05-010

STUDY OF THE CONSUMPTION AND THERMAL COMFORT OF HOUSEHOLDS AFFECTED BY ENERGY POVERTY

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As part of the EmpowerMed project, this work has been carried out in parallel to the collective assemblies organized in Barcelona by the Alliance Against Energy Poverty (APE), where the participants are offered the possibility of performing a study on the comfort and electricity consumption of their homes. Based on this data, a comparison has been made between the volunteers linked to the APE, the group affected by energy poverty, and other dwellings that represent the non-affected group. The characterization of the groups reveals a great gender inequality among the affected ones and shows the existing imbalance between the two groups in terms of educational and economic levels. In addition, the poor energy efficiency of the buildings leads to discomfort that affects both groups and has a negative impact on energy consumption, worsening the situation of those affected. The imposition of the new electricity tariff 2.0 TD has aggravated the circumstances as it implies a worrying increase in electricity bills. Finally, it has been shown that poverty levels can vary greatly depending on the energy poverty indicator studied.

Keywords: energy poverty; smart meters; thermal comfort; indoor air quality

ESTUDIO DEL CONSUMO Y CONFORT TÉRMICO DE HOGARES AFECTADOS POR POBREZA ENERGÉTICA

Integrado dentro del proyecto EmpowerMed, este trabajo se ha desarrollado en paralelo a los asesoramientos colectivos organizados en Barcelona por la Alianza Contra la Pobreza Energética (APE) donde se ofrece a los asistentes la posibilidad de realizar un estudio sobre el confort y el consumo eléctrico de las viviendas. En base a estos datos se ha realizado una comparativa entre las personas voluntarias vinculadas a la APE, grupo afectado por pobreza energética, y otras viviendas que representan el grupo no afectado. La caracterización de los grupos pone de manifiesto una gran desigualdad de género entre las afectadas y muestra el desequilibrio existente entre ambos grupos en términos educativos y económicos. A su vez, la escasa eficiencia energética de los edificios conlleva la presencia de numerosos motivos de desconfort que afectan a ambos colectivos e impactan de manera negativa en el consumo energético empeorando la situación de las personas afectadas y agravándose debido a la imposición de la nueva tarifa eléctrica 2.0 TD que implica un preocupante aumento en el gasto eléctrico. Por último, se ha evidenciado que los niveles de pobreza pueden variar mucho en función del indicador de pobreza energética estudiado.

Palabras clave: Pobreza energética; contadores inteligentes; confort térmico; calidad del aire interior

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1. Introduction

The term Energy Poverty (EP) was first used in 1970s in England due to the disparity between the income and costs associated with household energy expenditure. Five decades later, EP is still a reality in today's society and new forms of energy vulnerability are still being discovered (Martiskainen et al. 2021; Wang et al. 2022), which is why the true magnitude of the problem remains unknown. This situation is worsened by gender inequality, which means that women are more likely to suffer it (Aristondo and Onaindia 2018; Sánchez-Guevara Sánchez, Sanz Fernández, and Peiró 2020).

In order to deal with this situation, the European project EmpowerMed (Empowermed 2019) was created to empower women by offering them tools to take action against EP. The project also works to improve the health and well-being of those affected by EP and seeks to combat the social exclusion that can occur as a result of this situation. EP is an issue that affects the whole world, however, the reasons and factors vary greatly depending on the territories analysed (Halkos and Gkampoura 2021) so the project focuses its actions on the coastal areas of 6 Mediterranean countries: Albania, Croatia, Slovenia, Italy, France and Spain.

Since EP involves so many different environments and factors (Halkos and Gkampoura 2021), it is difficult to monitor and measure. In order to facilitate the study on a global scale and to assist EU Member States in their action against this issue, the EU Energy Poverty Observatory (EPOV) proposed the use of 4 main indicators and 18 secondary indicators (Thema and Voundung 2020).

The primary indicators are calculated using data from the Household Budget Survey (HBS), an expenditure approach, and the Living Conditions Survey (LCS), under a consensual approach. The LCS indicators are: Inability to keep home adequately warm and Arrears on utility bills. On the other hand, HBS indicators are: Low absolute energy expenditure (M/2), that characterizes the levels of Hidden Energy Poverty (HEP) and calculates the percentage of population with a total energy expenditure below half of the national median; and high share of energy expenditure in income (2M), that calculates the percentage of population with a proportion of equivalent energy expenditure, compared to the equivalent disposable income, above twice the national median. Note that equivalent energy expenditure is represented as energy expenditure in euros per equivalent person. This allows taking into account the presence of economies of scale in consumption, which makes it easier to compare households of different sizes. The equivalent person value of a household is calculated as the sum of the household members weighted according to the modified OECD coefficients (Mancero 2001).

