, 2011-06-20)[14]

The report "*Instituting Water Demand Management in Jordan*" (IDARA) offers detailed information regarding the patterns of water consumption in single-family homes within a study group of approximately 95 households. Data were obtained from water meters and data recorders connected to the tank outlets located on rooftops. Data from the water meter were collected in 10-second intervals, with a resolution of 0.5 litres per pulse.

The average daily consumption for the households in the entire study was 453 litres per household per day and the average is 389 litres per household per day. This average is around a 30% lower consumption than the average per household in the United States, which is around 670 litres per household per day. If the size of households in Jordan are also considered, which on average, has an occupancy of 5.6 inhabitants per household compared with 2.7 in the United States, consumption per inhabitant is much lower than the average in the United States.

The data presented in Figure 173 illustrate that the main use is *Taps* (45.8%), while in the overall studies in the USA, it was *Toilets* (25.5%). As illustrated in the chart, there is not a category for *Irrigation* in this study, which was conducted during non-summer months, controlling consumption over a period of 14 days per household.

This study also conducted an analysis of consumption in different flow rate levels. These usage patterns revealed a very different distribution to that shown in the sample of the Canal de Isabel II *Monitoring Panel.*

In Figure 174, it can be seen how 65% of the consumption in this case refers to the interval between 225 litres per hour and 600 litres per hour. Although the ranges in the Canal de Isabel II study are different, if similar points are selected, in total accumulated volumes, a comparison reference of consumption patterns at different flow rates can be obtained. Table 29 reflects the comparative data of the studies.

[14] Deoreo, W. B. (2011). Report on In-Home Water Use Patterns In Single Family Homes From Jordan. Colorado: Aquacraft Inc. Water Engineering and Management

The lower volume recorded at flow rates below 150 litres per hour is particularly notable, with regard to the results of the Canal de Isabel II study, possibly due to the recording quality at low flow rates.

