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Assessment of Social Housing Energy and Thermal Performance in Relation to Occupants' Behaviour and COVID-19 Influence—A Case Study in the Basque Country, Spain

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Abstract: Evidence shows that people have a major impact on building performance. Occupants' impact is especially important in social housing, where their occupants may present greater vulnerabilities, and their needs are not always considered. This study aims to analyse the socio-demographic influence in social rental housing concerning hygrothermal comfort and energy consumption in a case study located in Vitoria, Spain during the first 4-month period of 2020 and 2021 (during and after COVID-19 lockdown). An innovative data management system is included, where the users and administration can see in real-time the temperature and consumption in the dwellings. A 2-phase method has been applied; phase 1 is associated with outdoor climate conditions, building properties and social profile. Phase 2 determined the results in energy consumption, indoor hygrothermal comfort and occupant energy-use pattern. The results show that the comfort levels and energy consumption vary according to the analysed social profiles, as well as the heating activation periods and domestic hot water system usage. In conclusion, socio-demographic characteristics of social housing households influence the hygrothermal comfort of their dwellings, occupants' behaviour and heating and domestic hot water energy consumption.

Keywords: social housing; long-term monitoring; occupant behaviour; indoor hygrothermal comfort; energy consumption

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1. Introduction

In the European Union (EU), the analysis of the final end-use of energy developed in 2018 show that households were responsible for 26.1% of energy consumption, the second sector of the 3 dominant categories (transport, households, industry) dealing with the highest energy consumption [1]. Among the EU countries, Spanish buildings accounted for 30% of final end-use energy consumption in 2018, and the residential sector alone represented 17.1% [2]. With regards to the household energy consumption for space heating, space cooling, water heating, cooking and electrical appliances, they reached 42.2%, 1%, 17.3%, 7.5% and 32%, respectively, of the total consumption [3].

Furthermore, several studies show that the concurrence of low construction quality and energy inefficiency of buildings [4], combined with the role of the user [5] and the low socio-economic profile [6], lead to situations of energy vulnerability. The central role of occupants for achieving energy savings is increasingly recognised, and it is even more important in the social housing sector, where the environmental value is combined with the social purpose of reducing inequalities and energy vulnerability.

Households that are in a vulnerable situation are often unable or have significant difficulties in facing the economic expense required to maintain their housing in hygrothermal comfort ranges, resulting in living conditions that are inadequate and even detrimental to their health [7]. While energy refurbishment can mitigate these situations, by improving people's quality of life, it must be considered that it is the users themselves and their behaviour, the human factor, who consume energy and not the building itself; therefore, refurbishment strategies must be combined with the benefits of the effects of occupant behavioural change towards lower energy consumption.

In recent years, several European projects have focused on the occupants, their behaviour, comfort, and the relation of these factors to the energy efficiency of the building [8–11]. Furthermore, several authors study occupants' behaviour and the interaction between people and housing by defining occupancy profiles and energy consumption profiles [12–14] and the definition of metrics and methodologies that incorporate occupant behaviour into building assessment and design processes [15,16].

In 2020, the COVID-19 pandemic brought a new scenario to these challenges. Several countries implemented quarantines and lockdowns, forcing people to stay in their homes for long periods. In Spain, this period commenced in March and April 2020. This situation had a great impact on people's way of life and their interaction with the building [17]. This habit change has increased the number of hours people spend inside their homes, which has led to an increase in energy consumption [18–20]. As a result, the interaction of people with their homes and their lifestyle has a more significant impact on building performance.

Evidence shows that people have a major impact on building performance, which suggests that it is important to focus on the analysis of this impact attending to the characteristics and needs of the residents; this is especially the case in social rental housing where the profile of the people living there may present greater vulnerabilities and needs that are more specific.

In this sense, the aim of this study is to analyse the influence of the socio-demographic characteristics of social housing households in relation to the hygrothermal comfort of their dwellings, occupants' behaviour and heating and domestic hot water (DHW) energy consumption. This study has been carried out in a case study located in Vitoria, in the region of the Basque Country, in northern Spain. The constructed stock of public social rental housing has been categorised and a representative building has been selected, where a representative number of its dwellings have been classified by socio-demographic profiles and analysed their patterns and differences in their behaviour related to energy consumption and hygrothermal comfort in the dwelling.

For the development of the study, the analysis focuses on the first 4-month period of 2020 and 2021 (during and after COVID-19 lockdown). The approach mainly consisted of data collection through surveys and interviews, observation, desk research, and long-term monitoring meters. The data collected via monitoring, where an innovative system was used for managing and recording temperature and consumption data in each of the dwellings, is certainly of interest. This system allows for a real-time visualisation for both the users and the managing administrator. This allows the user to make decisions based on the thermal comfort achieved, the energy consumption and the related expenditure. At the same time, it allows for the administration to provide energy assistance to the users, detecting their needs and generating adapted solutions. For this reason, this analysis takes into account the user's accessibility to their thermal comfort and consumption situation and focuses on the analysis on those socio-demographic profiles that may present more vulnerabilities.

To this end, in order to achieve the objective of this study, we have analysed the most relevant previous literature on thermal comfort, occupant behaviour and built environment and different methodologies for data collection. Then, a methodology has been proposed to select the most representative dwellings of the selected building stock based on a study of the construction and social profile. It is in these dwellings where the analysis of hygrothermal comfort, DHW and heating consumption and different patterns of use for each profile is carried out.

2. Literature Review

In order to carry out this study it has been necessary to evaluate the following three parameters, directly related to the objective of the paper: indoor hygrothermal comfort; occupant behaviour and the built environment; and methodologies for data collection.

2.1. Indoor Hygrothermal Comfort

To protect the population, various standards and guidelines have been developed to set or limit indoor environmental conditions to achieve thermal comfort for their users. This comfort does not only affect the well-being, health and performance of its users but is also reflected in the energy consumption of buildings.

There are different standards for analysing thermal comfort. The two most widely adopted methods are the Energy Balance Model or empirical method (ISO 7730:2005 [21]) based on studies with air-conditioned chambers; and the Adaptative Models such as the American Society of Heating and Air-Conditioning Engineers (ASHRAE [22]). For these standards, different hygrothermal comfort ranges are established based on the outdoor environment and the conditions in the study room. Considering this, in its widest range, ISO 7730:2005 recommends a range of 19–27 °C and 40–60% for relative humidity. In addition, ASHRAE 55-1992 recommends a range of 20–26 °C and 30–60% relative humidity. The six primary factors that affect thermal comfort according to Fanger [23] are air temperature, mean radiant temperature, air velocity, humidity, metabolic rate and clothing.

In addition, the WHO has different guidelines where it establishes hygrothermal comfort ranges. In its proposal for comfort temperatures (18–24°C) [24], it proposes a lower range than the previously mentioned models, as it considers the most vulnerable profiles and the energy impact that must be made to maintain it. Regarding its proposal for relative humidity ranges (30–50%) [25], it proposes stricter ranges than other standards, due to a health point of view, above which the risk of respiratory diseases increases, and the concentration of biological pollutants indoors also increases. For this reason, guidelines such as the one presented by the WHO [26], are not only aimed at guaranteeing comfort ranges for the most vulnerable groups, but also to establish rules for action in buildings to improve their energy efficiency, which leads to improvements in the health of their users and a reduction in energy consumption.

