Requirements of water meters and telemetry systems used to monitor night flow consumptions: case study and recommendations

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Abstract

Assessment of water losses in water distribution systems and specifically analysis of real water losses involves measuring minimum night flow and desegregating it into household consumption, non-household consumption and real losses. Previous studies have concluded that establishing rules to estimate household night consumption is specific of each water utility, since they can be rather dependent on social-demographic (*e.g.*, property type, household size, daily habits, etc.), technical (e.g., pressure) and climate factors. For instance, in Portugal, the inexistence of similar studies at national level lead to the application of expedites rules developed in the United Kingdom. However, aspects such as the generalized installation of household water meters, a more heterogeneous type of properties and much lower utilization of domestic tanks can limit strongly the application of these rules at national level. The current study aims to support a Portuguese water utility to develop and implement a methodology to quantify household night consumption based on expedite rules dependent on social-demographic and billing factors, improving the control of real water losses at district metering area level.

The current paper discusses the main aspects taken into account in the selection of water meters and telemetry system, which may be adopted in other similar cases, and makes a set of recommendations. It highlights the need for having into account the size and characteristics of the population served within the study area, as well as the monitoring accuracy requirements inherent to the objectives of the study.

Introduction

SMAS of Oeiras e Amadora is a water and waste water utility located in the greater Lisbon (Portugal), supplying approximately 400000 inhabitants. It is one of the most developed water utility in terms of the approach of a formal action on water losses control.

The whole distribution system is currently split into District Metering Areas (DMA), with systematic metering carried and with calibrated models for most of the areas. However some shortcomings are still to be overcome. One of the crucial one is the lack of knowledge related to household night consumption. Results obtained in the UK are adopted, but is known that the extrapolation is not fully valid.

In this context, SMAS of Oeiras e Amadora lunched a research study with the collaboration of National Laboratory of Civil Engineering (LNEC) to define expedite rules for the assessment of household night consumption that are valid for their specific conditions. The paper focus on the requirements of consumption meters and telemetry system which will be installed in the study areas.

Methodology

This work is included in the second task of the study, which was dedicated to design, acquisition and installation of water meters and telemetry systems to collect household consumption data. It was preceded by a first task dedicated to the selection of samples of clients to be monitored and by a preliminary campaign, carried out not only to test water meters and telemetry equipments, but also to collect preliminary consumption data, helping in the selection of adequate size of each area to be monitored (further referred to as “study area”).

Study areas selection

Customer consumption will be monitored as clusters of similar characteristics, located in small areas (e.g., building or a set of buildings at street level) and not at household level. The option was adopted due to the fact that it allows for a more expedite solution to the water utility, in terms of data collection, and simplifies the application of the developed methodology to quantify household night consumption to other case studies. This type of study area does not require the substitution of existing household water meters neither the involvement of clients. In terms of telemetry system, this option is less demanding, in terms of data logging and communication systems. It has the disadvantage of measuring also water losses (i.e., at pipe, service connection and private connection pipe level) besides household consumption (i.e., use and plumbing losses), which involves the development of complementary methodologies to desegregate of household consumption from real water losses.

Study areas were selected from 8 district metering areas (DMA) with the number of households varying between 988 and 5549 households (Table 1). They were selected in order to have social-demographic and billing characteristics similar to the DMA where they are included (Table 1). During the first task of the project, a characterization of consumption in each DMA (in terms billed and bulk consumption) has been performed and relations with social-demographic variables have been found. Table 1 shows the social-demographic profile of each DMA. Social-demographic variables were obtained based on Census data for the basic statistical units that are included in the DMA, which are around 300 dwellings in size. Study areas were selected from basic statistic units with a social-demographic behaviour similar to the DMA. Selecting the sample of households, inside each basic statistical unit, whose billed consumption (i.e., per household consumption and tariff structure variables) is similar to the billed consumption at DMA level allowed the definition of the study area.

Table 1 Social-demographic characteristics of DMA where the study area was included.

