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# CHANGES IN WATER USE IN DIFFERENT COVID-19 PANDEMIC RESTRICTION SCENARIOS

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The COVID-19 pandemic has impacted in the lifestyle of people: it has changed habits, mobility and working dynamics, which has led to a rise in basic supply consumption in households. This paper aims to analyse the change in hot domestic water consumption during COVID-19 compared with pre-pandemic periods, in volume terms and the pattern change. For this purpose, an own-developed stochastic model to characterize domestic hot water use is modified to different restriction scenarios to adapt it to COVID-19 pandemic conditions. To validate the model, Urban Water consumption changes during 2020 in the cities of El Prat de Llobregat and Barberà del Vallès are analyzed in order to relate total use of water in residential homes and domestic hot water consumption. The mean increase for DHW found is around 7%. For good measure, daily water pattern consumption results increased from 10h to 13h and from 16h to 19h in this scenario, which is consistent with the literature review. Both results, volumetric and pattern, are considered valid.

Keywords: COVID-19; domestic hot water; Urban Water; stochastic model

# CAMBIOS EN EL USO DEL AGUA EN DIFERENTES ESCENARIOS DE RESTRICCIONES DEBIDO AL COVID-19

La pandemia del COVID-19 ha impactado en el estilo de vida de las personas: ha cambiado hábitos, movilidad, dinámicas laborales… Lo que ha provocado un aumento del consumo de los suministros básicos en hogares. Este artículo tiene como objetivo analizar el cambio de consumo de agua caliente sanitaria durante el COVID-19 comparado con períodos previos, en términos de volumen y cambio de patrón. Para ello, se modifica un modelo estocástico de desarrollo propio para caracterizar el uso de agua caliente sanitaria en diferentes escenarios de restricción. Para validar el modelo se analiza la evolución del consumo de agua urbana durante el año 2020 en las ciudades de El Prat de Llobregat y Barberà del Vallès con el fin de relacionar el uso total de agua en viviendas residenciales y el agua caliente sanitaria. El incremento medio de ACS encontrado se sitúa en torno al 7%. En buena medida, los resultados del patrón de consumo diario de agua aumentaron de 10h a 13h y de 16h a 19h en este escenario, lo cual es consistente con la revisión de la literatura. Ambos resultados, tanto volumétrico como de patrón, se consideran válidos.

Palabras clave: COVID-19; Agua caliente sanitaria; agua urbana; modelo estocástico

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# 1. Introduction

COVID-19 pandemic has come along with changes in the life patterns of people such as home office work and study related activities, increased occupancy of households due to lockdown policy and increased awareness of personal hygiene. Therefore, water use in households has increased and it has generally decreased in other sectors. Studies addressed to this topic, find an increase ranging from 4 to 23% in daily water household consumption during COVID-19 pandemic: 14.3% in the first lockdown period in Germany (Lüdtke et al., 2021), 15% during restriction period in England (Cooley et al., 2020), 20.18% during 2020 and 2021 in Turkey (Birisci & Öz, 2021), 11% from February to April 2020 in Brazil (Kalbusch et al., 2020), 23% (multifamily) and 9% (single-family) in California during 2020 (Nemati, 2020), 5% in Barcelona during 2020 (Montlleo et al., 2020) and 4,2% in March 2020 in Serbia (Cvetković et al., 2021).

As consumption of residential water use arises, domestic hot water (DHW) use does too. In a survey done in 367 households in Madrid, 43.6% of them resulted to have increased their consumption of hot water during March and April 2020 and its use is more intensive for families with children, more vulnerable households, and smaller dwellings (Cuerdo-Vilches et al., 2021).

Reproducing the variability between dwellings and modelling a household's consumption is still an ongoing research field, especially if the life patterns of people are being altered with lockdown policies or working from home directives. Existing tools and models for the prediction of DHW consumption profiles for buildings are artificial neural networks (ANN) and stochastic models, among others (Fuentes et al., 2018). In Korea, 918 households, corresponding to apartment complex with 16 buildings supplied by district heating, were selected to collect demand data and develop a machine learning model with an ANN DHW model (Kim et al., 2021). Under the same city water temperature conditions, DHW demand after the COVID-19 significantly increased compared to pre COVID-19. In the simulation model, DHW demand increases by 8.08%-16.41% depending on the month (excluding February), and the growing number of active cases leads to increased DHW demand and a shift of hourly DHW demand pattern, during weekends and weekdays.