In the previous literature review carried out by Diaz Lozano Patino and Siegel [27], indoor environmental quality (IEQ) is analysed in social housing in 49 different articles. This included analysing thermal comfort, indoor pollutant concentration and health effects on occupants. It is concluded that social dwellings do have worse thermal comfort, both in terms of overheating and too low temperatures, and higher indoor pollution, which consequently has a greater negative impact on the health of their occupants.

When the indoor comfort temperature cannot be reached, it is associated with the concepts of energy vulnerability, but this possibility is also influenced by other concepts such as economic poverty, high energy costs and energy efficiency of housing and appliances [28] presenting a higher risk of cardiovascular problems, respiratory diseases or other minor illnesses such as colds, increasing seasonal mortality. According to the survey carried out by the EU in 2020, 8.2% of the EU population cannot afford to keep their homes at a sufficient heating temperature during the cold season, reaching 10.9% in Spain [29].

2.2. Occupant Behaviour and Built Environment

Occupant behaviour refers to presence, movement and interaction with the dwelling and its elements and appliances. Previous studies have shown that occupant behaviour plays a significant role on building's energy consumption [30,31]. It has been generally studied by monitoring and collecting occupancy data, and the development of behavioural models and their implementation in simulation tools [32].

Monitoring building occupancy allows acknowledging not only occupants' behaviour, but also occupants' requirement and attitude towards sustainability [33]. Guerra-Santin et al. [33] established an approach to inform the design by considering the complexity of occupants' behaviour. The results show the impact of activity levels, employment, and household composition on occupants' behaviour.

In a more recent study [34], the author presents an approach to achieve near-zero energy buildings that considers the influence of occupant behaviour on building performance to eliminate uncertainties related to energy savings. The results show that there are large differences in energy consumption between household types, and if not considered in the energy savings and payback calculations, these could contribute to the pre-bound effect of the building performance gap. In this sense, it is important to include the impact of people's behaviour in the analysis of building performance.

Simplified methods for measuring occupant behaviour increase the gap between simulation and reality [15]. It is important to understand people's behaviour combining qualitative and quantitative approaches based on data and models. Monitoring and data collection, the first steps of analysis, require a correct definition of the variables and indicators to be included in the study. Balvedi et al. [5] classifies the variables that influence occupants' behaviour and their interaction with the building into three main groups: environmental-related: physical aspect related to the building characteristics and location; time-related: occupants routine; and random. Building characteristics and users profile have previously been studied [35], as well as the relationship of building characteristics and occupants' behaviour [36].

The most analysed variables among the socio-economic characteristics are the number of people in the household, their age, income, level of education and employment status [32]. The number of people in the household has been found to be one of the main socio-demographic variables influencing energy consumption [37]. Another factor influencing energy consumption is the presence of certain vulnerable groups such as elderly people, children or dependent people who sometimes spend more time indoors [38]. Age and income have a significant relationship with energy consumption [39].

In this context, it is necessary to consider that in vulnerable sectors such as families living in social housing, energy consumption may be conditioned by the socio-economic situation they are in [40].

In this respect, the pandemic brought new challenges and, as has been found in previous literature, there was an impact on the relationship between occupants and their housing, with changes in behaviour and habits having a negative impact on some aspects such as mental health [17].

In addition, this change in housing behaviour was reflected in an increase in energy consumption and a change in usage patterns. Different studies [18–20] have analysed the increase in different consumptions: electricity, DHW, heating, and water. The results of the variation in consumption vary according to the study, some studies such as the one carried out by J. Rouleau and L. Gosselin in social housing in Canada have found that DHW and electricity consumption varied during the period of confinement while heating consumption was almost unchanged [20]. In the same study, the change in the timing of heating demand was also reflected, with peak demand shifting from late afternoon to midday. In contrast, in the study by Cvetković et al. [19] an increase in heating was found. In general, all those who have analysed the consumption of DHW and electricity have seen an increase in their consumption.

2.3. Methodologies for Data Collection

According to the study carried out by Laskari et al. [41], different methods can be used to assess IEQ. They can be classified as subjective (qualitative data) or objective (quantitative data).

Subjective methods are the simplest to apply, but often the most complex and limited, such as surveys, which provide a very broad knowledge and have the lowest cost [41]. In previous studies in social housings, where the perception of IEQ by the user was studied, it was found that thermal and acoustic comfort had the largest impact on perception [42], but also olfactory comfort [43].

At the same time, it is the method with the greatest limitations, due to its high involvement and difficulty in reaching a large number of respondents. In the case of residential buildings, where environmental and occupancy conditions vary greatly from one dwelling to another, it is difficult to find a period that can be considered representative [41]. This complexity in surveys is also reflected in the diversity of opinions on the same environmental conditions, which makes it difficult to analyse the results if only this method is used. In addition, the concept of survey fatigue has also been recognised [44]; this can occur when several surveys are demanded at specific times.

Alternatively, there are objective methods, where the results are obtained from quantifiable data and not from perceptions. The most commonly used in this group is monitoring, which measures those variables and indicators considered relevant for each study. For their use, the sensitivity of the sensors and the need for calibration must also be taken into account, which influences their high cost [44]. Depending on the different characteristics of the space to be monitored, the monitoring strategies proposed will be very different.

In general, short-term measurements are used to obtain thermal comfort results through surveys and thus being able to link them to environmental conditions, such as thermography and permeability of the study [45] or its relation between indoor temperature, socio-economic data and building characteristics [28]. Long-term measurements are essential when the objective of the monitoring is to determine the state of the building over a significant period (temperature (T), Relative Humidity (RH), CO_2 and energy consumption) [45].

Often, both objective and subjective methods are combined to achieve a better understanding, allowing for the generation of an occupant satisfaction index [44]. As seen in previous literature, beyond surveys and monitoring, other methods can be applied, such as interviews, reviewing characteristics and physical conditions of the buildings or having access to the energy consumption of the dwellings (electricity, heating, DHW, cooling . . .) [28,46]. At the same time, through information from other sources, it is possible to have a greater and more detailed knowledge of the building, for example, through plans, energy certificates or technical evaluations. From this point, it is possible to obtain more detailed information on the construction and thermal characteristics of the case study.

3. Materials and Methods

To achieve the objective of this study, an evaluation method attempting to assess residential buildings' performance concerning occupants' behaviour is proposed. To this end, the method is divided into 2 general sections (see Figure 1): Phase 1, associated with outdoor climate conditions, building properties and social profile, and Phase 2, which may determine the results, indoor hygrothermal comfort, energy consumption and occupant energy-use pattern.

3.1. Phase 1: Case Study Selection Criteria

Based on the defined objectives, the methodology was applied in a residential social housing building. However, as people's behaviours are associated with the dwelling and its characteristics, it was decided to focus the analysis on a specific number of dwellings in the building.

The selection of the case study and the sample was made based on the following indicators: outdoor climate conditions, building/housing properties and social profile.

3.1.1. Outdoor Climate Conditions

The atmospheric parameters have an important role in providing a thermally comfortable indoor environment [47,48]. The relation between the outdoor condition and the type of building influences directly thermal comfort. For this reason, it is one of the indicators that was considered to determine the location of the building.