In Spain, on April 5, 2019, the Ministry for the Ecological Transition developed the national strategy against energy poverty (ENPE) (MITECO 2019) in which the bases to carry out an annual update of the main indicators and their subsequent publication were established. In 2020, an update of the indicators, the only one to date, was presented using data from 2019 (MITECO 2020).

The report shows a decrease in the indicators that measure the percentage of households unable to keep their homes at an adequate temperature and with delays in paying bills, which decreased by 1.5 and 0.6 points compared to 2018, placing them at 7.6% and 6.6%. Even so, when these data is converted into absolute values, it means that in 2019 there were 3.45 million people in Spain who were unable to keep their homes at an adequate temperature during cold months and that 3.07 million people were unable to pay their utility bills (Encuesta Continua de Hogares (ECH) 2020). Furthermore, if we look at the values of these indicators for 2008, 5.9% and 4.6% (Indicator | EU Energy Poverty Observatory n.d.), we can see that the values are still much higher than those of the period before the financial crisis.

In particular, it is interesting to review the data for 2M and M/2 indicators in dwellings with and without heating systems (see Table 1) as the proportion of affected households is much higher in unheated households showing a difference of 9.13 points in the case of disproportionate expenditure and 13.35 in HEP.

Table 1. 2M and M/2 indicators in dwellings with and without heating system, 2019

Indicator	With heating system	Without heating system
2M	13.36	22.49
M/2	5.67	19.02

These data evidence the effect of the construction characteristics of the dwelling as variables in the EP problem, since they are basic for providing an adequate comfort and are fundamental for the control of the energy consumption.

In Barcelona, the average age of buildings is estimated to be about 63 years. According to studies on the city's residential park, it is deteriorating due to a lack of rehabilitation works and limited space for new developments (DIAGNOSI ENERGÈTICA BARCELONA 2013). It should be mentioned that only 31% of residential dwellings were built after 1980 and, therefore, they do not comply with the law NBE-CT 79 which regulates, for the first time, certain energy efficiency requirements for building construction. Consequently, it can be stated that the majority of buildings are energetically inefficient. In addition, according to the results presented by the SPAHOUSEC project (IDAE 2011), the main energy source in multi-family buildings, 82% of the residential stock of Barcelona is electricity (De Santiago 2019), since part of the energy demands for climatization is met by electrical equipment.

Taking these primary motivations and the data from the Barcelona pilot site of the EmpowerMed project, this study analyses the thermal comfort, air quality, and electricity consumption of dwellings located in the province of Barcelona and carries a comparison between affected and not affected households.

2. Methodology

This work is integrated within the EmpowerMed project and, more specifically, is focused on the pilot project located in Barcelona. The type of approach to fight EP in this pilot site is based on the collective assemblies organized by the APE, from which the data set corresponding to the affected households has been obtained. In parallel, non-affected individuals have been approached in order to obtain a more diverse sample.

The sample analysed in this study counts on 27 dwellings located in the province of Barcelona, 14 affected by EP (AP) and 13 not affected (NA).

For the AP households, the procedure followed has three phases that coincide with 3 collective assessments. This procedure is detailed in (Casals Canals et al. 2021) but could be summarized as: in the first session, registration is made on the website of the electricity distribution company (*e-distribucion* as it is the main distribution company for the observed territory), a survey is completed and two sensors are given together with several indications on how to locate them inside the house; 15 days after, in the second session, the sensors are returned and the electricity consumption data is downloaded from *e-distribucion*; Finally, in the third session, the results of the individualized analysis are shared and strategies are provided to improve the thermal comfort of the home and adjust the electricity bill by making changes in the tariffs and the type of market that they have contracted.

Regarding NA households, the procedure has been different since not all the volunteers knew about the APE assemblies. For this reason, the volunteers have been contacted individually to explain the project and request their participation. Subsequently, a link to the survey and to the *e-distribucion* website was sent so that they could register autonomously. Finally, a videotutorial showing step by step how to download the data from the distribution company's webpage was created, and an email address was provided for sending the consumption files.

The aim of the survey, structured in 11 sections, is to collect information to develop a characterisation of the volunteers, the dwellings and the types of energy supplies contracted.