			Social-demographic variables (%)								
DMA	N.º of Households (DMA)	Study area ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A	5167	1	2.4	59.8	18.2	50.5	17.6	81.8	44.6	33.9	13.1
B	4560	2	71.1	24.7	17.0	77.3	9.7	77.6	57.5	17.2	38.6
C	2026	3	47.2	39.5	64.0	55.9	3.7	68.7	60.1	35.5	16.8
D	2522	4	59.6	28.7	59.3	69.6	25.3	85.5	39.4	19.6	34.6
E	3159	5	35.7	50.0	22.2	57.9	20.8	83.7	43.2	17.7	22.5
F	988	6	71.9	25.0	58.5	73.0	38.3	87.8	27.1	18.4	43.1
G	3635	7	1.6	92.2	29.4	62.7	27.0	86.1	35.9	23.2	27.7
H	5549	8	13.3	60.9	30.5	49.4	23.3	83.3	37.9	38.9	13.6

Where (1) is the rate of buildingss with age up to 1970 (%), (2) the rate of buildings age between 1970 and 1980 (%), (3) the rate of 1 or 2 storey buildings, (4) the rate of non-active workers, (5) the rate of university graduates, (6) the rate of economic mobility, (7) the rate of high-school drop outs, (8) the rate of families with teenagers and (9) the rate of families with elderly.

According to Table 1 and 2, study areas 2 and 5 are characterized by old people and old buildings, with lower per household consumption, consuming essentially on the first tariff T1 (bimonthly consumption less than 10 m3). Study areas 3, 4 and 6 area composed by detached houses with gardens having significant consumption on tariffs T3 and T4 (bimonthly consumption between 30 and 50 m3 and greater than 50 m3, respectively). Areas monitors 1, 7 and 8 are composed by young people and more recent buildings, compared to the other study areas, per household consumption is relatively higher and have significant consumption on tariffs T1 and T2 (bimonthly consumption less than 10 and between 10 and 30 m3, respectively).

Table 2 Characterization of selected study areas.

						Tariff weight (%)			
(1)	(2)	(3)	(4)	(5)	(6)	T1	T2	T3	T4
1	Service connection	21	1	254.0	290.0	56.7	43.3	0.0	0.0
2	street	31	4	295.0	228.6	69.1	30.9	0.0	0.0
3	street	28	17	315.0	270.2	52.9	41.7	5.4	0.0
4	street	23	15	274.0	285.5	44.9	38.6	9.0	7.6
5	street	32	2	265.0	198.7	80.6	19.4	0.0	0.0
6	street	28	24	672.0	576.1	27.0	39.3	18.3	15.5
7	street	33	2	348.0	253.1	62.0	39.5	0.0	0.0
8	Service connection	20	1	236.0	282.9	58.1	41.9	0.0	0.0

Where (1) is the study area ID, (2) is the consumption meter location, (3) is the number of households in each study area, (4) is the number of service connections, (5) is total daily mean consumption (l/h) and (6) is per household consumption (l/household/day).

Each area was limited in order to include a maximum size of around 30 households. This constitutes a sample acceptable to separate household night consumption from water losses components (Warren, 2002), minimizes the presence of non-household clients, as well as the number of service connections and public pipe length reducing water losses components. Study areas selected are also characterized by homogeneous pressure conditions, allowing comparisons between them. The viability of each study area was verified with field team in order to evaluate consumption meter and/or valve location and pressure conditions. Study areas were also selected in order to have reduced leakage level. In terms of pressure, study areas were selected with the aim of having at least 10 m c.a of pressure free besides pressure requirements according to design rules. This precaution allows minimizing the occurrence of pressure problems due to singular losses introduced by the accessories installed.

Preliminary campaign

A preliminary campaign was carried out not only to test water meters and telemetry equipments, but also to collect preliminary consumption data, helping in the selection of adequate size of each area to be monitored and permitting a preliminary analysis of household night consumption.

In the preliminary test, with a total duration of 1 month, carried out in study area 5, a volumetric water meter with a nominal diameter of 25 mm (Q_1= 26.25 l/h, Q_2=40.25 l/h, Q_3=3500 l/h, Q_4=7000 l/h) was installed. A curve error has been obtained, showing a start flow of 2.5 l/h and that at 7.5 l/h the error was of -25%. A reed pulse emitter with a resolution of 1 pulse per litre was used.