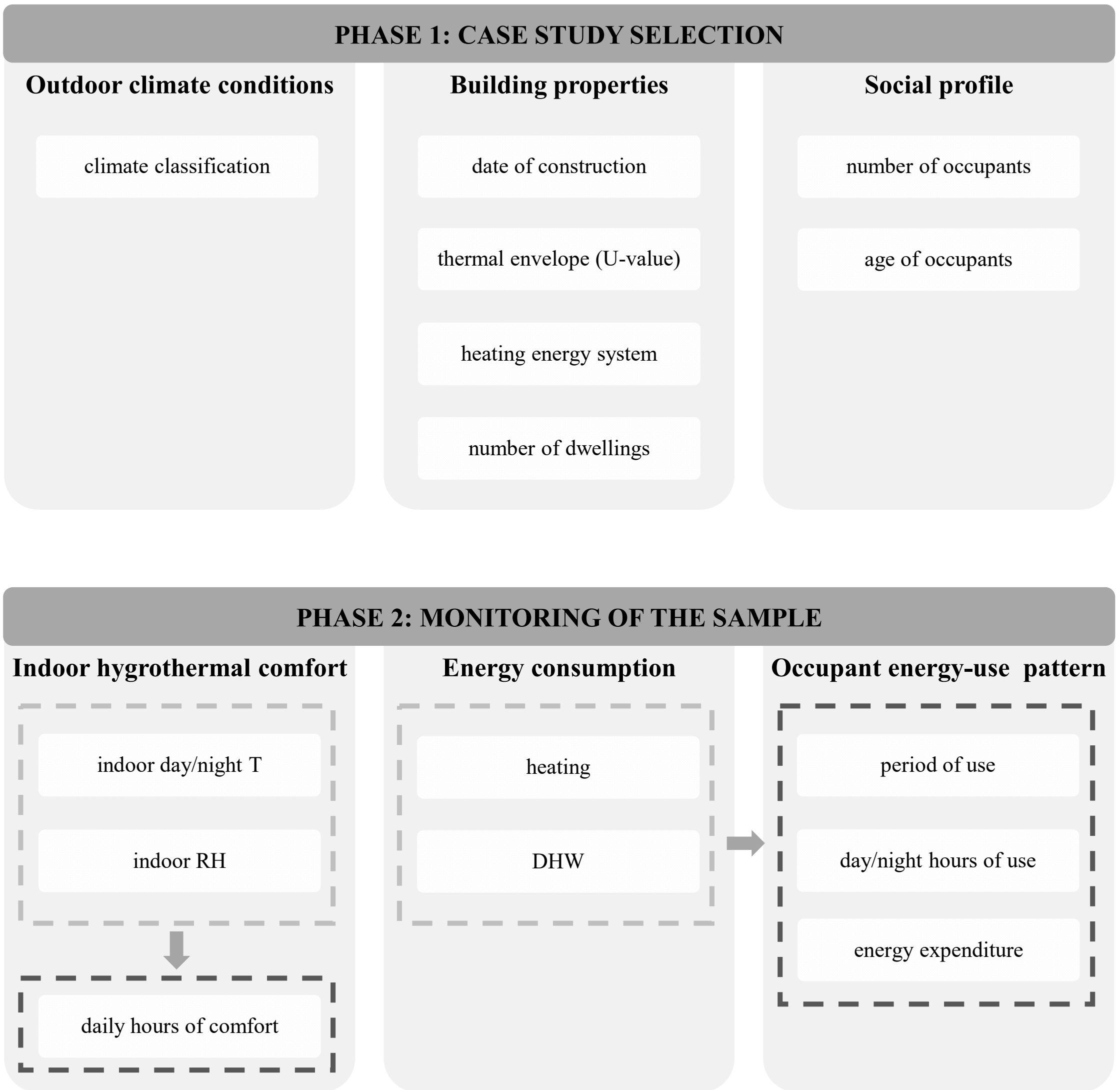

Figure 1. Method scheme.

There are different climate classifications. One of the most applied methodologies to classify the climate is Köppen's classification [49], which considers several variables regarding temperature and precipitation. This allows for a better comprehension of the main characteristics of the climate. In the case of Spain, for climate classification it is used the Technical Building Code (TBC) [50], which defines different climate zones identified by a letter, corresponding to the winter climate zone, and a number, corresponding to the summer climate zone.

3.1.2. Building and Housing Properties

The second aspect that was considered for the selection of the building under study is its construction profile. Databases such as EPISCOPE [51] reflect the need to define certain characteristics or parameters when describing the performance or properties of a building or dwelling [52]. The authors considered the following parameters of each building, which directly influence aspects such as the energy demand of each dwelling or the thermal comfort of the user:

- Date of construction: this defines the date of construction of the original building. In cases where the building had been energetically refurbished, the date of refurbishment was defined as "date of construction";

- Thermal performance of the building envelope elements (roof, floor, façade, and windows): although there are different databases or methodologies to calculate the thermal transmittance of the building envelope elements [53–57], based on the memory and the original plans of each building, during this study the real thermal transmittance of each envelope element was defined by the previous project reports;
- Performance and energy source of the energy generation system for heating, cooling and domestic hot water: based on the date of construction and building typology, databases such as TABULA [52] provide similar information. In this study, this information was based on the information obtained from the project reports and visits to each of the case studies;
- Number of dwellings in the building: to consider whether the building is significant within the analysed building stock, the size of the building, measured in number of dwellings in the building was taken into account.

Finally, it should be noted that, although its influence may be critical, especially in low-rise buildings or in dwellings located on the first floors [22], the influence of shadows cast by the building or adjacent elements were not considered during this methodology.

3.1.3. Social Profile

The role of the residents in the building performance is widely recognised by several authors [5,31,58]. That is why, as we have explained above, the analysis focuses on occupant behaviour, which is directly related to the dwelling and its immediate environment. In this sense, the dwellings of the sample were selected based on the social characteristics of the residents and family types.

In recent years, the study of the definition of behavioural profiles and the use of housing for energy saving and the reduction in the environmental impact generated by the residential sector has increased. There are three main approaches in the definition of household profiles: household profiles by household characteristics (socio-demographic and socio-economic) [59], energy use or behavioural profiles of residents [36,60], and variables on needs, values, and attitudes [40,61].

Guerra-Santín [62] identifies occupant behaviour profiles based on the characteristics, needs and lifestyles of the residents. The author uses the number of people in the household and their age to define the household profile [63].

For the application of the methodology, the authors selected a representative number of dwellings which were also representative of the family social profiles. The influence of the residents on the building performance was analysed. The dwellings were selected based on the occupants' social profiles. For this selection, the research carried out by Guerra-Santin et al. [62] was taken into account and transferred to an official state source such as the classification defined by the INE in the Household Budget Survey [64]. This classification is based on the number of people living in the dwelling and their age.

3.1.4. Case Study Selection

The abovementioned methodology was applied to the social-rented housing stock located in the Autonomous Community of the Basque Country, a region situated in Northern Spain.

Basque Government's social-rented housing stock has more than 7700 dwellings in 234 buildings which are located in the 3 provinces of the Autonomous Community.

The housing stock can be classified considering different variables: the year of construction, the climatic classification of its location, the number of dwellings in the building, number of stories, thermal performance of the building such as thermal transmittances and window properties and the type of DHW and heating generation. Most of these data on Alokabide's building stock can be seen in summary form in Appendix A. These data have been obtained through the diagnosis developed by the Local Public Company Alokabide under the name "Plan Zero Plana" [65].