2.1 Indoor environmental analysis

Environmental comfort is described as a set of environmental factors, natural or artificial, that determine a state of physical or psychological well-being. Depending on the sensory perception involved, four types of comfort can be evaluated: lighting, acoustic, thermal and air quality (Lai et al. 2009). This research focuses on the final two.

In indoor spaces there are numerous factors that can affect indoor air quality, such as the emissions generated by the activities carried out inside the space, the air conditioning systems or the very presence of the occupants. Since the sources of air pollution are not modifiable, the way to improve air quality is through ventilation and it can be studied in terms of CO_2 concentration. The limits applied to evaluate comfort are set out in the I.S EN16798-1-2019 standard (see Table 2).

The way chosen to interpret thermal comfort has been through the operative temperature (T_{op}) as this parameter makes it possible to determine the temperature experienced by a person in a closed environment. The optimal operating temperature for each space corresponds to a situation of thermal neutrality, however, some allowable ranges are established around this temperature within which it is recommended that all occupied rooms are located (see Table 2). Households should be classified as IEQII for new buildings and IEQIII for existing ones. These ranges or categories are calculated according to the type of cooling/heating that the space has. In non-mechanically cooled/heated environments, the adaptive model is used, which considers the effect of certain parameters, such as the possibility of opening windows or putting on and taking off clothes, which make people more thermally tolerant than the models developed by Fanger (De Dear, Brager, and Cooper 1997).

Table 2. Categories of the operative temperature and de CO_2 concentration levels

Category	Expectation	T_{op} [ºC]	CO_2 [ppm]
I	Occupants with special needs	$t_{op} = (0.33 \cdot \bar{t_r} + 18.8) + 2$ $t_{op} = (0.33 \cdot \bar{t_r} + 18.8) - 3$	550
II	Standard level.	$t_{op} = (0.33 \cdot \bar{t_r} + 18.8) + 3$ $t_{op} = (0.33 \cdot \bar{t_r} + 18.8) - 4$	800
III	It will not provide any health risk but may decrease comfort.	$t_{op} = (0.33 \cdot \bar{t_r} + 18.8) + 4$ $t_{op} = (0.33 \cdot \bar{t_r} + 18.8) - 5$	1350
IV	Acceptable only for very short periods of time throughout the year.		>1350

Note that the corresponding CO_2 concentration indicated on Table 2 should be added to the outdoors concentrations set for the study at 400 ppm.

In order to calculate the limits of each category, it is necessary to know the average outdoor temperature ($T_{o,rm}$), which has been obtained from different meteorological stations (Meteocat n.d.) according to the location of each dwelling.

To collect the environmental data, two sensors have been installed in each dwelling for a period of approximately 15 days. One of the sensors (model RC-5 from Elitech) measures the temperature of the bedroom and the other one measures temperature, humidity and CO_2 concentration of the space more commonly used in the dwelling, the living room. The model of this second sensor varies depending on the monitored home: Wöhler's CDL 210 sensors have been used for NA households and the Comet U3430 model for AP households, since they do not need to be connected to the electric power while recording and they were given already measuring to enhance the participation of volunteers in the project (the less work it supposes for the user, the higher the success rate).

Each of the dwellings was treated separately, calculating the percentage of time elapsed in each comfort category and afterwards a comparative analysis is done for both AP and NA households. Note that measurements were carried out on different dates, so the average outdoor temperature differs. This fact has to be considered when analysis of the results.

2.2 Data collection: Electricity consumption

The data required for the study are the maximum demanded power and the consumption curves downloaded from the website *e-distribución*.

The platform allows consumption curves to be downloaded in two different ways: by massive download of curves or by periods of 60 days. As a result, not all consumption data have been obtained in the same way, and in many cases, when using the massive curve download option, the data retrieved did not match the house's monitoring period because downloads were based on the billing period, implying up to one month imparity. Therefore, in order to complete the annual analysis and the one by climatic seasons (summer/winter), months from different years have been taken, and as in some cases the consumption period collected only belonged to one climatic season (because participants had, for instance, a recent contract), the number of dwellings analysed varies according to the period studied. The annual study has data from 17 dwellings, while winter and summer datasets count on 20 and 18 dwellings respectively.

Given that the work was carried out prior to the approval of the new 2.0 TD tariff, the main framework of the project is based on the old rates of the regulated and the free market (Casals Canals et al. 2021). Note that all the data is processed with a program developed by the Institut de Recerca de l'Energia de Catalunya (IREC) (Ortiz et al. 2021).

