URBAN WATER DEMAND IN SPANISH CITIES BY MEASURING END USES CONSUMPTION PATTERNS

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Abstract: Knowledge of residential end uses of water is an essential tool for an adequate urban water management. Results can be obtained through different methodologies which can vary from a simple survey to a direct measurement of water consumption. With no doubt, direct measurement is the most accurate technique since it only reflects how water consumption is really done and not the users' opinion about how they use water. Most of the studies in which water consumption has been measured had been carried out in American cities. Water consumption profiles of European users are not the same as those in the States due to differences in users' habits and household and appliance characteristics. It is in this sense where the value of this paper lies in. It is the first study in Spain in which residential water demand is described by direct measurement of water consumption.

1. Introduction

Growing population, with increasing water demand, is causing greater and more frequent problems to water utilities. For this reason, an adequate management is essential in order to optimise the use given to the water resources available and to minimise losses and misuses in the system.

Strategies followed by managers and politicians in Spain during the last decades have been mainly focused on the supply side of water management, whereas practices from the demand side have systematically been neglected for years. At present, however, these ones are considered as critical for saving water, and both utilities and citizens agree and believe that future trends in water supply lie in water conservation programmes and retrofitting of facilities. These approaches will require for residential users to reduce their water consumption by installing efficient devices, such as low-flow showerheads and low-volume toilets, and to control leakage flows at domestic facilities.

However, to take these conservation programmes into practice, a good knowledge of residential water demand is necessary. In other words, to estimate the real savings that can be met it is essential to know how much water is used in the different appliances and the flow rate at which water is used. Up to now, the methodologies used in Spain to characterize water consumption were based solely on surveys in which users were asked about their water consumption practices and household appliances. The problem of this method lies in its lack of accuracy. The results show users opinion about their own water consumption practices. Furthermore, surveys do not allow quantifying how water is consumed at the residences and where.

With no doubt, direct measurement in households is the most accurate way to characterize water demand. However, measurements of water consumption need to be taken in great detail in order to make possible the identification of each domestic device. Probably, the cost of the equipment needed is the main reason that explains why there has not been carried out, in Spain, studies of this type.

This paper tries to fill the lack of information in this field, being the first study published in Spain where water demand is characterised by detailed measuring of end uses.

Aspects analysed in this paper are:

- ✓ Household water use distribution
- ✓ Hourly water consumption patterns
- ✓ Number of uses in appliances. Water volume used in each of them.
- ✓ Water consumption flow rates.

2. A brief description of Spanish urban water demand

During 2001, 4804 million cubic metres of water were supplied in Spain for urban uses which include residential, industrial and municipal demand. The average per capita water consumption was 165 litres per day (*Instituto Nacional de Estadistica*, 2001). As in every country, residential water consumption represents a significant percentage of total urban demand and therefore, substantial water savings can be expected by retrofitting the facilities with new devices.

For the most part, water consumption inside residences has its origin in faucets, showers, baths, toilets, dishwashers, clothes washers, etc. Outside the houses water is mainly used for irrigation purposes. However, in Spain, water saving opportunities for residential sector seems to be limited and probably lower than it is usually thought. Outdoor water consumption is uncommon since most people live in flats and consumption flow rates are already quite low. Moreover the typical flushing discharge for toilets is frequently less than 9 litres and clothes washers only use, according to manufacturers, about 60/70 litres per load.

The aim of the work is to estimate the real water saving capability at Spanish residences, by measuring in detail water consumption at several households. The research will try to obtain water uses distribution and the characteristics of water demand at different appliances. These data will allow calculating how much water can be saved when replacing faucets, toilets and shower heads.

3. Methodology applied

Water characterization in rectangular pulses

There have been several researchers that have study identification of residential uses of water. The first study published in this field was carried out by DeOreo (1996), in which a flow trace analysis of water consumption was performed. For this work water demand was measured in detailed, every 10 seconds, at various households. Different flow traces were detected for each use, which made possible the identification of several uses like clothes washers, dishwashers, showers, etc. This experience was put into practice in several studies mainly in North America and Australia, like “Residential End Uses of Water”, Mayer et al. (1999).

In order to facilitate the analysis it is necessary to reduce the amount of data collected by the measuring equipment and the original data requires some simplification. As Wells (1994) and Buchberger (1996) showed, it is possible to characterize water consumption with rectangular pulses. In this way, daily water consumption in a household can be represented as a sequence of rectangular pulses. Each pulse is defined by a starting time, t_0, a duration T and a flow rate. This form of representation improves data processing and makes data files more manageable.

