# RESIDENTIAL AND NON-RESIDENTIAL MINIMUM NIGHT CONSUMPTION ANALYSIS BASED ON SMART-METER DATA

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## ABSTRACT
Accurate estimation of users' minimum night consumption (MNC) is essential for effective leakage assessment in water distribution networks using the Minimum Night Flow (MNF) method, based on which leakages are quantified by subtracting users' consumption from the network nighttime inflow. However, the limited availability of MNC data—often scarce and mostly tied to local contexts—can lead to misestimations of leakage rates. This study contributes to the literature on MNC assessment by analysing hourly water-consumption data from about 1,700 residential and non-residential users in three Italian districts, with the aim of investigating the related MNC values and distributions. Results indicate that residential MNC values range between approximately 1.3 and 2.5 L/user/h, with increasing values likely due to irrigation of private gardens. Conversely, non-residential MNC values are higher and more spread, ranging from about 3.3 to 7.1 L/user/h, reflecting heterogeneous water-consumption patterns including a few highly demanding activities operating overnight. Overall, the study findings can contribute to more accurate leakage assessment, and reveal the need for targeted monitoring, particularly for non-residential users.

**Keywords:** Minimum Night Consumption; Residential and Non-residential Users; Water Distribution Networks

## INTRODUCTION
Detailed water-consumption characterisation and leakage-rate assessment are nowadays needed to ensure effective and sustainable management of water distribution networks (WDNs) [1]. In the last decades, the introduction of smart meters has enabled the collection of high-resolution water-consumption data, often at sub-daily intervals (e.g., hourly readings), thus supporting more informed decision-making in water resources management [2] and allowing accurate quantification of leakages in WDNs. In fact, a commonly used technique for leakage assessment is the minimum night flow (MNF) method, based on which leakages are assessed as the difference between the minimum net inflow entering the WDN (MNF, usually occurring at night) and users' water consumption at the same time (minimum night consumption, MNC). The effectiveness of this method strictly depends on the availability of accurate MNC

values, which are essential to distinguish between actual water consumption and leakages. However, few estimates of this parameter are available in the literature and most of them were obtained in relation to the residential sector and specific contexts [3]. These estimates are generally transferred worldwide, often resulting in leakage misestimation, potentially leading to the implementation of ineffective strategies for leakage mitigation.

This study contributes to filling the previously identified gap in the literature on MNC values by providing an estimate based on data from approximately 1,700 users—both residential and, innovatively, non-residential—across three Italian districts that underwent smart water monitoring over the course of one year. Specifically, hourly water-consumption data are analyzed to statistically assess MNC values and their distributions across different user types, addressing the current gap related to the lack of local MNC estimates for both residential and non-residential sectors.

## METHODS AND MATERIALS

The analysis of residential and non-residential MNC relies on the availability of hourly water-consumption data collected at the level of individual users, which are exploited to evaluate the daily average patterns of consumption both at the user level and the overall-district level.

In greater detail, hourly water-consumption data collected at the level of individual users are exploited to evaluate: (1) the daily average water-consumption patterns (L/h) of each user, and (2) the pattern related to the overall district (i.e., all users grouped together). In fact, the daily water-consumption pattern of the overall district allows the hourly time interval during which the net inflow is the lowest (i.e., the time of MNF occurrence) to be identified. MNC values are then analysed by investigating the daily average patterns of water consumption in relation to each user with reference to the time of MNF occurrence.

From an operational standpoint, the mean $\mu$ and standard deviation $s$ of the sample comprising the *n*–MNC values observed across the *n*–daily average water-consumption patterns (where *n* is the number of residential or non-residential users included in each district) are calculated. Additionally, the 95%-confidence interval ($CI$) is assessed for each user type and district by adding and subtracting the margin of error $t^* \times s/\sqrt{n}$ to the mean $\mu$ (where $t^*$ is the t-critical value corresponding to a 95% confidence level [4]) as shown in Equation (1):