As regarded the construction period, it is concluded that it is a young residential park; almost all buildings have been built after the first Spanish Building Regulations NBE-CT 79 [66]. Considering the stock under study, almost 64% and 70.5% of the buildings and dwellings, respectively, belong to the 2002–2011 construction period, followed by those built after 2011.

Providing the size of buildings, based on the number of dwellings they have, it can be said that the majority (56.62%) are large buildings, that is, with more than 40 dwellings. Hence, 83.25% of the dwellings are located in these buildings.

As mentioned above, Alokabide's housing stock is located in the three provinces of the Autonomous Community of the Basque Country. Considering the climatic classification of the Spanish TBC [50], 60.29% of the buildings and 70.55% of the dwellings are located in climate D, followed by 36.03% and 28.43%, respectively, located in climate C. As for the classification according to Köppen [49], the vast majority of the Basque Autonomous Community is classified as Cfb, temperate without dry season with temperate summer, except for some specific areas in the south of the community which is classified as Csb: temperate with dry and temperate summer.

The energy system used for heating and DHW production (individual or centralised system) is almost evenly divided when considering buildings, with values of 47.79% and 52.21%, respectively. However, this equality is not reflected in the number of dwellings supplied by each of the systems; the centralised system supplies almost 63% of the dwellings, while the individual system supplies 37% of the dwellings. The type of energy could be considered almost unique, with natural gas being the most widely used, in 93.38% of the buildings and 95.45% of the dwellings.

Based on the diagnosis of the 136 residential buildings in "Plan Zero Plana" of the Basque social-rented housing stock, the method was performed on a representative building. The building location, construction properties, social classification and occupant-based control is summarised in Table 1.

The socio-economic and socio-demographic data for the case study were obtained through surveys carried out in 2021 as part of the Basque Government's E-Lagun project for the energy management of social housing in the Basque Country [67].

A sample of 15 dwellings was selected for the analysis of the indicators. These dwellings correspond to 3 social profiles found in the INE classification in the Household Budget Survey [64]: couple with 3 or more children (P1, 5 dwellings), single adult with children (P2, 5 dwellings), single person (P3, 5 dwellings). The results are shown as the average for each profile, so that differences and patterns can be detected in each profile. Data protection and anonymity associated with each household is also ensured. All of the information is considered confidential; all of the personal values and any possible identification of the dwelling has been excluded. Figure 2 shows the floor plan of the building under study. The 15 dwellings present the same typology, oriented North-South.

Table 1. Case study buildings summary.

Outdoor Climate Condition	
Location	Vitoria-Gasteiz
Köppen-Geiger climatic zone	Cfb
Local climatic zone (TBC)	D
Building properties	
Year of construction	2010
No. stories	Ground + 8
No. dwellings	126
Façade (1) transmittance (W/m^2 K)	0.31
Façade (2) transmittance (W/m^2 K)	0.33
Roof transmittance (W/m^2 K)	0.34
Floor transmittance (W/m^2 K)	0.54
Frame	Aluminium
Glazing	Double, 4 + 8 + 5 mm
Window transmittance (W/m^2 K)	3.3
Heating/DHW energy system	Centralized
Heating/DHW energy class	Natural Gas
Ventilation	Natural
Social profile	
No. single person (≥65 years) dwellings	1
No. single person (<65 years) dwellings	6
No. couple dwellings	4
No. couple with a child dwellings	9
No. couple with 2 children dwellings	7
No. couple with three or more children dwellings	7
No. single adult with children dwellings	10
No. other dwellings	1
Unknown	81
Occupant-based climate control	
Control system	AuGe

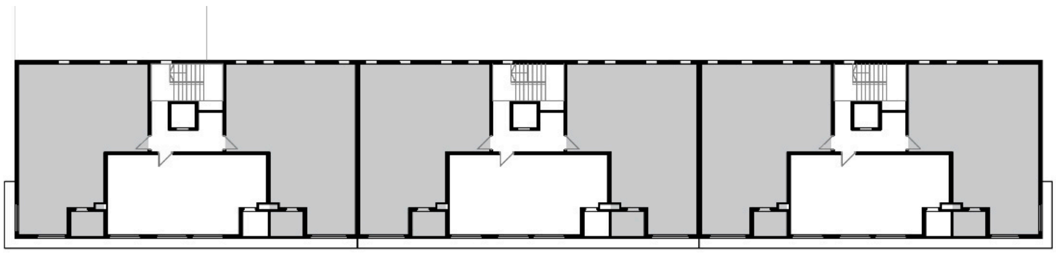

Figure 2. Floor plan of the case study.

3.2. Phase 2: Monitoring of the Sample

The analysis focuses on the first 4-month period of 2 consecutive years: 2020 and 2021. Within the first period, the interval from March to April 2020 is strongly influenced by the lock-down caused by COVID-19 (Spanish dates). The COVID-19 and the lock-down have highlighted the existing problems and the needs that housing does not solve, in particular the capacity that each household had to achieve comfort [68] as well as an increment in the energy consumption in the households [18].

In terms of data collection methods, the most commonly used method is monitoring. In general, there are short-term and long-term monitoring methods. Short-term monitoring is generally used to support surveys to verify the environmental conditions under study, while long-term monitoring is used to determine the state of a building over a long period.

The method was performed in a building with a long-term monitoring (energy consumption for heating and DHW, indoor temperature and relative humidity) and energy self-management AuGe system carried out by STECHome within the AUGE project [69]. This energy self-management system is aimed at controlling and measuring occupants' interaction with the building for achieving energy savings combined with the social purpose of reducing inequalities and fuel poverty situations. It provides real-time information on the dwelling performance, temperature, and relative humidity. Both the users and the building managers have a free web platform from which all the variables and situations of the tenants and the system are managed.

This study used a long-term monitoring already carried out on the study sample. From this monitoring, the hourly data collected on the selected dates was chosen.

The technical equipment used includes, among others, temperature and humidity sensors located in the living rooms of the dwellings, actuators on shut-off valves, consumption data control units (heating, DHW) and Wi-Fi connections. Additionally, tablets or mobile apps, are included for user/occupant access, which is linked to banking gateways and an online viewing platform.

The sensors used for temperature and relative humidity are the model RFM-AMB, of the Bmeters manufacturer [70] with a typical accuracy of ±0.4 °C and ±3%, respectively.

Heating and DHW consumption were measured with the Sontex Superstatic 789 [71]. This model measures the flow rate in individual heat exchanger tubes with a measurement accuracy of ±0.0005 m^3/h.

Regarding the communication system, it was deployed a gateway C300 and a series of R300 repeaters of Usanca manufacturer to establish the Wireless M-Bus communication protocol inside the building. The result is that the heating system can be remotely controlled and self-managed by the users and the public administration. Both of them can check total energy consumption.