In practice, it is not unusual to find water consumption of two or more appliances overlapped. Several pulses can merge into a longer one in which flow fluctuations appear every time a new appliance starts or finishes. Other times, the flow fluctuations measured are consequence of users modifying flow rates or water temperature at showers or faucets.

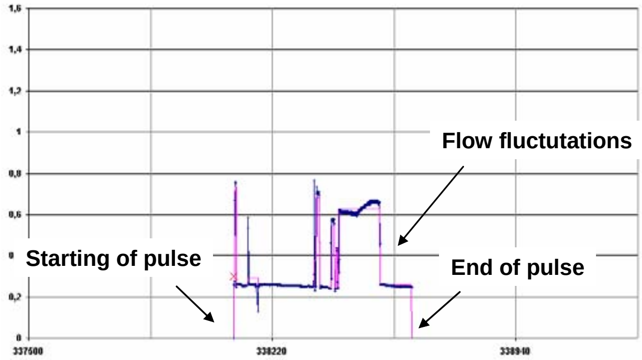

Figure 1. Flow fluctuations in pulses

End uses consumption patterns

After characterizing water consumption with rectangular pulses and using flow trace analysis principles, the original measured data is prepared for the identification of different residential uses. The key factor in this identification process is the shape, flow rate and sequence of consumption pulses. Each use adopts a particular shape that allows a trained technician to identify different devices at any residence. The identification is also possible when two or more uses overlap. Some devices, like clothes washers and dishwashers present cyclic patterns of pulses with similar volume and flow rate. Usually dishwasher intake flow rate and volume are lower than those for clothes washers, as shown bellow (figures 2 and 3). Toilets present a characteristic pattern at the end of the filling with a decreasing flow rate (figure 4). However, most modern fill valves for toilets close instantaneously, increasing the difficulty when recognising this use.

Different examples of flow traces for several uses are shown in figures 2-5.

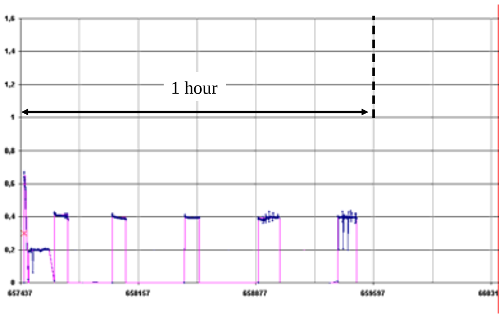

Figure 2. Clothes washer pattern.

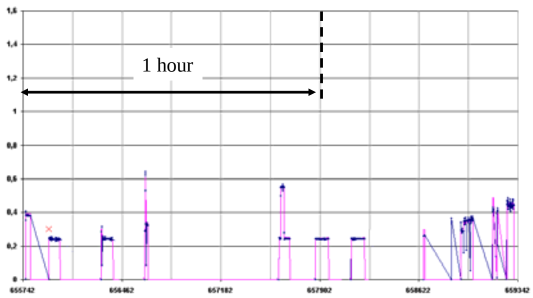

Figure 3. Dishwasher pattern.

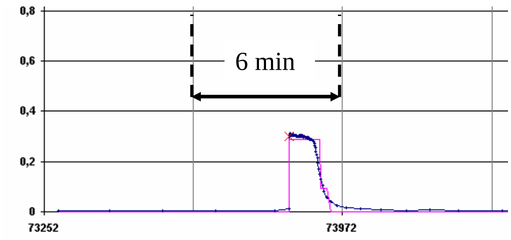

Figure 4. Toilet pattern.

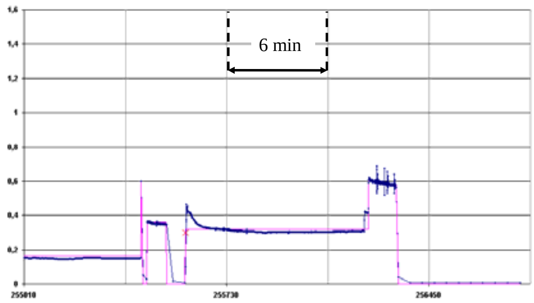

Figure 5. Shower pattern.