In terms of data logging, two types of data acquisition have been tested: fixed time, with an acquisition rate of 1 minute, and pulse time with a minimum sampling interval of 0.1s. For this type of data acquisition, two data loggers were used: a pulse time data logger with two digital input channels, with 256 Kbytes per channel and fixed time data logger with four input channels, where two can be analogical, with a total capacity of 512 Kbytes. Fixed time data logger was used to measure consumption and pressure.

Pressure values were read from a pressure transducer located downstream of the water meter with a fixed time of 1 minute (Figure 1b). Data were sent remotely via GSM and downloaded via website.

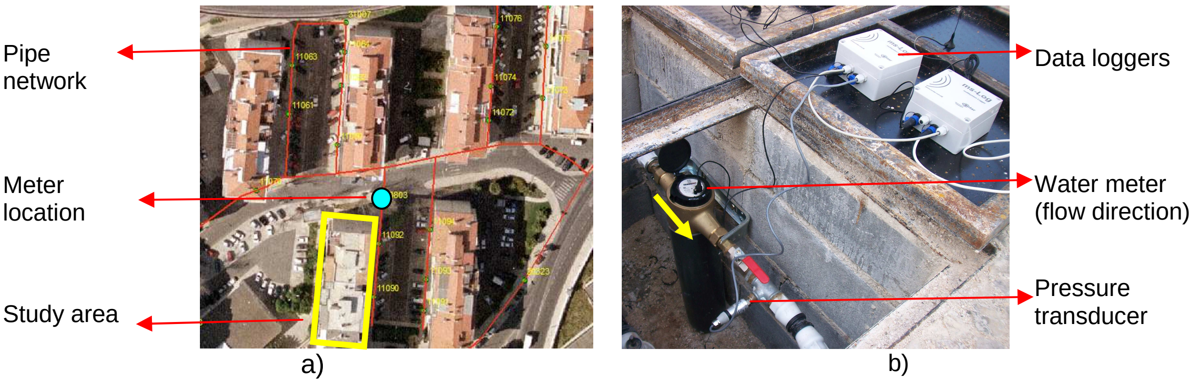
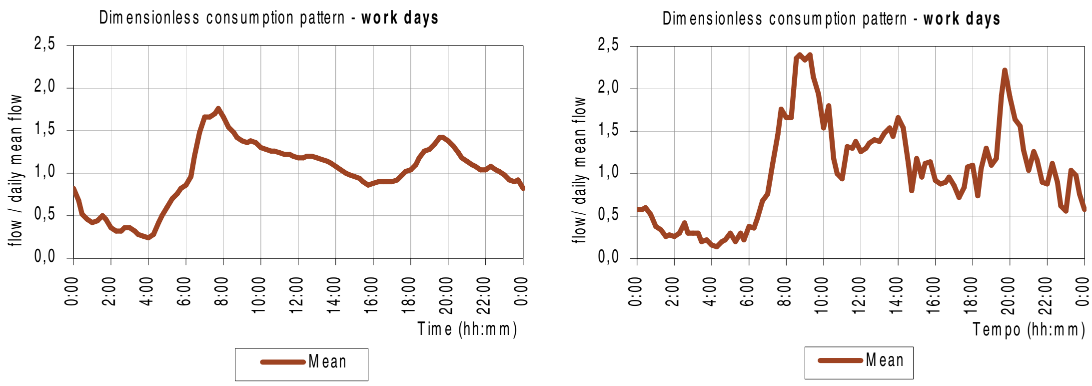


Figure 1 Study area 5 (a) and water meter and data loggers used in the preliminary campaign (b).

Figure 2 compares consumption patterns at DMA level (Figure 2a) and at study area level (Figure 2b) during the campaign (21st of September until 24th of October of 2007). The patterns shown were obtained from 15 minutes standardized data and are dimensionless. Even though the difference between consumption patterns at DMA level and study area level in terms of shape, where the variability throughout the day is considerably higher at study area level, both patterns reveal that the higher consumption takes place during the morning and dinner period. Another important aspect is the significant consumption during the day which indicates the presence at home during the day is relevant. According to Table 1, DMA E (which includes study area 5) has a significant percentage of families with elderly, corresponding to non-working people with a probable significant presence throughout the day.