This paper aims to analyse and simulate the change in DHW consumption during COVID-19 compared with pre-pandemic periods, in volume terms and the pattern change. For this purpose, an own-developed stochastic model to reproduce DHW use is modified to different restriction scenarios to adapt it to COVID-19 pandemic conditions. To validate the model, urban water consumption changes during 2020 in two cities of Catalonia region are analysed in order to relate total use of water in residential homes and domestic hot water consumption.

The structure of this paper is as follows: Section 2 contains the methodology and description of the stochastic model and describes how the validation data is processed, Section 3 is dedicated to the resulting outputs of the model, Section 4 concludes the paper.

# 2. Methodology

## 2.1 Stochastic model description

This study uses a detailed stochastic model of occupancy, appliances and DHW consumption of household in the Mediterranean climate which is already designed and described in previous literature (Tejero et al., 2018). To summarize, it is a model which was developed to obtain electric appliances and DHW use profiles, in order to reproduce the variability of household occupancy and activity. The model allows obtaining synthetic profiles representing the most important characteristics of the mean dwelling, by means of a stochastic approach. The model (Figure 1) uses two main databases: Time Use Data (TUD) surveys collected by the National Statistics Institute (INE) of Spain in 2010 to characterize occupancy and activity and the SPAHOUSEC database (Institute for Energy Diversification and Saving - IDAE, 2016) for equipment stock and use to define the load profile of each equipment and DHW extractions.

The synthetic profiles are reproduced in 3-min time resolution during one year. The occupancy model is based on the Markov chain theory (current state only depends of previous step) and uses transition probabilities matrices for switching between three possible states: out, passive and active. As Tejero et al, (2018) stated "these probabilities vary depending on the time of the day and the number of occupants of the household".

The output of the model contains information about:

- The current state of inhabitants
  - out - not at home
  - passive – at home, not consuming electricity nor DHW
  - active – at home consuming electricity or DHW
- the activity being held (Table 1)
- the equipment used (stove, microwave, oven, dishwasher, washing machine, drier, other: iron/vacuum cleaner, 1st PC, 2nd PC, 1st TV, 2nd TV, radio, refrigerator, freezer)
- the type of DHW extraction produced (short extraction, shower and bath)
- the global electricity consumption of equipments (W)
- the global DHW consumption (in litres/min at 45ºC and W).

Activities are grouped and classified according to main and secondary activity answer of the Time Use Survey, as Table 1 shows.