3.2.1. Indoor Hygrothermal Comfort

For the assessment of indoor hygrothermal comfort in dwellings, there are different standards and guidelines. They can be grouped into those based on energy balance methods or adaptive models. All of them have established criteria for limiting thermal comfort to certain temperature ranges. These ranges are based on the influence of different variables on the user's thermal perception, including airspeed, radiant temperature, metabolic activity, and clothing. For this study, the WHO recommendations were followed, which take into account the conditions in the most vulnerable dwellings and establishes an indoor temperature limit of 18 °C in the dwelling during the winter, and 24 °C during the summer [24], with a relative humidity range between 30% and 50% [25]. These WHO recommendations have been chosen because they consider health aspects and the energy impact of achieving the different comfort conditions. In addition, the proposed comfort temperature range is lower than that proposed by other standards.

The monitored data are dwellings temperature (°C) and the Relative Humidity (%). Through this data collection, the number and percentage of hours in which hygrothermal comfort conditions are maintained inside the dwelling were analysed according to each social profile that inhabits it.

3.2.2. Energy Consumption: Heating and DHW

Energy consumption in buildings is conditioned by the socio-demographic, socio-economic and lifestyle characteristics of the residents [36,59,60], and can therefore considerably vary between different types of households. During this work, the information on the energy consumption of heating (kWh), and domestic hot water (m^3) was based on the information obtained through the monitoring systems installed in each case study.

3.2.3. Occupant Energy-Use Pattern

The International Energy Agency has identified people's behaviour as one of the main drivers of energy use in buildings [72]. However, the preferences, needs and behaviours of residents are not constant. In this sense, behavioural profiles may vary over the lifetime of the building according to different factors [73]. This identification of the impact of user behaviour on the energy efficiency of buildings has been studied in different European projects such as COMPASS [11] and MOBISTYLE [10]. To this end, to find patterns of behaviour of each profile during the period analysed, this study analysed the monitored data of energy consumption throughout the day, differentiating between the hours of the day or night that are consumed, as well as their frequency and level of consumption. Heating and DHW expenditures were also considered according to data used by the public administration [69], allowing us to compare both consumptions in equal units to establish a pattern of which represents the highest expenditure for each profile.

4. Results

To provide a comprehensive overview of the results, this section is divided into three sub-sections according to the study analysis that is indoor hygrothermal comfort, energy consumption and occupant energy-use pattern, which facilitate the assessment of the influence of the variables considered and generates a discussion on their relationship.

Additionally, as explained in the previous section, the results obtained are shown according to the dwelling division based on the three social profiles (dwelling level).

4.1. Indoor Hygrothermal Comfort

In this study, the periods between January and April 2020 and 2021 have been analysed. This period corresponds to the period during and after the COVID-19 lock-down period, according to the dates of Spanish lock-down. The analysis allows to detect changes in behaviour between periods and social profiles.

The hygrothermal comfort was analysed based on the monitoring data of temperature (°C) and relative humidity (%) of the dwellings under study. The results were classified into 2 temperature and relative humidity ranges to determine the hygrothermal comfort [24,25]: comfort (18 °C < T + 30 < RH < 50) or discomfort (T < 18 °C; T > 24 °C + RH < 30%; RH > 50%).

These ranges make it possible to determine the number of hours per month that households are in a situation of comfort or discomfort.

The analysed profiles present different situations in terms of temperature and relative humidity. While P1 is the profile with the lowest average temperatures in 2020, in 2021 it is P3 that has the lowest average temperature. However, P1 is the profile with the lowest measured temperature of 11.2 °C in January 2020, as shown in Figure 3.

A similar situation occurs in the case of relative humidity. P1 has a higher average relative humidity in 2020, while in 2021 it is P3 that has a higher average relative humidity. The maximum relative humidity values for each profile are 71.5% in 2020 and 71.1% in 2021, respectively.

These results show a change in the use of the dwelling that can be influenced by different factors: ventilation periods, time spent by the residents in the dwelling, etc. These factors may be a consequence of the socio-economic situation of the household, as well as the increase in periods inside the dwellings caused by COVID-19.

Figure 3 shows a trend change in housing temperature between 2020 and 2021. Considering that the case studies are social rented dwellings, there may have been changes in residents between one year and the next, leading to a variation in the temperature trend. However, there is no data to confirm the change in the number of people living in the dwellings analysed. Another factor that has influenced the results is the outdoor climatic conditions. Table 2 shows that the months in 2020 were warmer than in 2021. For the four months analysed, the average temperature in 2021 was almost 1 °C lower than in 2020. In particular, the average temperature in April 2020 was 12.35 °C compared to 9.78 °C in 2021.

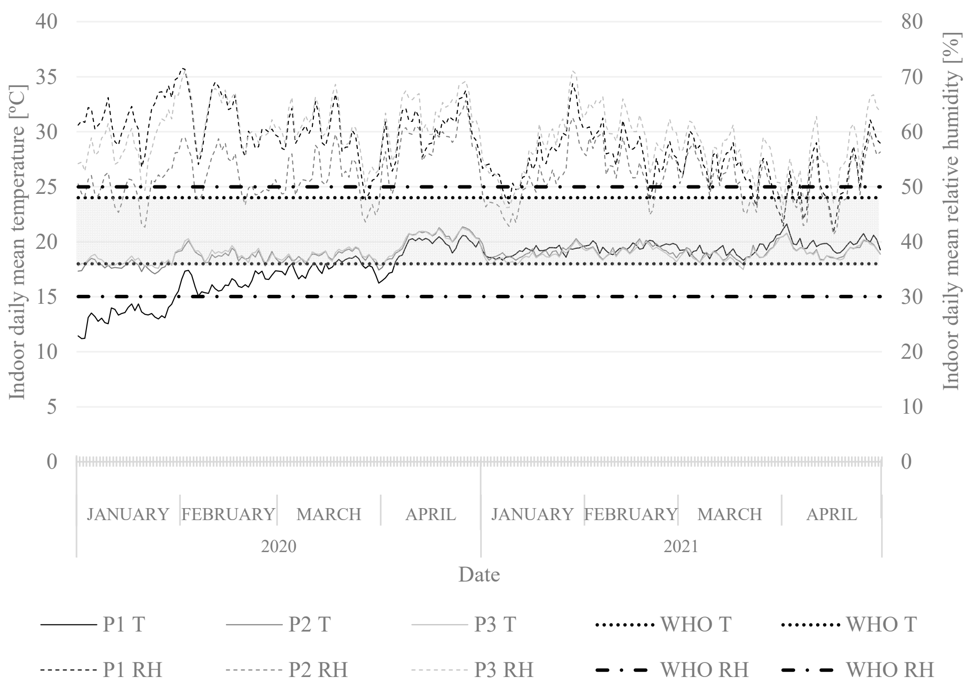

Figure 3. Indoor daily mean temperatures per household type.

Table 2. Hygrothermal comfort monthly hours per household type.

Year	Month	% Comfort			Outdoor Mean Temperature (°C)	Outdoor Mean Relative Humidity (%)
		P1	P2	P3		
2020	January	7%	26%	14%	5.92	98
	February	5%	22%	5%	9.19	98
	March	14%	24%	6%	8.48	98,1
	April	7%	5%	2%	12.35	81,9
2021	January	17%	31%	1%	5.13	78.09
	February	16%	17%	1%	9.78	71.66
	March	27%	25%	4%	7.64	72.89
	April	33%	35%	9%	9.78	67.95

Comfort level 18 °C ≤ T ≤ 24 °C and 30% ≤ RH ≤ 50%.