$$CI = (\mu \pm t^* \times \frac{s}{\sqrt{n}}) \quad (1)$$

Drawing from the works [5, 6], MNC values are explored in relation to three Italian districts: (*A*) the peripheral area of a medium-sized city in Northern Italy, including approximately 300 users (96% of which are residential, 4% non-residential); (*B*) a seaside resort on the Adriatic Sea, including about 200 users (95% residential, 5% non-residential); and (*C*) the metropolitan area of a large city in Southern Italy, including nearly 1,200 users (77% residential, 23% non-residential). More specifically, the most common residential user types range

from detached houses with gardens (in the case of district *A*) to multi-apartment buildings (in the case of district *C*), with an intermediate scenario in district *B*, where about half of the inhabitants reside in semi-detached or detached houses and the other half in multi-apartment buildings. Moreover, non-residential users mainly comprise small commercial establishments (shops, restaurants and cafes, pharmacies, etc.) and public services (medical clinics, sports facilities, etc.) across all three districts.

## RESULTS AND DISCUSSION

Preliminary to the application of the methodology for MNC analysis in relation to the three Italian districts, the water-consumption datasets were pre-processed to assess the consistency of the data collected by the smart metering systems and to detect potential anomalies. No irregularities—such as malfunctioning meters, inactive users, or post-meter leakages—were identified, and missing data remained consistently below 15% in each district, confirming the overall suitability of the datasets for the analysis.

Regarding the identification of the time of MNF occurrence, analysis of the normalized aggregate district-level patterns (Figure 1) indicates that it consistently falls between 2:00 and 3:00 AM across all three districts. Consequently, MNC is assessed for all users and districts with reference to this hourly time window. However, it is worth noting that the time of lowest water consumption can vary significantly at the individual user level. In fact, only 18%, 23%, and 22% of users in districts A, B, and C, respectively, exhibit their minimum water consumption within the identified MNF hourly time window.

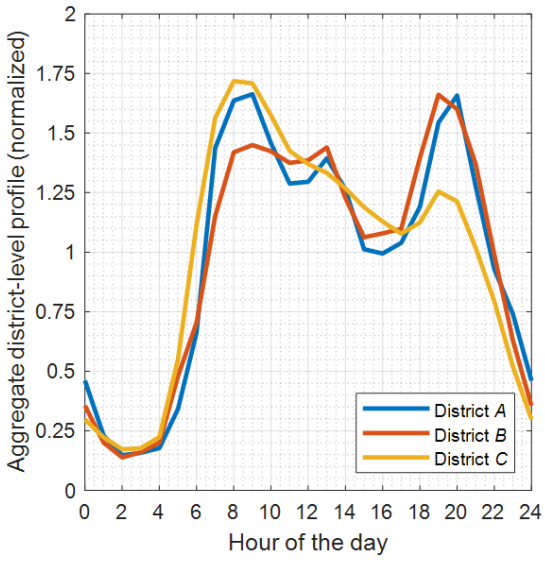


*Figure 1. Aggregate district-level patterns (normalized) of the three Italian districts in which MNC is evaluated.*

As far as MNC values are concerned, different results are obtained for residential and non-residential users, distributions of which are shown in Figure 2. In particular, for residential users, the lowest MNC value ($CI = 1.3 \pm$

0.1 L/user/h) is observed in district *C*, which is almost entirely composed of multi-apartment buildings. Conversely, higher values emerge in relation to districts *A* ($CI$ = 1.7 ± 0.4 L/user/h) and *B* ($CI$ = 2.5 ± 0.4 L/user/h), both characterised by a larger presence of semi-detached and detached houses with private gardens. Overall, these results suggest that the presence of gardens can contribute to higher residential MNC values, as demonstrated in previous studies [7]. Furthermore, it is noteworthy that the 95% confidence intervals for residential MNC are relatively narrow across all three districts, with low margins of error (from 0.1 to 0.4 L/user/h) indicating limited data variability and a homogeneous behaviour among residential users, attributable to the relatively low standard deviation.