**Figure 1: Inputs and outputs of the own-developed stochastic model**

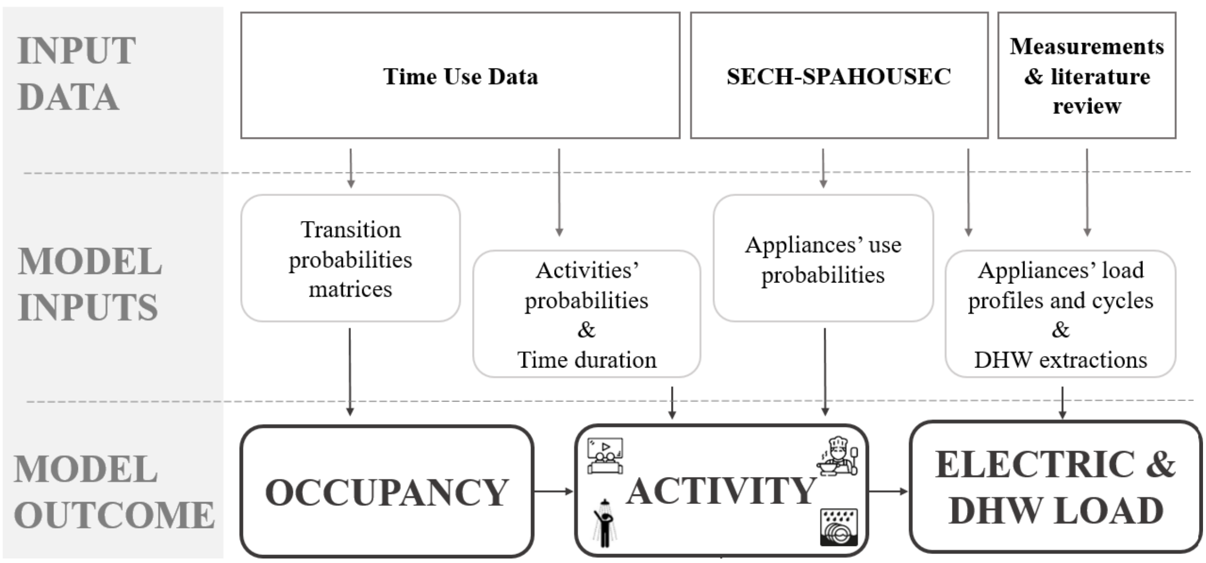


**Table 1: Taxonomy of activities considered in the model**

| 1. Activity | 2. Description | 3. Main TUD | 4. Secondary TUD |
|---|---|---|---|
| **5. 0** | 6. OUT & PASSIVE | 7. | 8. |
| **9. 1** | 10. Cooking | 11. Food preparation, baking and preserving 12. | 13. |
| **14. 2** | 15. Cooking + TV | | 16. Watching TV, video or DVD |
| **17. 3** | 18. Cooking + Radio | | 19. Listening to radio or recording |
| **20. 4** | 21. Cooking + Others | | 22. |
| **23. 5** | 24. Dishwashing | 25. Dishwashing | 26. |
| **27. 6** | 28. Laundry | 29. Laundry | 30. |
| **31. 7** | 32. Others | 33. Cleaning dwelling<br>34. Ironing<br>35. Visiting and receiving visitors<br>36. Celebrations | 37. |
| **38. 8** | 39. Others + TV | | 40. Watching TV, video or DVD |
| **41. 9** | 42. Others + Radio | | 43. Listening to radio or recording |
| **44. 10** | 45. PC | 46. Computer programming and related activities | 47. |
| **48. 11** | 49. TV | 50. Watching TV, video or DVD | 51. |
| **52. 12** | 53. Radio | 54. Listening to radio or recording | 55. |
| **56. 13** | 57. Personal Care | 58. Cleanliness and dressing | 59. |
| **60. 14** | 61. Personal Care + TV | 62. Cleanliness and dressing | 63. Watching TV, video or DVD |
| **64. 15** | 65. Personal Care + Radio | 66. Cleanliness and dressing | 67. Listening to radio or recording |

The model described is used as a Prepandemic scenario baseline which is compared to another scenario defined: the Strict-Lockdown scenario.

### 2.2 Strict Lockdown stochastic model

The scenario of Strict Lockdown is defined considering two societies: home-office and essential workers society. Essential workers are those who perform operations and services in sectors that are essential to ensure the continuity of critical functions. Home-office workers include those who are able to maintain their job related activity in a virtual environment. Those whose activity has been suspended, are considered part of the home-office group, since it is assumed that the major difference between the profiles is the fact of departing from the house.

The TUD used collects pre-pandemic conditions and does not reflect, for example, the real behaviour of people during strict lockdown, so this has to be considered as a limitation fact.

The DHW volumes are studied with annual daily means and a weighted average is calculated for both profiles to compare it to Prepandemic conditions. There are certain inconsistencies surrounding the portion of home-office workers during strict lockdown, ranging from 16,2% to 85%. Finally, INE data (2022) is consulted, and it is found that home office percentage during 14 March 2020 to 21 June 2020 is 49,7%.

Both profiles, home-office and essential workers, are run 500 times, simulating 500 household profiles during 1 year. The concerning outputs, DHW consumption and activities related to it, are studied both in volumetric terms and focusing on the pattern. The volumetric output for the strict lockdown scenario is calculated by means of a weighted average of both profiles, counting 49,7% for home-office and 50,3% for essential workers.

### 2.2.1 Home-office Strict Lockdown Profile

The major hypothesis stated in the Home-office Strict Lockdown scenario is that people can only leave home for “Shopping” and “Walking the dog” TUD activities. These are similar conditions to those Spanish home-office workers households from 14 March to 4 May 2020. Analysing the TUD under this statement, inhabitants are only 2% of the time outside home. It is considered a plausible percentage, since it implies more or less 2h of shopping weekly per inhabitant and the time of walking the dog, negligible.

In order to reflect also the consumption derived when working or studying at home, as well as other leisure activities, additional activities are added to the existing model (Table 2). In this user profile, “Travel to/from work” activity is considered as passive state. As for the equipment, 2 extra PCs are added to the possible stock in each dwelling, for the activities “Work” and ”Study”, respectively. The activity sport is related to a short 3-min shower if it lasts for more than 1 hour.