FIGURE 173. COMPARISON OF END USES IN JORDAN AND THE UNITED STATES OF AMERICA

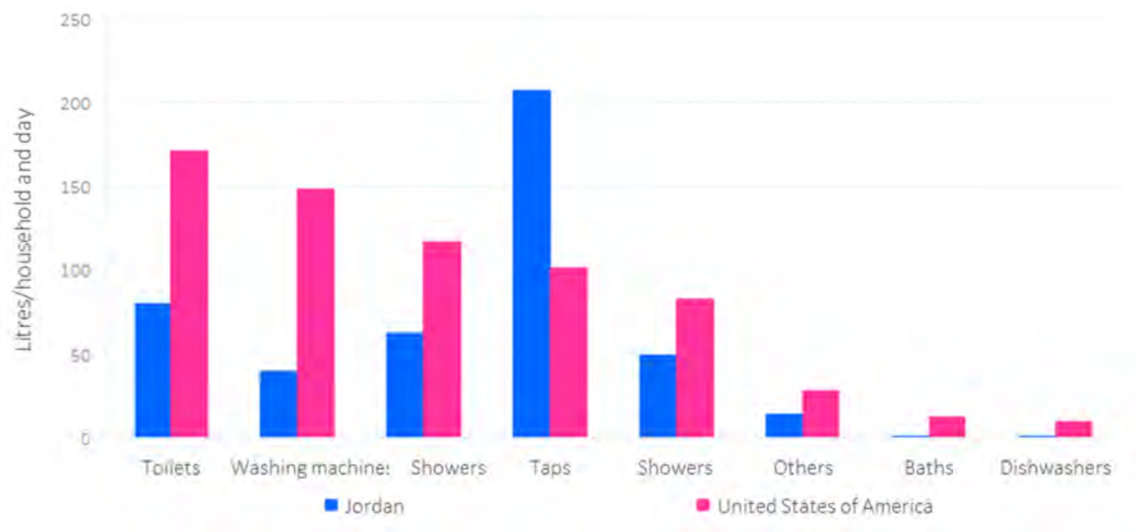


FIGURE 174. HISTOGRAM OF CONSUMPTION IN HOUSEHOLDS IN JORDAN

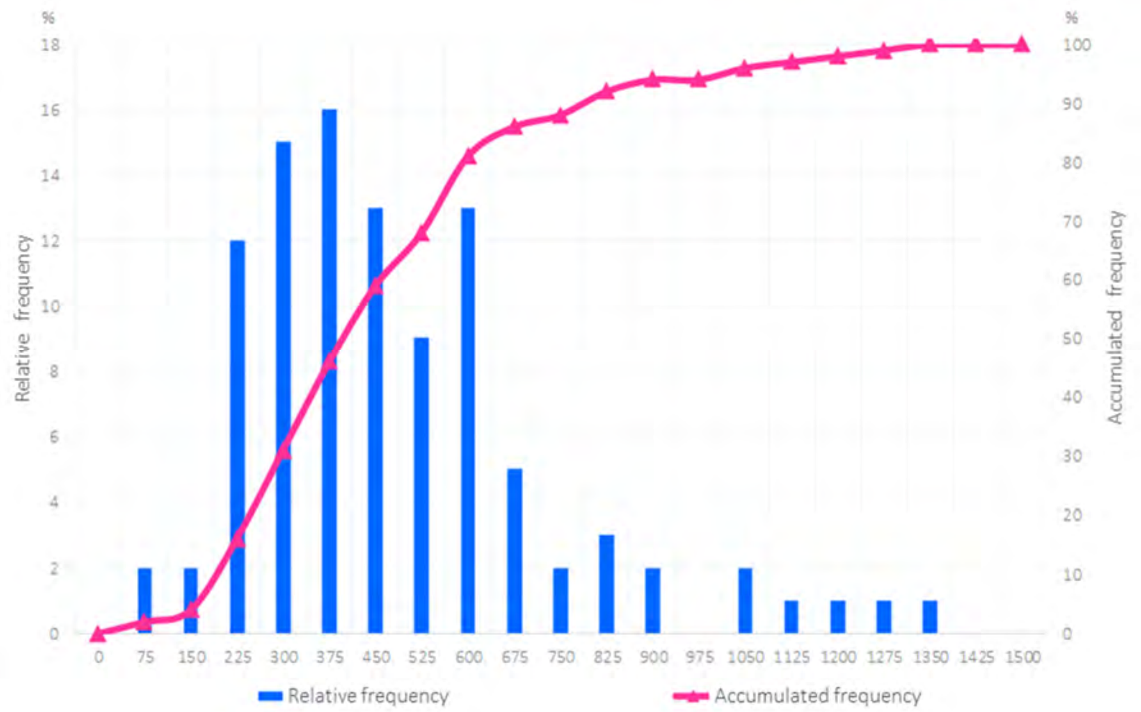


TABLE 29. HISTOGRAM COMPARISON IDARA - CANAL DE ISABEL II

Litres per hour and accumulated consumption percentage								
IDARA	75/2%	150/4%	300/31%	450/59%	600/81%	825/92%	975/94%	1,200/98%
Monitoring Panel Canal de Isabel II	3/3%	162/22%	312/30%	444/43%	576/61%	840/88%	972/94%	1,236/98%