3. Results

From the analysis of the surveys, a great gender inequality in terms of participation stands out, as 73% of the surveys were completed by women. In the case of the AP group, 12 surveys were answered by women and the remaining ones correspond to volunteers that live alone, a man and a person who did not identify as either male or female. In the NA group, female participation is somewhat lower but still higher than male participation, namely 64%, however, this depends on the approach made when searching for NA volunteers.

63% of the respondents, AP and NA, live as leaseholders, of which 4 do not currently have the lease in their name, and 9 of the 14 AP dwellings have the Residence Risk of Exclusivity Report (IRER).

The family profile of the sample is quite diverse, but it is worth highlighting that the 3 single-parent families that participated have a woman as the main provider and all of them belong to the AP group. It is also interesting to note that 4 of the 5 childless couples belong to the NA group.

From an approach based on the educational level of the two groups, it can be seen that there is a large difference in the educational profile between the two groups. On the one hand, only 58% of AP individuals have completed compulsory education. In contrast, all NA have more specialised levels of education.

In connection with this, for those dwellings that receive income from paid work, an average remuneration of 772.13 € is calculated for the AP group and 1,840.97 € for the NA. When analysing the total number of dwellings, the equivalent income, calculated according to the modified OECD coefficients (Mancero 2001), is 500.5 € for the AP group and 1,816.2 € for the NA group. It should be noted that all NA dwellings have income derived from paid work but, in the case of the AP households, there are 4 that only receive income thanks to subsidies and 2 dwellings that do not have any income at all.

Given these statistics, it is not surprising that 71% of AP volunteers report difficulties or great difficulties when in facing monthly payments, and that 8 out of 14 households report experiencing bill payment arrears in the previous 12 months.

Regarding the state of the dwellings, it is worth noting that 70% of the total respondents (AP and NA volunteers), indicated that they had perceived deficiencies in their dwellings, such as dampness, rotting windows or floors, fissures, leaks and draughts. Additionally, 59% of respondents reported suffering from glare, lack of sunlight and hot/cold walls or floors during the summer, a figure that rises to 78% in winter.

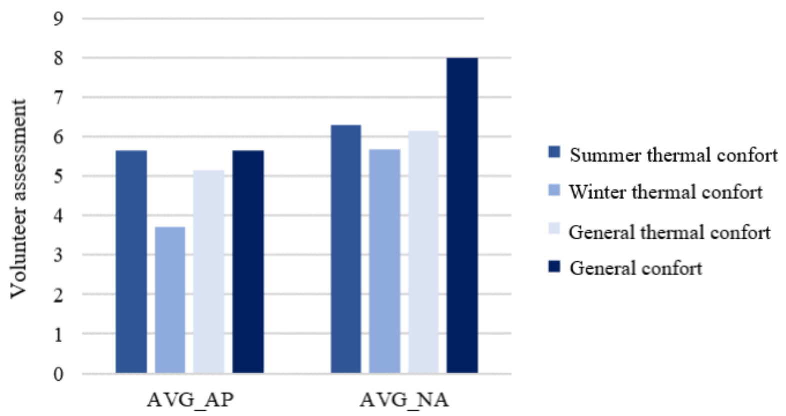
There are also 19 out of the 27 studied dwellings that do not have a heating system of which 7 use electric radiators, 4 use butane heaters, 4 use a combination of the above systems and 3 have no heating system at all of which 2 belong to the AP group. In terms of cooling systems, 9 dwellings have air conditioning in some room or in the whole house, 6 use fans and 12 dwellings are cool by means of natural ventilation.

Finally, 70% of all analysed dwellings indicate that they are unable to maintain an adequate temperature during winter, while in summer season this value drops to 52%.