**Table 2: Activities added and equipment related**

| 68. Activity | 69. Description | 70. Equipment related |
|---|---|---|
| **71. 16** | 72. Work | 73. 3rd PC |
| **74. 17** | 75. Study | 76. 4rd PC |
| **77. 18** | 78. Culture & religion | 79. 1st PC |
| **80. 19** | 81. Sports | 82. 1st PC & DHW device |

### 2.2.2 Essential Strict Lockdown Profile

This profile is similar to the previous one with the main difference that “Working time in main and second job” and “Travel to/from work” TUD activities are considered outside activities.

### 2.3 Water consumption analysis

Registered water consumption data is gathered to validate the change of behavior during the Strict Lockdown scenario. Water injected in the system ($m^3$) and bimonthly billing volumes by sectors ($m^3$) are obtained thanks to the municipal companies Aigües del Prat, S.A (APSA) and Servei d'Aigües de Barberà Empresa Municipal, S.A (SABEMSA). Both supply water services to the cities of El Prat de Llobregat (~65.000 inhabitants) and Barberà del Vallès (~33.000 inhabitants). The daily water injected is available since 2016 to June 2021 (1643 values each municipality) and billing bimonthly volumes are available from 2018 to 2020 (18 values each municipality). It must be taken into account that no lectures were done in residential households from March to June 2020, i.e in 2020 there are five monitored values and one estimation. Thus, for the residential sector, Strict Lockdown and Reopening periods are not differed.

Two relevant analysis are undertaken:

- General week trends of water injection (for all sectors): An average baseline from 4 previous years (2016-2019) is calculated and compared to 2020
- Annual residential billing volumes: the sector consumption is normalized per population (yearly data from INE by municipality) and days in a year for domestic rates

Several restrictive measures are taken in 2020. The periods are determined taking into account restriction references and change of electric pattern consumption in Barcelona, in order to apply the same dates criteria for both municipalities. In this paper the periods considered are:

- Prepandemic period: 1 Jan to 14 March 2020
- Strict Lockdown: 14 March to 4 May 2020
- Reopening: 4 May to 20 June 2020
- New normal: 20 June to end 2020

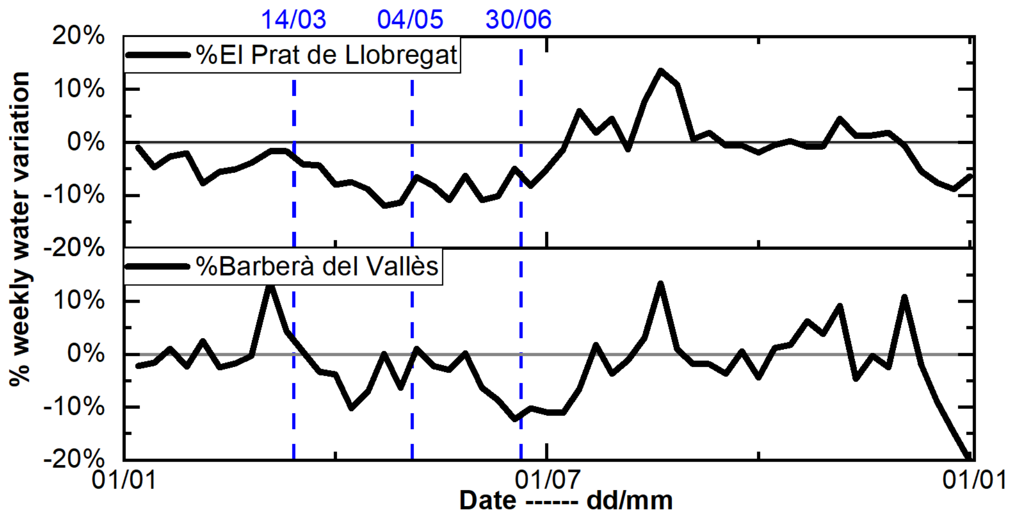
Moreover, the Catalan Water Agency (ACA) has yearly water data from 2012 to 2020 separated in domestic sector, economic activities and total consumption (data obtained from billing information) from all Catalan municipalities (~ 7,78M inhabitants). An average Catalan value can be calculated, from a 4 previous years baseline (2016-2019) and can be compared to 2020 values.