7.8. FINAL CONSIDERATIONS

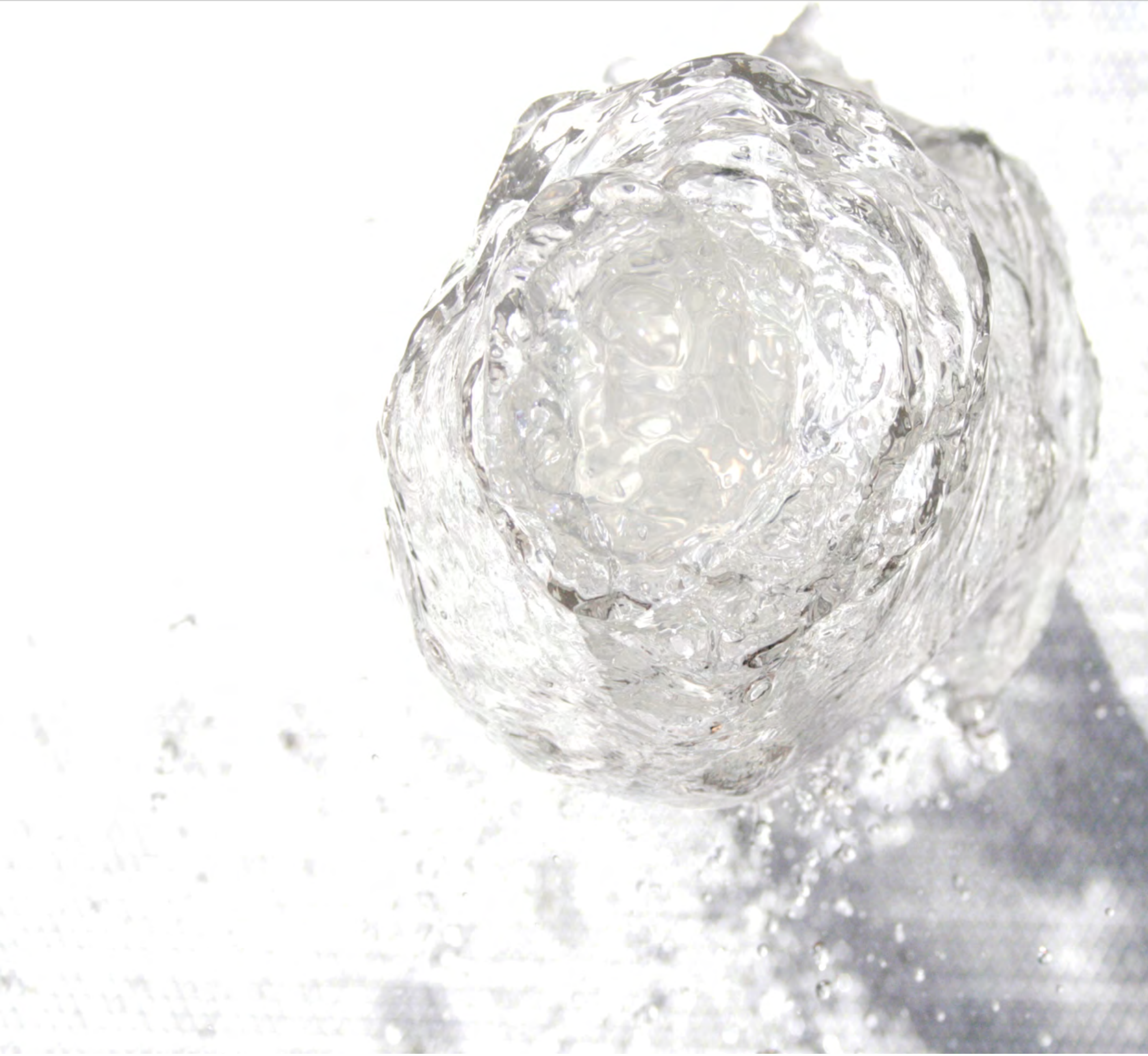
As explained in the preceding chapter, the results obtained in similar studies carried out in other countries are hardly comparable with those carried out in the Comunidad de Madrid.

Although the ideas of the studies carried out in other countries may be similar, what is immediately evident, is that consumption figures in both the studies in the United States and in Australia, are much higher than those recorded in Madrid with the *Monitoring Panel.*

The difference in the figures obtained may be due to numerous factors, some of which may be:

- **Differences in the type of buildings;** in this study, around 87% of the households are flats, while in other countries they refer mainly to single-family homes with gardens or terraces.
- **Differences in the volume of water in appliances such as *Toilets:*** in other countries toilet tanks have a greater discharge volume, and in the case of *Washing machines,* these appliances consume more water per wash cycle.
- **Differences in water efficiency habits** and in terms of awareness among users regarding water usage.
- **Different annual periods of the studies.** In the studies conducted in the United States and Australia, households were monitored over shorter periods of time, with a maximum of 4 weeks, therefore the time of the year, weather conditions and even the modification of consumption habits, as a result of being monitored, may have a significant impact on the results.

APPENDICES



APPENDIX 1. BIBLIOGRAPHIC REFERENCES

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APPENDIX 2. TABLE OF FIGURES

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