For the study area, daily mean consumption corresponds to 189.4 l/h, night mean flow (mean flow between 3:00 – 4:00) to 41.1 l/h, per household consumption to 142.1 l/household/day and per household night consumption to 1.28 l/household/day. Warren (2002) has found that daily mean consumption has a significant relationship with night consumption.



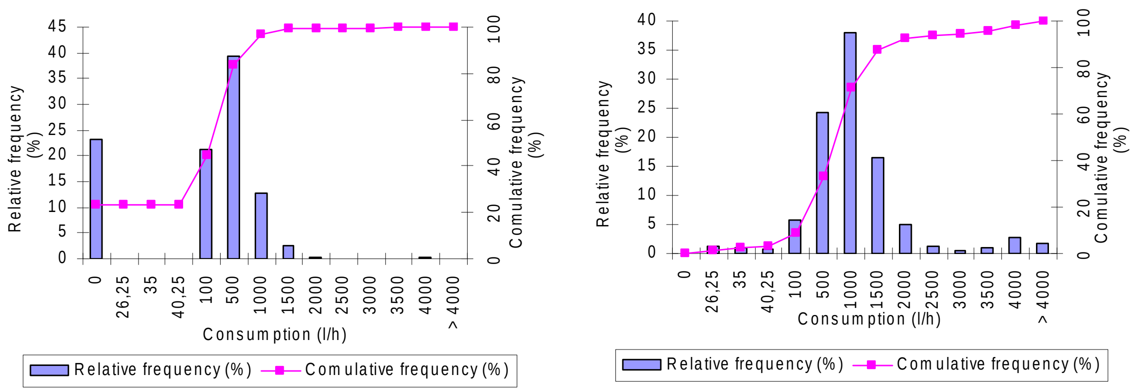
a) b)

Figure 2 Consumption patterns at DMA (a) and at study area (b) level for work days between 21/09/2007 and 24/10/2007.

Comparing consumption data collected using a data logger with fixed time interval and pulse time, important differences have been found (Figure 3). Consumption data obtained with fixed time interval (with a time step of 1 minute and a resolution of 1 pulse/liter) lead to an overestimation of the frequency of consumption below transitional flow and did not allowed an accurate description of household night uses. In the case of fixed time intervals, 23.1% of the records were lower than transitional flow (Q_2 = 40.25 l/h), corresponding to null values, and in the case of pulse time 3.0 % of the records were lower than Q_2, with a minimum value of 3.8 l/h.

In agreement to Figures 2b) and 3, fixed time data acquisition (with a time step of 1 minute and a resolution of 1 pulse/litre) allows a reasonable consumption analysis if consumption is aggregate into time steps of 15 minutes. Although, this type of acquisition does not allow a detailed description of household night uses.

An increase of resolution (e.g.,0.1 pulse/litres) could reduce significantly the frequency of null values of consumption and allow a better description of household night consumption using fixed time data acquisition.

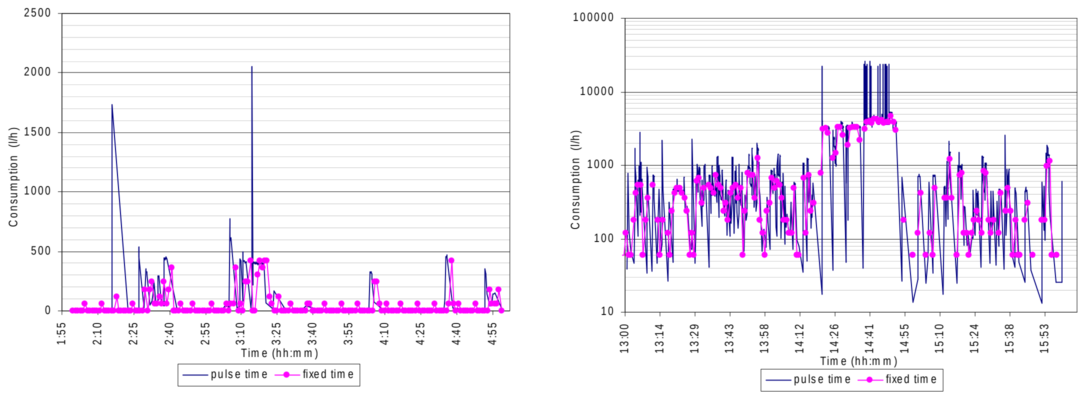


a) b)

Figure 3 Distribution of consumption using fixed time (a) and pulse time acquisition (b) between 21/09/2007 to 1/10/2007.