## 3. Results

### 3.1 Registered data analysed: Weekly behaviour for all sectors

A similar trend marked by restriction periods is observed in the consumption of the two analyzed municipalities. Figure 2 shows the percent variation of the water consumption during the year 2020 compared with the baseline constructed with values from 2016-2019. Consumption is similar to previous years until week 8 to week 11, when it is slightly decreased in El Prat de Llobregat and highly increased in Barberà del Vallès. However, from week 13 to week 27 there is a general decrease of consumption in the municipalities, most notable in El Prat de Llobregat. This is due to a period of mobility and sector restriction. From week 28-29 to week 49 there is a generalized boost, noting that sectors are reactivating. This oscillating behaviour can be attributed to the different phases and reactivation of industrial and commercial sectors. The industry sector is stopped in the last month of the year generating a strong decline in consumption at the end of the year.

**Figure 2: Weekly water injection variation to the system during 2020**




Note: The variation is the comparison with an average baseline 2016-2019

The annual difference of consumption is not a significant value: there is an increase of 0,2% in El Prat de Llobregat and a decrease of 1,1% in Barberà del Vallès, which is low for interannual variability. The mean variation values per period can be found in Table 3.

**Table 3: Comparison with average baseline 2016-2019**

| TOTAL 2020<br>INJECTED WATER VARIATION | Barberà del Vallès | El Prat de Llobregat |
|---|---|---|
| Prepandemic period | 1% | -4% |
| Strict Lockdown | -4% | -8% |
| Reopening | -6% | -9% |
| New normal | -2% | 1% |

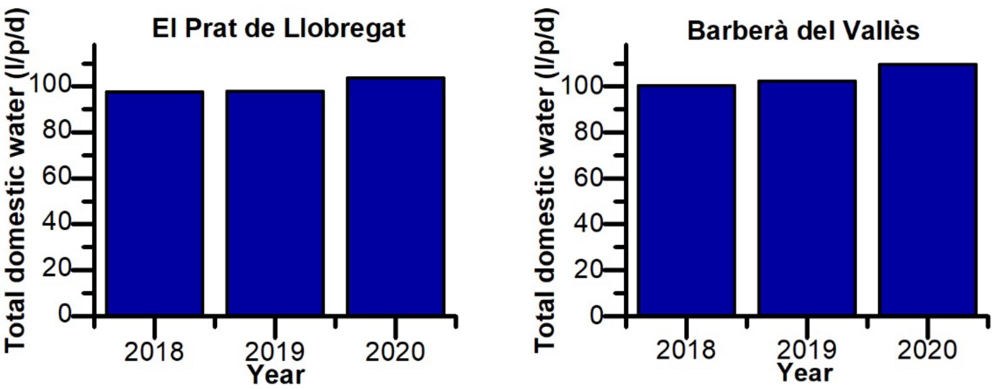
### 3.2 Registered data analysed: Annual behaviour for residential sector

Analyzing annual values, the water residential consumption in El Prat de Llobregat stabilizes around 102-97 litres/person/day (l/p/d) from 2008 up to date, being 100 l/p/d the mean. However, an increase of 5 l/p/d is clearly noted during 2020, respect to the mean of the seven previous years, rising to similar levels in 2007 (before the economic crisis). For Barberà del Vallès, the domestic consumption is stabilized between 100 - 105 l/p/d but there is an increase up to 110 l/p/d in 2020.

This implies that domestic consumption has rised 6% in El Prat de Llobregat and 8% in Barberà del Vallès in 2020, i.e considering all periods considered in this paper. In Figure 3 this slight increase can be noted in 2020 for both municipalities. These values are consistent with the Catalan average mean increase which is 5%.

As for data from March to July (Pandemic periods of Strict Lockdown and Reopening conditions), the increase is 11% in El Prat de Llobregat and 12,5% in Barberà del Vallès. No lectures were registered in the residential sector from March to June 2020, consequently Strict Lockdown and Reopening periods are not differed in this case.

**Figure 3: Daily average total domestic water consumption per inhabitant and day**




### 3.3 Synthetic data of Prepandemic model: DHW volumetric results

To prove the stochasticity of the model, daily DHW water consumption for 5 simulated households in a random week is plotted in Figure 4. The colours represent the different households and each timestep represents 3 minutes. It can be seen that no colour pattern is followed during one week. The values of consumption depend on the DHW extraction performed.