Description of the software package developed for uses identification

Specific software has been designed to perform the whole data processing in an easier and faster way. In raw data, every water use is displayed by a great number of flow rate values, and thus, the signal had to be smoothed to avoid disturbing oscillations that would hinder analysis and uses identification. By means of MSAccess code, it has been possible to simplify each water use into one or more flat rectangular pulses. At the same time, the software suggests an initial identification for every use based on the typical parameters for the different water devices: duration, flow, volume and shape. Finally, the most relevant information is presented, including graphical results, parameter values, date and time. Some buttons allow the software user to navigate along the flow trace to visualize data for specific time or consumption. Furthermore, the user may also change the initial identification suggested by the software for every consumption number.

Next figure shows the software interface. A number is assigned to every water consumption for navigation and analysis purposes. All the consumption characteristics are associated to that identifier, and all the information is in turn compiled in a database for its later study. Once the database is ready (i.e., data has been transferred from the data-loggers and processed by the MSAccess modules), it is possible to execute some queries to obtain the desired results, like water uses distribution, hourly consumption pattern per use, average consumption flow rate of the different appliances, etc.

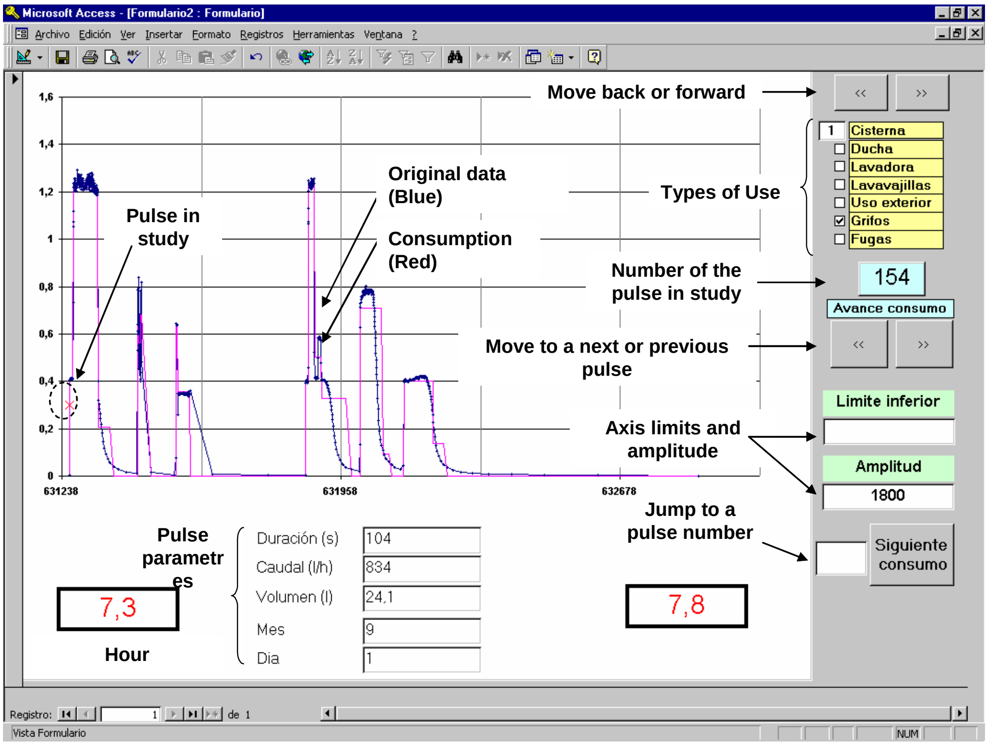

Figure 6. Example window of software interface.

Difficulties in water uses identification

Problems in water use identification arise when several water uses take place at the same time. In this case, their corresponding flows appear overlapped, and distinguishing them is not a simple task. The problem gets even worse when the total volume of the consumption has to be distributed into the different uses. To speed up the calculations (there can be thousands of water uses recorded in the database) it has been necessary to prepare some algorithms that automatically perform this task.

Basically, it is possible to classify most of overlappings into two types according to the time when they occur. Sometimes, one use takes place while a longer one is already on. Then, the total flow shows a sudden increase caused by the sum of both uses. On another occasions, one use occurs immediately after another one, so that the final appearance is that for a single, uneven and oddly long use. Next figures show these two cases of overlapping. In figure 7, the software detects a single consumption, although is clear that two different toilet flushing take place consecutively. In figure 8, two consecutive toilet flushing are shown again, but now several faucet uses overlap the first toilet flushing, increasing the total consumption flow to ‘strange’ levels for what should be an ordinary toilet flushing.