According to Figure 4a, using pulse time data acquisition, it is possible to analyse individual night uses, characterized by short duration (mean duration value = 78.3 s) and instantaneous consumption values around 300 l/h (0.08 l/s) in most of situations. Pulse time acquisition allowed also identifying a minimum consumption around 10 l/h. Note that this value has an error greater that -5%, according to metrological characteristics of consumption meter. In terms of leakage at household level, Arregui (1998) refers values between 5 l/h and 30 l/h, which are significant lower than household night consumption. These aspects pointed up the importance of introducing uncertainty analysis in the estimation of household night consumption.

In terms of consumption meter, the results obtained lead to the analysis of viability of installing a consumption meter with higher accuracy on minimum flows, without causing pressure drop problems to the clients.



a) b)

Figure 4 Variation of consumption using pulse time and fixed time data acquisition during the night (2:00 – 5:00) (a) and during the day (13:00 – 16:00) (b) in 26/09/2007.

Analysing maximum consumption values an underestimation has been obtained comparing in terms of fixed time data acquisition was observed compared with pulse time readings (Figure 4b and Figure 5). In terms of pulse time, for the period shown in Figure 4b, it was obtained an average duration pulses of 4.9 s and minimum pulse duration of 0.14 s. According to Figure 5 peak consumption and for the period between 21/09/2007 and 4/10/2007, peak consumption is less than 4286 l/h in 80% of days, using pulse acquisition data, and less than 3780 l/h in 80% of days using fixed time data acquisition, which represents of difference of 12%. Between 26^{th} and 27^{th} of September significant higher values of consumption were recorded during a short period (< 10 minutes) due to valves manoeuvres in the network and maximum consumption values obtained using fixed time data acquisition correspond only to 20% of the maximum value obtained using pulse time data acquisition (Figure 4b).

An increase in terms of time step (e.g., time step = 1 s) using fixed time data acquisition could increase significantly the sensibility to real maximum consumption values. Although, it is not the main goal of the study analyse maximum consumption values and the amount of data to be collected, sent and stored would increase significantly. Nevertheless the analysis of maximum consumption values is important to design consumption meters, to allow a better characterization of daily consumption and to obtain indirect results involving the relation between maximum consumption values and social-demographic characteristics of clients.

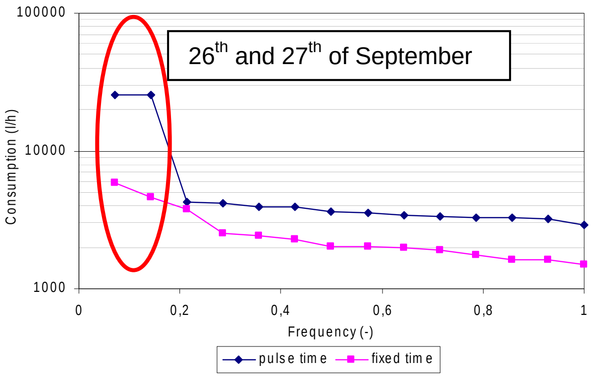


Figure 5 Variation of instantaneous maximum consumption values between 21/09/2007 and 4/10/2007 using pulse time and fixed time data acquisition.

Excluding maximum consumption values due to valves manoeuvres in the network, the values obtained are significant lower than maximum value estimated based on design rules usually used for house plumbing - 14.4 m3/h (Pedroso, 2000). Although the results obtained correspond to a campaign of short duration, according to Census data, study area 5 is included in a network with significant percentage of old and retired people. This fact may lead to lower values of simultaneity coefficient. Although in other study areas – such as study areas 1, 3 and 8, with different people characteristics (e.g., higher percentage of families with teenagers) or with swimming pools and gardens, higher peak factors can be obtained (Table 1).