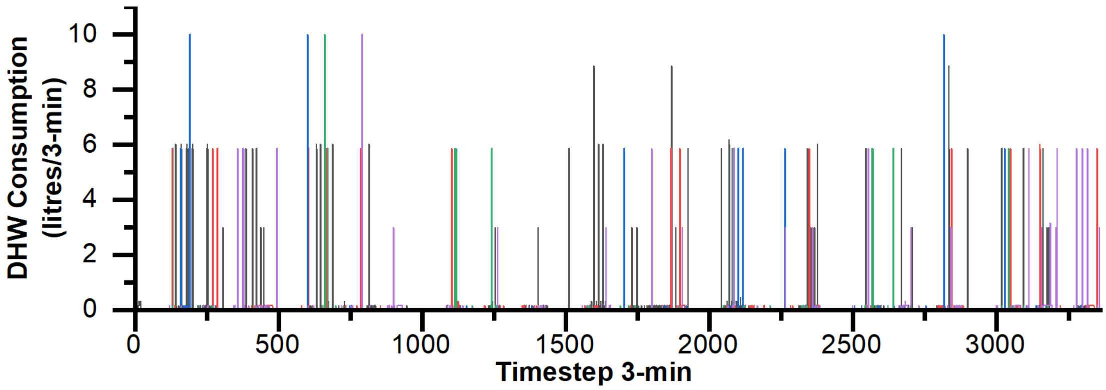
The battery of 500 simulations have the same household distribution characterization per number of occupants which is described in Table 4. This distribution is the same for each of the profiles described (Prepandemic, Home-office Strict Lockdown and Essential Strict Lockdown).

**Table 4: Distribution by occupant number for 500 households**

| Number of occupants | Number of households | Distribution |
|---|---|---|
| 1 | 106 | 21,2% |
| 2 | 165 | 33,0% |
| 3 | 127 | 25,4% |
| 4 | 82 | 16,4% |
| 5 | 20 | 4,0% |

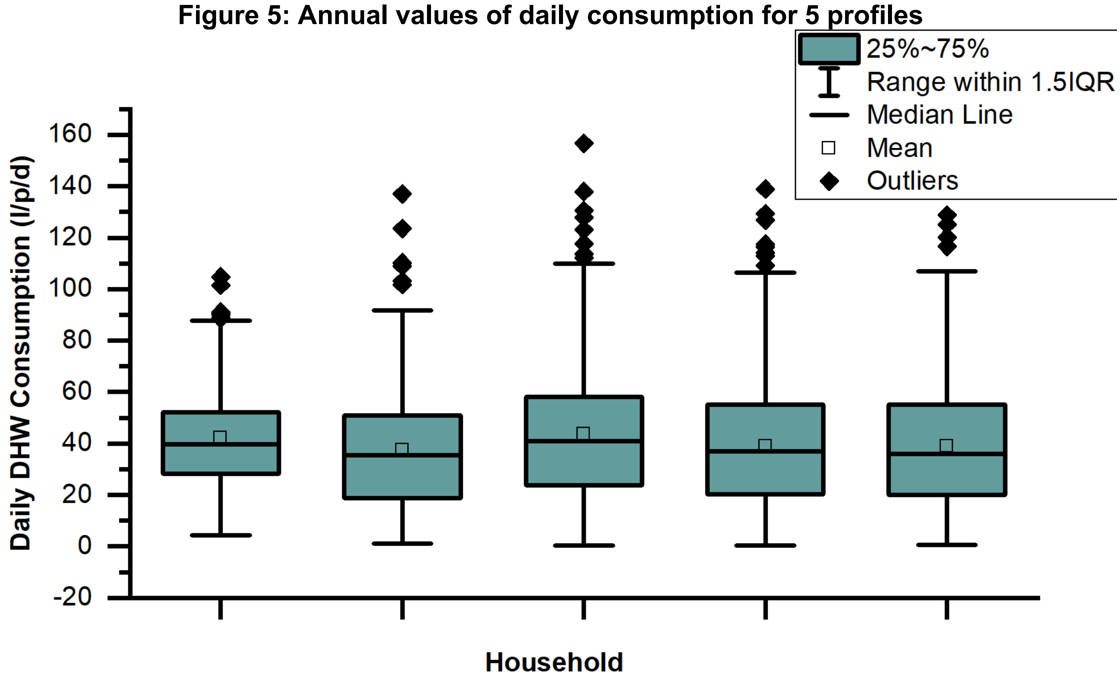
Secondly, a relation between total water consumption and hot water must be found to validate the output results of the pre-pandemic stochastic model. Existing literature analysing the relation between total water and hot water consumptions in the domestic sector has been reviewed. A study carried out in the US (Water Research Foundation, 2016), in a sub-sample of 94 homes single-family buildings, the average household hot water use was 172.2 litres per inhabitant day, which accounted for 33.2% of total indoor water use. A research using 3 years of cold and hot water monthly records from around 10.300 apartments for households in Belgium (Meireles et al., 2022), concludes that from a total annual mean of 168 l/day/household, a 32,4% of the total amount is attributed to domestic hot water. In 2014, 10 apartments in the same building were monitored during 18 months in the Community of Madrid (Gutierrez-Escolar et al., 2014). The average amount of DHW consumption was 25.7 l/p/d, resulting in a 18,2 % of an average total consumption of 141 l/p/d. This DHW data for Belgium and Spain is for a reference temperature of 60ºC.