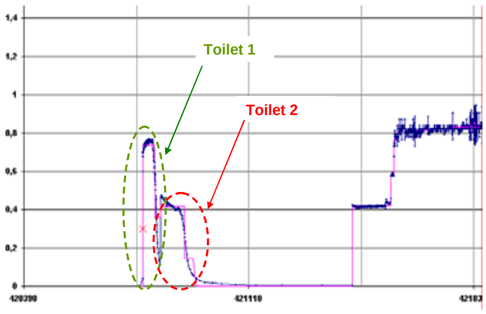

Figure 7. Two toilets overlapped.

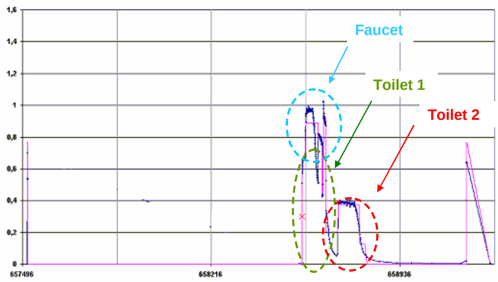

Figure 8. Two toilets and faucet overlapped.

4. Case study: Water consumption at four Spanish cities

Sample description

Once the purpose of the study is defined, the next step consists of selecting the sample. When proceeding to do so, particular aspects to consider are the proper size and type of sample. To obtain general and representative results, the sample must contain the different cases that can be found in a water distribution system: types of houses, occupancy rates, socioeconomic standards, etc. There exists a great variability for the particular values of those parameters, which hampers the work: if a sample contains many different cases but in too low quantities, it will not be representative enough, hence to get a significant sample some features will have to be sacrificed.

In addition to the household typology, the sample selection is also restrained by the real feasibility for installing the measurement equipment at the consumer's facilities. Technical problems can arise when trying to install the equipment, meter and data-logger, mainly caused by the effective dimensions of the meter vault.

For the case study, the selected sample was compounded by 64 no garden building apartments, located in four different villages in the East coast of Spain. Measurements were performed for 807 days in all, though distributed in the following way:

VILLAGE	Nº OF HOUSES	DATES	Nº OF DAYS
Village 1	16	July 1998	187
Village 2	20	December 2002 May 2003	249
Village 3	17	March 2001 June 2001 February 2002	108
Village 4	11	September 1998 December 1999	263

Table 1. Sample composition

Measurement equipment

For this project, in which detailed consumption measurement is needed, special data acquisition equipment was used. The equipment consisted of one precision oscillating piston water meter, one pulse-emitter (0.1 l/pulse) and one data logger with a capacity up to 256.000 records. The original water meters were replaced by this equipment during the monitoring period, and restored back at the end of the study. Figure 9 shows a picture of the equipment used during the study.

Figure 9. Precision water meters and data-loggers used for the study

5. Results

Distribution of water uses

After the whole data process (uses identification, average rate calculation, etc.) was finished, the final results were obtained by querying the database. These results are shown in the pie chart bellow.

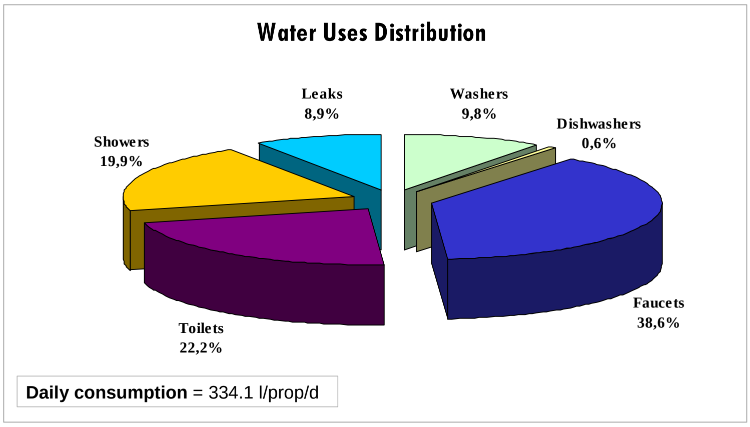

Figure 10. Water uses distribution.

The final water uses distribution obtained in this study is the following: faucets (38.6%), toilets (22.2%), showers (19.9%), clothes washers (9.7%), leaks (8.9%) and finally dishwashers (0.6%). The average water consumption per property and day is 334.1 litres.

Hourly water consumption pattern

Also by querying the database, the pattern curves for water consumption are obtained. These curves show the different water quantities that are needed along the day, and hence the hour at which peak consumption takes place can be easily identified.