Table 2 shows the percentage of hours in each month that are in hygrothermal comfort for each profile analysed. The results show that for the 2 years analysed, P3 is the profile with the highest percentage of hours in hygrothermal discomfort, whereas the month with the highest discomfort was January 2021, with 1% of the hours in a comfortable situation. Based on Figure 3, it can be concluded that the least comfort in this profile is due to the relative humidity values in the dwelling being above 50% (6% of the days analysed for P3). After analysing the hygrothermal comfort according to ISO 7730 [21], where the recommended level of indoor humidity is range of 40–60%, the days in comfort increase from 17%, 26% and 5% to 40%, 67% and 19%, respectively, for P1, P2 and P3.

In March and April 2020, the period of lockdowns in Spain due to COVID-19, the 3 profiles show a lower comfort situation compared to 2021. In this period, temperature and relative humidity are in the comfort thresholds 10% of the days. In March and April 2021, this increases to 24%.

4.2. Energy Consumption: Heating and DHW

Regarding the energy consumption of the selected dwellings, two different consumptions have been considered, heating and DHW. To analyse consumption according to each profile, the authors compared the average daily heating and DHW consumption data for each profile (kWh/day and m^3/day, respectively) and the number of days on which heating and DHW were activated in the period analysed. This has allowed us to analyse how much is being consumed.

By analysing heating consumption, as can be seen in Figure 4, for heating activation days, we can see a large difference in the 3 profiles between consumption in 2020 and 2021, with a much higher consumption level in 2021. These values evolve in line with those previously reflected in Table 2, the percentage of days in comfort, with a lower comfort in 2020 than in 2021. Comparing between profiles, in 2020, P1 has activated the heating the least number of days during the coldest months and P3 has activated it the most, with P2 obtaining very similar values. In contrast, in 2021 the 3 profiles have a very similar number of heating activation days.

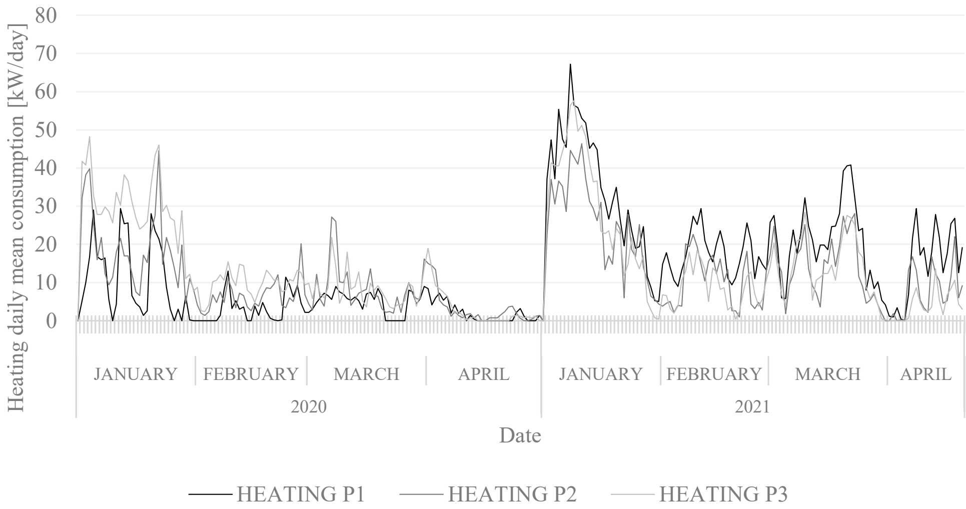

Figure 4. Heating daily mean consumption per household type.

By analysing how much has been consumed, as can be seen in Figure 4, we can see that there is a large difference in consumption between 2020 and 2021, especially in P1, which goes from minimum consumption (638.2 kW) to maximum (2466.2 kW), while in P3 dwellings consumption remains similar (1511.8 kW to 1619.9 kW). In 2020, P3 registers the maximum value of 48.2 kW consumed in a day, while in 2021 it is P1 that exceeds this value with 67.2 kW consumed in a day.

One limitation of this heating consumption study is the possibility that users may have other heating sources other than those monitored, such as an electric heater, which are not reflected in the monitored values. This increase in heating consumption is also a consequence of the difference in outdoor temperatures year to year. As shown in Figure 4, the heating increases are in line with the lower average temperature in 2021 compared to 2020 shown in Table 2.

In terms of DHW consumption, see Figure 5, there is a difference between profiles when comparing the number of days that DHW is used, with P2 being those dwellings with the lowest number of days that DHW is activated both in 2020 and 2021. In addition, P3 has activated the DHW on the greatest number of days.

Analysing how much DHW was consumed on average by each profile, P2 is the profile that consumed the least in both 2020 (6.7 m^3) and 2021 (9.1 m^3), with a slight increase in consumption from one year to the next. In 2020, P3 had the highest average daily consumption (20.7 m^3), above P1 (15.4 m^3), while P3 had the highest daily consumption of 0.3 m^3. In 2021, consumption between P1 and P3 was similar, with P1 even higher than P3 (17.6 m^3 and 16.5 m^3, respectively), with P1 recording a maximum of 0.4 m^3 in one day.

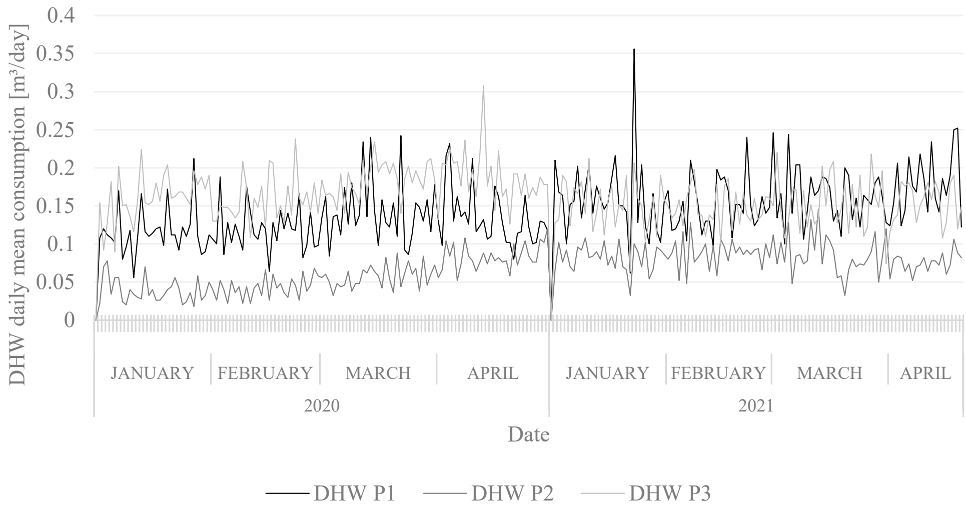

Figure 5. Domestic Hot Water daily mean consumption per household type.

4.3. Occupant Energy-Use Pattern

Consumption profiles depend on the occupants' characteristics. The profiles analysed show disparate behaviour, mainly in the morning (7 am–1 pm) and night (10 pm–7 pm) periods, as can be seen in Figure 6. In the night period, P1 has the highest heating consumption, while in the morning period, P3 has the highest consumption. This consumption can be mainly linked to the hours of use of the dwelling and the age of the occupants.