3.1 Analysis of the Indoor Environmental Comfort

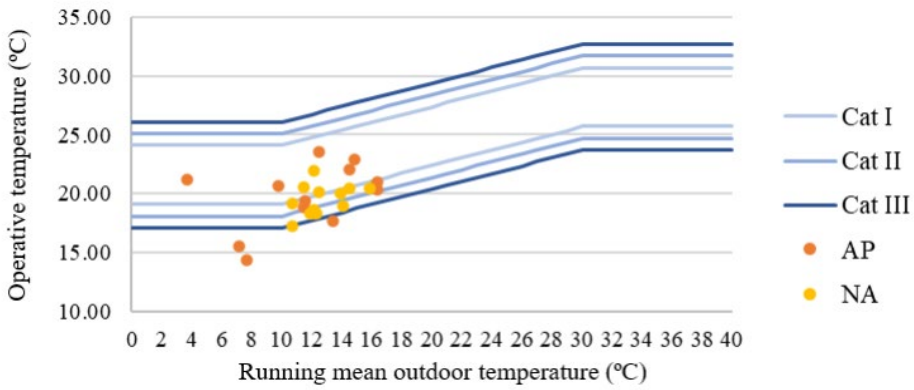
The perception of thermal comfort is considerably worse during winter than in summer and in both cases it is worse for the AP group (see Figure 1). The average evaluation of the AP in terms of general thermal comfort is 1.4 points higher than in winter, but only 0.5 points lower than in summer. In the case of the NA group this value is more balanced between the summer and winter assessment with differences of 0.2 and 0.5 in each case. There is also a big difference between the general comfort of the two groups, with the AP group rating 5.6 points and the NA group rating 8. A considerable improvement between the thermal comfort rating and the general comfort rating can also be seen in the NA group, but this is not transferred to the AP group.

Figure 1. Assessment of the volunteers of thermal and general comfort



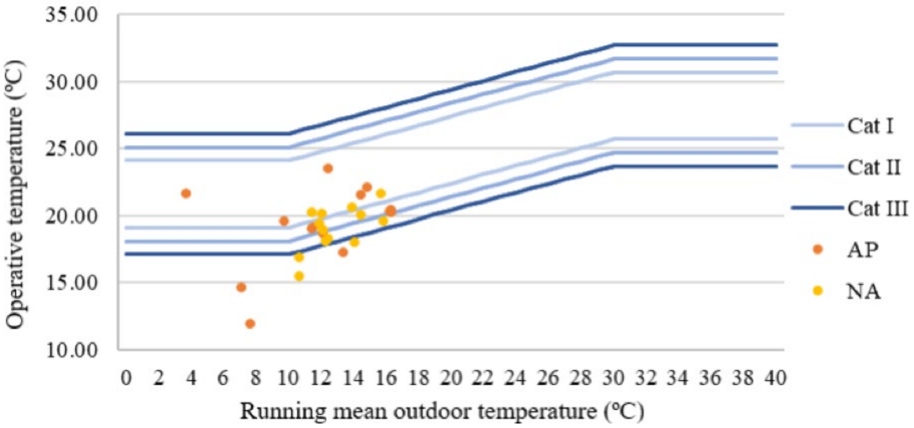
Analysing the data obtained from the measurements, it can be seen that, in the case of the sensor located in the living room, the average operating temperature of 4 dwellings is below the limit set by category 3 of thermal comfort according to the adaptive method (see Figure 2), spending between 96.64% and 100% of the time in category 4. It also coincides with the fact that these are the only dwellings that experience temperatures below 16 ºC.

Figure 2. Average operative temperature of the living room of dwellings by thermal comfort categories



It can be seen that the bedrooms tend to be at lower temperatures than the living room and that, in this case, there are 6 dwellings with the average operating temperature in category 4 (see Figure 3), the 4 mentioned above and two more. In this case, they spend between 91.23% and 100% of the time in category 4, with the exception of one dwelling, which spends in this category 62.67% of the time.

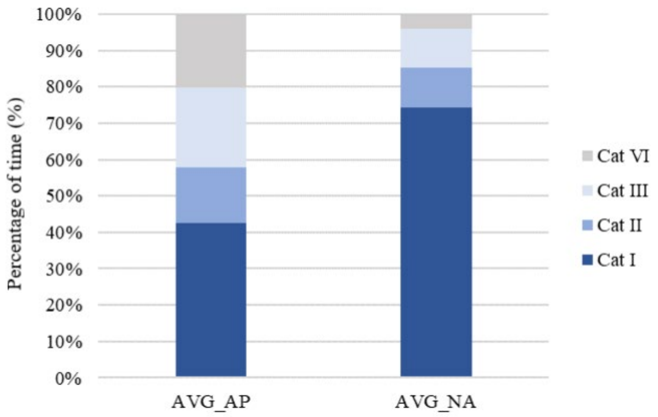
Figure 3. Average operative temperature of the bedroom of dwellings by thermal comfort categories



The analysis of the different heating methods shows an improvement in comfort for gas and central heating systems. However, the heating habits of each household should have been taken into consideration when making the comparison, as well as the placement of the sensor, the volume of the room and the number of occupants.