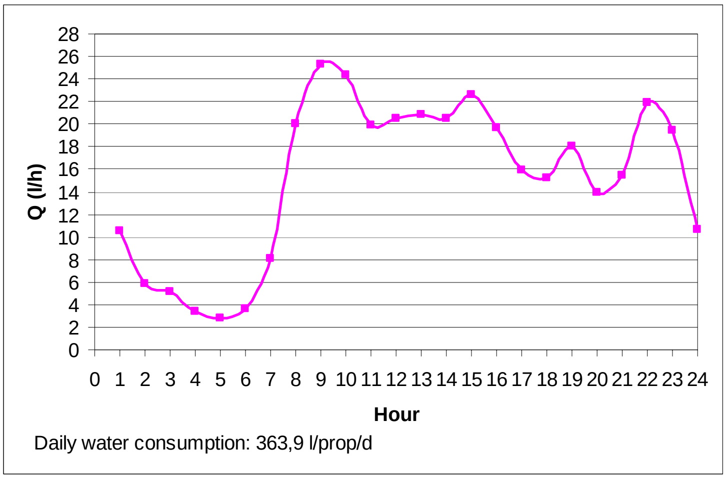

Figure 11. Pattern curve for water consumption

Water consumption begins to increase at 6 a.m, the peak flow (25.3 l/h) is reached at 9 a.m., and after an uneven decrease along the day, there appears a second peak (21.9 l/h) at about 10 p.m. For night time, the lowest flow (2.8 l/h) takes place between 4 and 5 a.m.

Appliances modulation curve

Hourly water consumption by each device is shown in the following graphs, as well as the average water use per person and day.

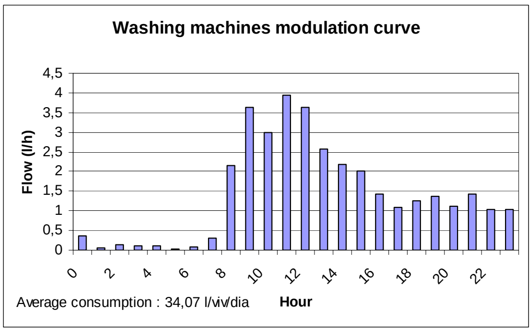

Figure 12. Clothes washer pattern curve.

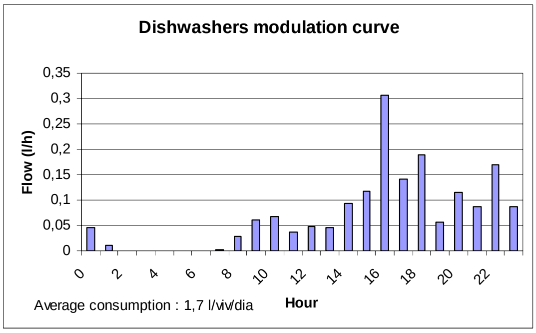

Figure 13. Dishwasher pattern curve.

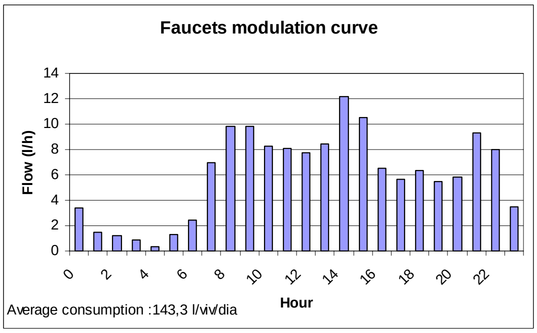

Figure 14. Faucets pattern curve.

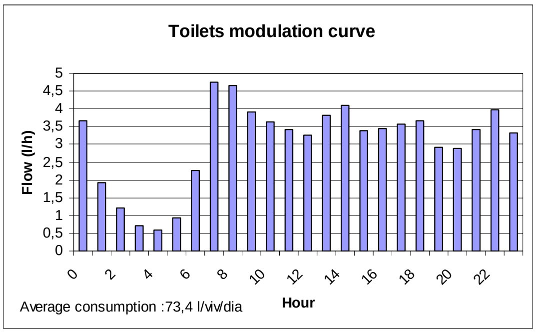

Figure 15. Toilets pattern curve.