**Figure 4: DHW consumption profile outcome of the stochastic model**




The Spanish Building Code (Código Técnico de la Edificación, 2019) establishes a mean consumption of 28 l/p/d at 60ºC, which would fit inside a ranging percentage of 35-18% applicable to Mediterranean households. Using a thermal equivalence to 45ºC, this value rises to 42 l/p/d. Considering that the prepandemic consumption is around 100 l/p/d and the Prepandemic stochastic model outputs a daily average mean of 42,2 DHW l/p/d at 45ºC (or 28,2 at 60ºC) it implies that DHW at 60ºC accounts for 28.2% of water consumption. Figure 5 boxplots five examples of the daily DHW consumption for a year. Assuming the facts, it can be concluded that the results obtained in the Prepandemic stochastic model are consistent with the data analyzed in the municipalities of El Prat de Llobregat and Barberà del Vallès.

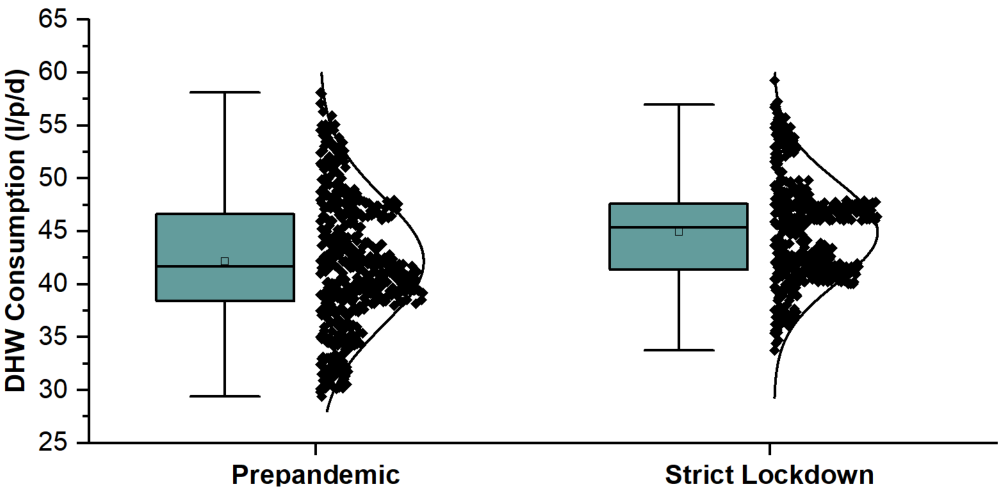
**Figure 5: Annual values of daily consumption for 5 profiles**




### 3.4 Synthetic data of Strict Lockdown scenario

Applying the percentage for each profile described in the methodology (49,7% home-office and 50,3% essential), the annual median has increased 8% in the new scenario, potted in Figure 6. The annual mean has increased around 7%. As discussed in the introduction (Section 1), total domestic water in 2020 has rised ranging from 4 to 23%, depending on the region and the restrictions. For specific data in Catalonia, this increase is around 5-8% for all year and 11-12,5% from March to July (Pandemic periods of Strict Lockdown and Reopening conditions, which are not differed due to resolution limitation). Despite results being lower as expected, they can be considered valid, since the portion of increase of hot water may not be linear to the total increase of water consumption.

**Figure 6: Daily average results of Prepandemic scenario vs Strict Lockdown scenario**




In any manner, it can be noted that there is repeatability in a certain consumption level, which is more visible in the Strict Lockdown scenario. This is attributed to the fact of frequently spending time at home, what makes patterns in the model to be cyclic.

In spite of the fact that home-office profiles spend additional time at home, the major increase of consumption is attributed to the essential strict lockdown profile. This result can be interpreted as a consequence of boosted hygiene measures in these homes, since the Personal Care activity has higher probability from respect Home-office profiles. In Table 5, the mean daily consumption values are given for all scenarios and profiles.