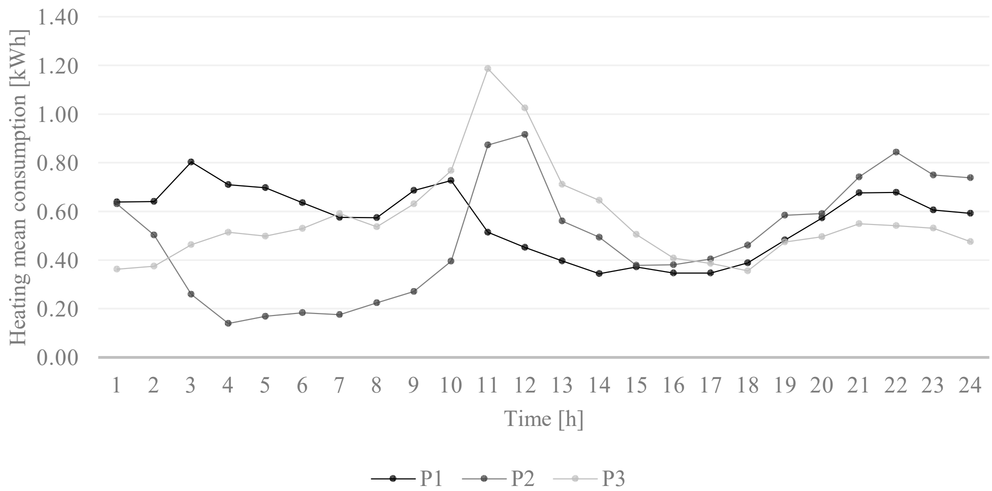

Figure 6. Domestic Heating mean consumption of the monitored period per household type.

It should be noted that households with children have higher consumption in the night period. However, the profiles of 2 adults and 1 adult activate the heating a greater number of hours per month in 2020, as shown in Table 3. In the year 2021, this trend slightly varies, with an increase in hours of activation of P1. This variation corresponds to that observed in hygrothermal comfort, which may be a consequence of a change in the socio-economic or socio-demographic conditions of the samples analysed in P1.

Table 4 shows the theoretical cost data for heating and DHW based on the monitored consumption data and the natural gas price per kWh and m^3. The natural gas price per kWh has been obtained from the official Eurostat database [74], while the natural gas price per m^3 has been provided by the building management company.

Table 3. Heating activation daily periods per household type.

Year	Month	Period	Number of Days			% Monthly		
			P1	P2	P3	P1	P2	P3
2020	January	<3 h/day	6	0	0	21%	0%	0%
		6 a 3 h/day	3	0	0	10%	0%	0%
		>6 h/day	20	31	31	69%	100%	100%
	February	<3 h/day	13	1	0	59%	4%	0%
		6 a 3 h/day	3	6	1	14%	23%	4%
		>6 h/day	6	19	26	27%	73%	96%
	March	<3 h/day	8	0	0	28%	0%	0%
		6 a 3 h/day	0	6	0	0%	24%	0%
		>6 h/day	21	19	31	72%	76%	100%
	April	<3 h/day	20	20	20	77%	83%	74%
		6 a 3 h/day	2	1	1	8%	4%	4%
		>6 h/day	4	3	6	15%	13%	22%
2021	January	<3 h/day	0	0	1	0%	0%	3%
		6 a 3 h/day	1	3	0	3%	10%	0%
		>6 h/day	30	27	29	97%	90%	97%
	February	<3 h/day	0	3	1	0%	11%	4%
		6 a 3 h/day	0	7	1	0%	26%	4%
		>6 h/day	28	17	25	100%	63%	93%
	March	<3 h/day	0	2	3	0%	7%	10%
		6 a 3 h/day	1	1	1	3%	3%	3%
		>6 h/day	30	27	27	97%	90%	87%
	April	<3 h/day	12	14	15	41%	50%	52%
		6 a 3 h/day	1	1	3	3%	4%	10%
		>6 h/day	16	13	11	55%	46%	38%

Table 4. Energy consumption expenditure per household type.

Year	Month	Heating			DHW		
		P1	P2	P3	P1	P2	P3
2020	January	23.79€	40.19€	64.49€	17.40€	5.82€	24.34€
	February	6.89€	13.28€	20.36€	17.21€	6.15€	22.71€
	March	11.52€	18.97€	19.03€	22.25€	8.85€	28.51€
	April	3.79€	5.40€	4.67€	20.08€	12.49€	28.18€
2021	January	71.75€	51.41€	59.19€	23.99€	12.30€	22.73€
	February	34.32€	20.12€	17.05€	21.00€	12.26€	20.69€
	March	42.97€	28.23€	29.31€	25.39€	13.30€	23.79€
	April	20.72€	10.86€	5.78€	17.78€	7.51€	15.49€

It can be observed that the DHW expenditure of P2 is significantly lower compared to the rest of the profiles, specifically 42% lower compared to Profile 3.

It is worth noting that in 2020, P1 has higher DHW costs than heating costs, including the month of January. In February 2020, P1 has a monthly DHW expenditure of 71%, compared to the rest of the profiles with 32% and 53%, respectively.

While in 2020, P3, consisting of a single person, has the highest expenditure on heating and DHW, in 2021 it is P1, consisting of a couple with 3 or more children, that has the highest expenditure. In the 2 years studied, the P2 of an adult with children has the lowest expenditure on both heating and DHW, up to 60% less than the total expenditure.

These expenditure trends are directly linked to the habits of the residents, as well as to their needs and socio-economic situation. It may be conditioned by the use of other appliances to heat the dwelling or the lower use of DHW as a consequence of using other installations outside the dwelling.

5. Discussion

This study sought to analyse the influence of the socio-demographic characteristics of social housing households in relation to the hygrothermal comfort of their dwellings, occupants' behaviour and heating and domestic hot water energy consumption.

The research has been carried out in a building in Vitoria that is representative of the social rental housing stock in the Basque Country, in the north of Spain. This dwelling was selected according to construction criteria. From it, following socio-demographic criteria, under the same classification presented by the INE, three profiles have been selected that may present greater vulnerability: couple with three or more children (P1), single adult with children (P2) and single adult (P3), five dwellings have been selected for each of these profiles. In total, this analysis was carried out in fifteen dwellings, monitoring data on temperature, relative humidity, domestic hot water consumption and heating.

The temperature and relative humidity data were used to calculate the number of hours of comfort for the three profiles under study. Furthermore, the heating and domestic hot water consumption, contrasted with the energy price, has provided the energy costs and consumption trend throughout the day for the different households. As the case studies are social rented housing, it has been assumed for the analysis that there has not been a change in tenants in the period under analysis.

The current study found that there is a difference between profiles in terms of hygrothermal comfort levels and heating and DHW consumption. During the year 2020, P1 was the profile that consumed the least heating and DHW and therefore the one that achieved the least comfort on average in the dwelling. While the comfort values of P3 were very similar. Whereas during the second year analysed, the average consumptions of the three profiles are very similar, but it is P3 that records the highest values of hygrothermal discomfort. As well, in all three profiles the energy consumption in 2021 was greater than in 2020, during COVID-19 lock-down period, when the occupancy was almost permanent in the household not only did they consumed less heating and DHW, hygrothermal comfort was less achieved than the following year. This increase in consumption has been influenced by the variation in outdoor temperature between the two study years, being lower in the year 2021.