In terms of data loggers, fixed time data loggers recorded 1440 records/day/channel (it was used 1 digital channel for consumption and 1 analogical channel for pressure) and pulse time data logger recorded on average 5738 records/day (is was used only one digital channel), which represents collecting around four times more information when compared with fixed time data logger. Considering only local collection of data, fixed time data logger had enough capacity to collect consumption and pressure data during 60 days while pulse time data logger reach the full memory capacity in 14 days, for 256 Kbytes of capacity.

Meter selection

In order to select the most adequate meter for installation in each study area (Table 2), minimum and maximum consumption values were estimated. In terms of minimum flow values, water meters were designed to measure accurately household night consumption (i.e., use and plumbing losses). With exception of study areas 1 and 8 (Table 2), consumption meters will be installed at street level, thus it is important to assess the importance of background losses in pipe networks, service connection and private pipes (when applicable).

Background losses components were estimated based on BABE methodology (Lambert, 1994). Considering an average pressure of 50 m c.a. and that infrastructure is in good condition, background losses have been estimated (Morrison *et al.*, 2007) and the results are shown in Table 3. In two study areas (study area 1 and 8), consumption meter will be installed at the entrance of the building and only in three study areas with detached houses (study areas 3, 4 and 6) have been considered private pipe losses. Most relevant values of pipe network losses (5 – 8.6 l/h) and service connection losses (18.8 – 30 l/h) were obtained for study areas 3, 4 and 6. For these study areas pipe network losses are similar to plumbing losses. Those study areas are characterized by pipe lengths and service connections varying between 250 - 430 m and 15 – 24, respectively (Table 2).For the other study areas, plumbing losses are significantly higher that the other background losses. For study areas 3, 4 and 6 will be performed step tests during night period possible to separate background losses (essentially due to pipe network and service connection losses) from household night consumption. Thus, to cope with this test, the selected consumption meter should measure with acceptable accuracy background losses around 25 l/h in these study areas (Table 3). Since the period to collect consumption data will range between 9 - 12 month, involving Summer period, it is important to analyse possible tendencies on night consumption and identify if they area due to different household night uses along the period or due to changes in background losses components. According to results obtained during the preliminary campaign a good agreement has been obtained with estimated background losses.

Table 3 Estimation of minimum and maximum values of consumption for the study areas.

Study área ID	Maximum flow (m^3/h)	Background losses (l/h)				
		Pipe network	Service connection	Private pipe	Total	Plumbing
		(1)	(2)	(3)	(1)+(2)+(3)	
1	10.80	-	-	-	-	5.25
2	14.40	1.20	5.00	-	-	7.75
3	13.68	5.04	21.25	0.56	26.85	7.00
4	11.52	5.43	18.75	0.50	24.68	5.75
5	14.40	0.66	2.50	-	-	8.00
6	13.68	8.57	30.00	0.79	39.36	7.00
7	15.48	0.22	2.50	-	-	8.25
8	10.80	-	-	-	-	5.00

In terms of maximum flow values, water meters should be designed to respect maximum consumption values that can take place and minimizing pressure losses introduced. Maximum consumption values have been estimated based on design rules usually used for house plumbing (Pedroso, 2000). Significant differences have been obtained for study area 5, indicating and overestimation of peak consumption using design rules.

Due to study requirements, in terms of household night consumption, and the uncertainty associated to maximum consumption values, the adoption of a single consumption meter covering with accuracy the large range of estimated flow values was difficult. For this reason, a combined consumption meter has been adopted. This consumption meter is composed by a principal consumption meter with a nominal diameter of 50 mm (woltman meter) and a maximum flow of 90 m^3/h and a secondary meter with a nominal diameter of 20 mm (volumetric meter) and a minimum flow of 12.7 l/h (according to Directive n.º 2004/22/EC). Although with cost significant higher when compared to a single consumption meter, this type of consumption meter allows eliminating pressure drop problems with clients and minimizes the degradation of consumption meters to maximum consumption values, making possible, at the same time, to satisfy consumption meter requirement in terms of household night consumption. This type of consumption meter has also de advantage of being easily applicable in other study areas with higher number of clients. Arregui *et al*. (2006; Morrison *et al.*, 2007) pointed out possible disadvantage that must be verified during the campaign and it is related with the probability of failure in the changeover valve leading to important metering errors.