Regarding non-residential users, the analysis reveals that MNC values are generally higher and exhibit greater variability compared to residential users across all three districts. Specifically, non-residential MNC ranges from $CI$ = 3.3 ± 5.3 L/user/h in district *B*, to $CI$ = 4.4 ± 9.4 L/user/h in district *A*, and up to $CI$ = 7.1 ± 4.8 L/user/h in district *C*. Interestingly, despite most non-residential users exhibiting minimal consumption at the time of MNF occurrence—80% in District A, 64% in District B, and 67% in District C consuming less than one litre per hour—the mean non-residential MNC values exceed those of residential users across all three districts. It is important to emphasize that, regardless of the sample size—which varies significantly from ten non-residential users in district *A* to 272 non-residential users in district *C*—the margins of error for non-residential MNC are considerably large, ranging from 4.8 to 9.4 L/user/h. This is primarily due to highly unbalanced samples, characterised by the presence of few activities that consume large volumes of water overnight (e.g., commercial establishments, catering services, or other productive facilities operating throughout the night) which contrast with a significant proportion of non-residential users with negligible nighttime water consumption. This pronounced heterogeneity in non-residential water-consumption patterns contributes to the wide dispersion of MNC values observed within the non-residential sector, revealing the need to investigate non-residential users individually for a detailed assessment of their related MNC.

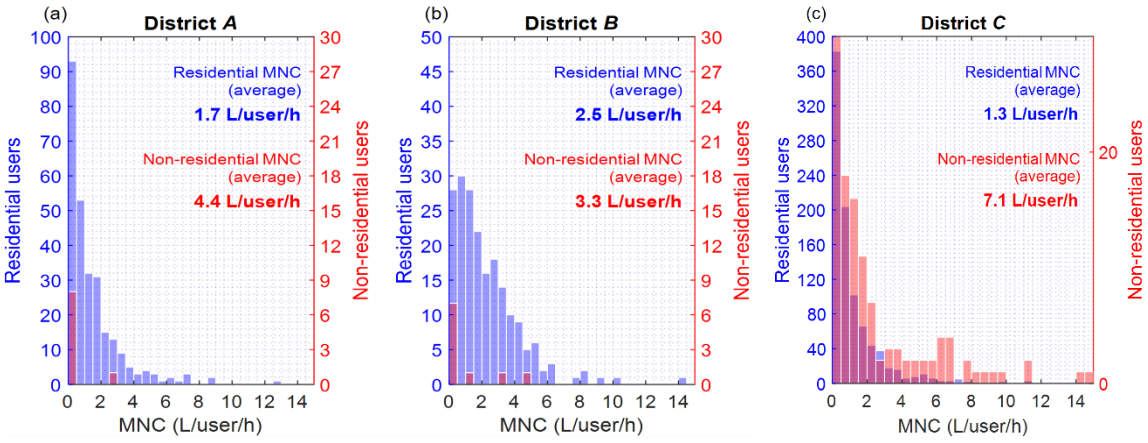


*Figure 2. Statistical distribution of residential and non-residential MNC.*

## CONCLUSIONS

Exploiting hourly water-consumption data collected by means of smart meters, this study aimed to investigate minimum night consumption (MNC) for about 1,700 residential and non-residential users across a sample of three Italian districts differing in location, size, and building typologies. The objective was to contribute to the existing literature on MNC by addressing the lack of local estimations. The key findings of the study can be summarised as follows:

- residential MNC ranges between 1.3 and 2.5 L/user/h based on the district concerned, and tends to increase with the proportion of detached houses featuring private gardens, likely due to the additional use of water for irrigation, particularly during the warmer months;
- margins of error for residential MNC are relatively low (0.1–0.4 L/user/h), revealing a limited standard deviation and indicating fairly homogeneous behaviours in terms of water consumption among residential users during nighttime hours;
- non-residential MNC varies from 3.3 to 7.1 L/user/h according to the district considered, being the related average values higher than residential values despite many non-residential activities ceasing overnight;
- the average non-residential MNC is strongly influenced by a small number of highly-demanding users, resulting in more spread values compared to residential MNC, and with higher margins of error (4.8–9.4 L/user/h). This highlights the importance of individually analysing the water consumption characteristics of non-residential activities.

In conclusion, the results of this study—revealing the dependency of residential MNC on user type, and highlighting the need for targeted monitoring of non-residential users due to their heterogeneous behaviours at night—are expected to support water utilities and practitioners in improving their understanding of night-time water consumption, while contributing to the broader knowledge of both residential and non-residential MNC characterization.

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