**Table 5: Mean daily consumption and variation respect from Prepandemic scenario**

| Scenario | Mean DHW consumption (l/p/d) | Mean increase resp. Prepandemic | Median DHW consumption (l/p/d) | Median increase resp. Prepandemic |
|---|---|---|---|---|
| Prepandemic | 42,2 | 0% | 41,7 | 0% |
| Essential Strict Lockdown | 46,0 | 9% | 45,9 | 10% |
| Home-office Strict Lockdown | 43,9 | 4% | 44,0 | 6% |

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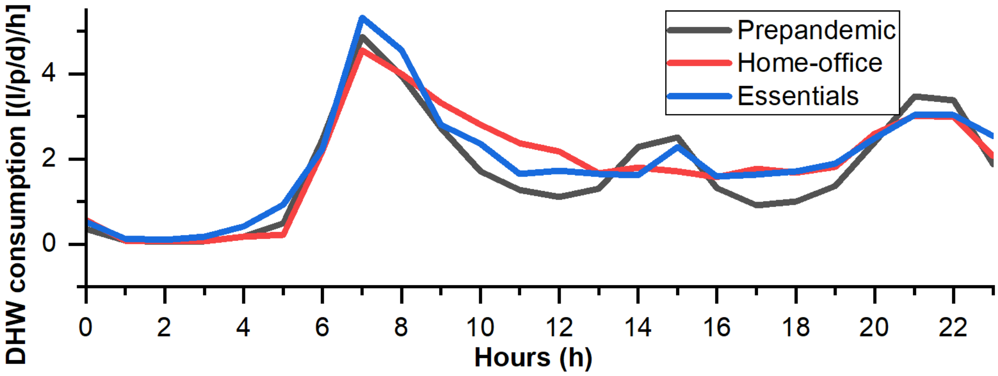
Figure 7 shows an increase of consumption from 10h to 13h and from 16h to 19h in the Strict Lockdown scenario. Peaks are less steep, especially in home-office profiles.

**Figure 7: Hourly average pattern results – All scenarios and profiles**




Note: The output of the daily average pattern is given in litres at 45ºC consumed in each hour of the day.

Considering the resolution of the available data in El Prat de Llobregat and Barberà del Vallès, its examination in terms of water patterns is not possible. Instead, the patterns are compared with literature review. DHW consumption profiles in residential households present typically two peaks that occur in the morning and the evening (Fuentes et al., 2018) and is largely affected by the presence of holidays (Kim et al., 2021).

This last study in Korea, which develops an ANN DHW model, states (Kim et al., 2021): “For weekdays, the peak demand at 07:00-08:00 is similar before and after the COVID-19 pandemic, but the value has increased at every hour after the COVID-19 pandemic. This implies that the usage at peak demand has relatively decreased”. Furthermore, the simulated model finds a DHW demand increase by 8.08%-16.41%.

As for the concerning model of this paper and especially in the home office workers profile, this statement is confirmed. Although the output of the model designed in this paper does not differ between weekdays and weekends, the general trend is to have a similar behaviour in peak hours, and increase the consumption in valley hours. In addition, the total DHW demand increase found is around a slightly lower range, being 8% (if medians are compared) and 7% (for means) in this study.

## 4. Conclusions

Broadly, the study carried out in this paper aimed to characterize changes in DHW profile consumption using a stochastic-based simulation model in a Strict Lockdown scenario and to validate results with measured hot and cold water consumption. The mean increase for DHW found is around 7%. Although results were expected to be higher (around 15%) due to the hard restrictions assumed in the hypothesis, they can be considered valid, since the portion of increase of hot water may not be linear to the total increase of water consumption. For good measure, daily water pattern consumption is plotted and result increased from 10h to 13h and from 16h to 19h in this scenario, which is consistent with the literature review.

The results of the simulations demonstrate the validity of the modified model, obtaining thusly new profiles that draw a Strict Lockdown scenario. However, to improve the model, the input database should be updated with the activity and conditions performed during COVID-19. Plus, residential measured data for validation had a low resolution since no smart meters are used. For further research, new scenarios and pandemic periods could be explored.

The Strict Lockdown scenario represents a period of increased occupancy in homes, and could reappear in future extreme weather conditions where buildings might be used as climatic shelters.

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**Communication aligned with the Sustainable Development Objectives**