These values allow to establish a first approximation of the influence that different profiles have in achieving hygrothermal comfort in the dwelling. By understanding how consumption occurs and what the patterns of each profile are, there are differences between the consumption hours and the peaks found in each profile. While P2 and P3 maintain longer hours of consumption, P1 has more consumption peaks. Especially in 2021, as in 2020 P1 consumed much less compared to the other profiles.

The current study has validated the influence of different household profiles living in social housing on energy consumption and hygrothermal comfort in the dwelling, in particular, in social rental housing where the social profile of the residents may present a greater socio-economic and energy vulnerability. The discrepancies detected between hygrothermal comfort and energy consumption show the impact of people on the use of the dwelling and its facilities, in particular on the possibility of using other types of appliances to heat the dwelling or other sanitary facilities. It was also detected that consumption hours are linked to social profiles and to the existence of minors in the home.

It has been observed that through the data collection system used it is possible to define occupancy and heating patterns that allow a personalised solutions to be given to users. Previous studies evaluating the differences in energy performance in dwellings of 5 different social groups observed a clear relationship has also been established between the behaviour of the occupants and the profiles analysed [36]. Other studies have not only found differences between the profiles analysed, but also the influence of construction characteristics and the country where the study was carried out [33].

This combination of findings verifies the advantage of using the self-management system to ensure an energy support by the public administration, in order to detect the needs and ensure the well-being of the residents. With the long-term monitoring, was obtained real data that could be contrasted with the social data provided by the administration.

In this study, several limitations influenced the results. Firstly, since these real data are from a specific case and each occupant must be considered unique, even within the same profile, there are different behaviours for each person living so extrapolating it to other studies or applications must be taken into account. [33]. Nevertheless, the methodology used is applicable to other case studies, taking into account the singularity of each dwelling.

Secondly, as these are case studies of rented dwellings, there may have been periods of non-occupancy or changes in tenant, although in all the considered data there is a consumption of heating and/or DHW that allow to deduce that there is occupancy in the dwelling. This possible vacancy or change in tenant could not be verified, so the results consider the same tenants for the entire period analysed. This limitation is also reflected in Table 1, which shows the lack of knowledge of which social profile inhabits 81 of the 126 dwellings that make up the building under study. It was also not possible to determine the real occupancy, as well as the ventilation habits, the use of other heating elements or the use of other facilities outside the dwelling.

Thirdly, the behaviour of each dwelling was found to have a strong influence on the behaviour of the profile. This is because the study has been carried out by profiles, calculated through the average of the five dwellings that make up each profile.. Some dwellings have been found to have a different behaviour to others, such as very low temperatures or almost zero heating consumption, that have influenced the final result of the profile.

This study was limited by the influence of relative humidity for the comfort model chosen. As has been shown in the results section, when the relative humidity increased to 60%, the discomfort in most of the dwellings greatly varied. Using other more accurate methods such as adaptive methods, which take into account the outside temperature [22], or other methods that also take into account the frequency and occupancy of the dwellings [75] should be considered.

Nevertheless, the methodology used is applicable to other case studies, taking into account the singularity of each dwelling. Finally, based on the findings in this research, it would be interesting for future research to analyse the impact during the warm periods of the year. On the other hand, including other factors into the analysis of comfort, such as CO_2, VOCs, PM, lighting and noise, may provide relevant information, as well as the analysis of other socio-demographic profiles where economic aspects are included.

6. Conclusions

The aim of the present study was to compare the levels of comfort and consumption for fifteen social rented dwellings of three different social profiles in the same building. This building is part of the public social rental housing stock of the Basque Country, in the north of Spain, located in Vitoria and managed by Alokabide. The period analysed was the first four months of the years 2021 and 2020, including the period of confinement. In this study, hygrothermal comfort, operating temperature, and relative humidity, and DHW and heating consumption were compared by social profile, establishing different patterns and use for each profile.

This study has identified that there is a difference between the three profiles in all the aspects analysed. The profile of single adults with children is the one that achieves the greatest comfort in the two periods analysed, whereas the single adult profile is the least comfortable. These values evolve in line with those reflected in heating consumption. Similarly, heating consumption increased from 2020 to 2021 for all of the profiles. Therefore, it can be concluded that the analysis of heating and DHW consumption is influenced by the social profile that lives in the dwelling, not only in total consumption but also in how their consumption differs between them throughout the day.

This allows us to predict consumption patterns for future tenants of the dwellings. In this sense, the authors have validated the influence of the socio-demographic characteristics of social housing households in relation to the hygrothermal comfort of their dwellings, occupants' behaviour and heating and domestic hot water (DHW) energy consumption.

Moreover, we have verified the advantage of using the self-management system that allows the user to make decisions based on the thermal comfort, energy consumption and the related expenditure. At the same time, it allows the administration to provide energy assistance to the users, detecting their needs and generating adapted solutions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Number of buildings and dwellings per construction period.

Construction Period	N° of Buildings	Percentage	N° of Dwellings	Percentage
Before 1900	1	0.74	4	0.05
1900–1920	1	0.74	8	0.11
1921–1930	0	0.00	0	0.00
1931–1940	0	0.00	0	0.00
1941–1950	0	0.00	0	0.00
1951–1960	0	0.00	0	0.00
1961–1970	1	0.74	8	0.11
1971–1980	0	0.00	0	0.00
1981–1990	1	0.74	24	0.32
1991–2001	12	8.82	390	5.26
2002–2011	87	63.97	5222	70.49
After 2011	33	24.26	1752	23.65

Table A2. Number of buildings and dwellings per size of building.

Size (n° of Dwellings)	N° of Buildings	Percentage	N° of Dwellings	Percentage
1	0	0.00	0	0.00
2	0	0.00	0	0.00
3 to 10	5	3.68	34	0.46
11 to 20	21	15.44	311	4.20
21 to 40	33	24.26	896	12.10
More than 40	77	56.62	6167	83.25

Table A3. Number of buildings and dwellings per climatic zone.

Local Climatic Zone	N° of Buildings	Percentage	N° of Dwellings	Percentage
C	49	36.03	2106	28.43
D	82	60.29	5226	70.55
E	5	3.68	76	1.03

Table A4. Number of buildings and dwellings per EPC grade.

EPC Grade (kWh/m^2 Year)	N° of Buildings	Percentage	N° of Dwellings	Percentage
A (<37.50)	5	3.68	365	4.93
B (37.50–57.70)	17	12.50	854	11.53
C (57.70–86.10)	15	11.03	974	13.15
D (86.10–128.20)	51	37.50	3208	43.30
E (128.20–271.90)	44	32.35	1959	26.44
F (271.90–318.10)	3	2.21	35	0.47
G (≥318.10)	1	0.74	13	0.18

Table A5. Number of buildings and dwellings per EPC energy system.

Energy System	N° of Buildings	Percentage	N° of Dwellings	Percentage
Individual	65	47.79	2746	37.07
Centralized	71	52.21	4662	62.93

Table A6. Number of buildings and dwellings per EPC energy class.

Energy Class	N° of Buildings	Percentage	N° of Dwellings	Percentage
Natural Gas	127	93.38	7071	95.45
LPG	1	0.74	15	0.20
Electricity	8	5.88	322	4.35

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