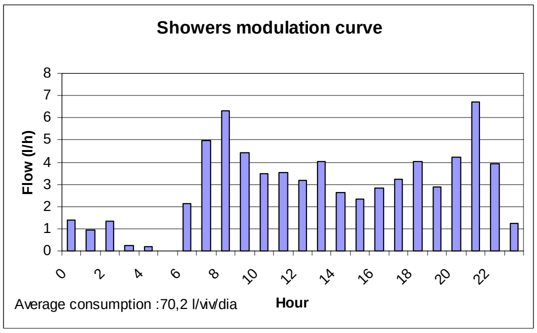

Figure 16. Showers pattern curve.

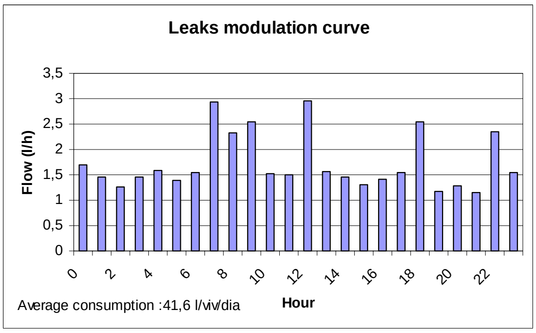

Figure 17. Leaks pattern curve.

Number of uses and volume per device

Some indoor devices use very similar water volumes every time. Such devices are toilet tanks, washers, and dishwashers. Table 2 shows the average results for those devices, after a careful analysis of the data available.

	l/household/day	Vol (l)	Uses/household/day
Washers	34.1	60	0.6
Dishwashers	1.7	20	0.1
Toilet tanks	73.4	8.7	8.4

Table 2. Average values for main indoor water uses.

Every washer uses approximately 60 litres per cycle, though that is an average value, since the definite figure may range from 20 to 100 litres. Taking 60 litres as a reference, the resulting number of uses per household and day is lower than one.

Concerning dishwashers, the figure obtained for the average water use in every cycle is 20 litres. As for the washers, this value may change depending on the selected program, but in any case, such a low figure clearly shows that dishwashers are not very common in the households of the sample (which on the other hand can be easily understood, since they were located y rather small cities).

Finally, the average used volume per toilet flush turns out to be 8.7 litres. This figure demonstrates that current toilets in the studied households are far from the older models of low-flush toilets, which use around 4 to 6 litres depending on the kind of flush.

Flow rates for water use devices

The average flow rates obtained for every water use devices in this study are the following:

Washers:	414 l/h
Dishwashers:	259 l/h
Faucets:	302 l/h
Toilets:	400 l/h
Showers:	490 l/h
(Leakages:	17 l/h)

According to the Spanish standards, *Normativa de Instalaciones Interiores de Suministro de Agua*, the lowest acceptable flow rate for washers and dishwashers is 720 l/h. As shown above, the real values at real households are at the moment far from the standard. However, such apparently big difference is due to the fact that the standard is related to the flow rate capacity of facilities, and not to the flow rate that a particular device, such as washers, could need. In this way, the final flow rates used are restricted by the manufacturers themselves.

As to the toilets, the measured value (400 l/h) is not obviously the flushing flow rate, but the average tank filling flow rate. In this case, Spanish standards point 360 l/h as the lowest acceptable value, well below the average shown above, so that this condition is properly fulfilled.

The standards for faucets and showers are 360 l/h and 720 l/h, respectively. So, again it is found that the standards are not met, since 302 l/h and 490 l/h are the measured values.

After this analysis, it could be concluded that the current standard might be excessively demanding, and a revision could be recommended, or that the facilities do not meet the standard and better designs should be required. Furthermore, the results obtained clearly show that indoor facilities are kept in a rather faulty condition, supplying inadequate flow rates.

6. Conclusions

To conclude some particular points should be remarked:

- This is the first study in which residential water demand for several Spanish cities have been characterised by direct measurement of water consumption.
- The software used to identify, analyse and manage flow measurements has been originally developed at the Instituto Tecnologico del Agua. This software is under continuous improvement and newer versions are currently being developed.
- From the authors' point of view, the results yielded by this methodology are the most useful for a number of purposes (water conservation, drought management, tariff design or demand elasticity assessment) that today are still based on rather disperse and low reliable data.

- Finally, it is interesting to mention that the water uses distribution is similar to previous studies (Vickers, 2001). Significant differences are found for washers -57 lpcd (Mayer et al., 1999) vs. 33 lpcd. Instead, the differences expected for toilets were surprisingly not too large -70 lpcd vs. 74.2 lpcd-, and the volume lost through leaks in the facilities was also similar -36 lpcd vs. 30 lpcd.

7. References

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