Telemetry system selection

The telemetry system adopted to monitor the study areas were analysed in terms of emitter type, data logger and communication system.

In terms of emitter type, an optical solution has been adopted allowing a resolution of 1 pulse/litre and 1 pulse/ 0.1 litres in the principal and secondary consumption meter, respectively. This solution allows a higher resolution and eliminates the problems associated to reed pulse emitters, such as the generation of artificial pulses, sensitivity to electromagnetic interferences and inability to detect flow direction (Arregui *et al.*, 2006).

Using a reed pulse emitter only a resolution of 1 pulse/100 litres and 1 pulse/ litre in the principal and secondary consumption meter, respectively, was possible. Although, reed and inductive pulse emitters doesn't need of external electricity, conversely to optical emitter. This aspect can become very significant in the case of pulse time data loggers where battery consumption is higher comparatively to fixed time data logger.

In terms of data logger the most relevant characteristics considered were the number of and type of input channels (i.e., 2 digital and 1 analogical), protection class, type of data acquisition, capacity and type transmission of data (i.e., local or remote).

Relatively to input channels, it is necessary to collect digital data on both consumption meters (i.e., principal and secondary meter) and analogical data about pressure. Data loggers with pulse time acquisition are more variable in terms input channels characteristics. In some cases it is not possible to collect digital and analogical data in the same data logger, involving the acquisition of two data loggers, whilst in others, besides this possibility, it is possible to parameterize each input channel, varying the time step in the case of analogical input and the number of pulses between records of each digital channel separately (e.g., a parameterization can be performed to only the 50th pulse will be stored). This last option allows saving memory and can be very important if local collection of data is adopted. Protection class IP 68 was adopted for data loggers.

Pulse time reading provides a more detailed description of night uses, although involves collecting a higher amount of data, which spends more battery energy, an aspect critical in this study since the total duration will be about 7-9 months, and communication costs are higher comparatively to fixed time.

Fixed time data acquisition, with a resolution higher than 1 pulse/litre (e.g., 1 pulse/ 0.1 litres), can also satisfy household night consumption data requirements, being a more robust solution. Fixed time data acquisition allows a long duration of batteries and generally it is possible to measure consumption and pressure using the same data loggers. This solution is vary practical when local collection of data is adopted, since it is possible to know when the data logger reach full capacity in opposition to pulse time data logger. For the data loggers analysed, it was observed that fixed time data loggers are compatible with all emitter types (i.e., reed, optical and inductive) conversely to pulse time data logger.

Memory capacity is crucial especially if local collection of data is adopted. Aspects related to memory allocated per channel and the options available when memory is full were also assessed. Considering local collection of data. memory capacity of loggers was analysed in order to have enough capacity to collect data only each 15 days. A collection of data with a higher frequency increases significantly the costs associated to this task.

Remote transmission of data allows a better monitoring of consumption and pressure values in the 8 study areas and the introduction of some adjustments throughout the campaign. According to the preliminary campaign no communication problems were found. For the study, remote collection of data was adopted using fixed time data acquisition (with a resolution of 1 pulse/0.1 litres and a time step of 1 minute), since satisfies study requirements, collects consumption and pressure data with enough detail, minimizes problems with data collection (e.g., battery life), and communications costs and allows a better monitoring during all the campaign.

Conclusions

The results demonstrate the need of a water meter with broad range of flow values, to handle with minimum night flows without limiting household consumption due to pressure drop or affecting reliability of water meters. A comparison with water meters available in the market has been carried out. In terms of telemetry, factors such as pulse emitter type (e.g., reed, optical or inductive), reading resolution, type of reading (e.g., fixed time interval, pulse time) can influence significantly consumption measurements and enforce the methodology of analysis.

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