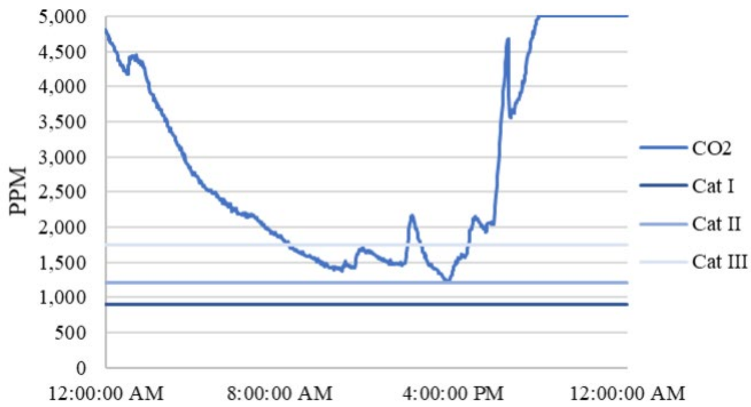
In terms of air quality, if a comparison is made between the two groups, there is an improvement of 32 percentage points for the NA group in terms of time spent in category 1 (see Figure 4).

Figure 4. Average of the AP and NA groups of the percentage of time spent in each category of air quality



When comparing the effect of heating systems in relation to the indoor air quality, there is a clear worsening of the readings when using butane stoves. As shown in Figure 5, which represents a one-day CO_2 measurements of a house with this heating system, when the heater is in use, the sensor reaches its limit of CO2 concentration, set on 5000 PPM.

Figure 5. Concentration of CO2 particles of a real day of reading of a house with a butane stove



3.2 Analysis of the electric consumption

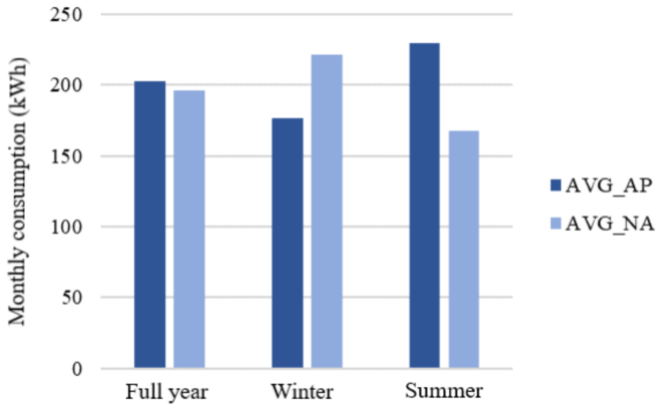
The electricity study includes data extracted from the analysis of monthly and hourly electricity consumption, a comparison of the cost of the tariffs in force before 1 June of 2020 and, the economic impact of the 2.0 TD tariff based on the consumption habits of volunteers.

When analysing the average consumption of the 12 months of the year (see Figure 6), the consumption of the AP dwellings represents 51% of the total. This is due to a higher consumption during the summer months since during the winter months the consumption of these dwellings is considerably lower than the one of the NA group.

It is assumed that, in cold months, the tendency is to spend more time at home and make intensive use of heating systems, so it can be seen that NA homes in general spend more.

During the summer season, though, the difference in consumption between the two groups could be related to the fact that people with more economic resources tend to travel and go to second homes and in the case of AP these options may not be so common. However, it is surprising that the consumption of these homes is higher during the summer than during the winter.

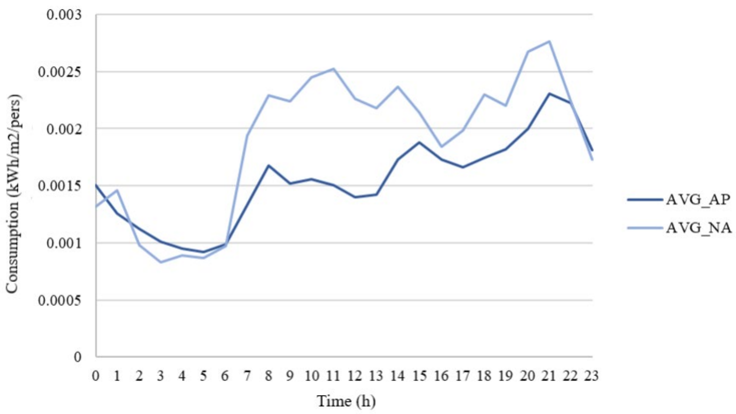
Figure 6. Average monthly consumption of AP and NA dwellings per year, winter and summer



When analysing the average hourly consumption data for each of the groups, the comments made from the monthly analysis are highlighted. In winter, the hourly profile (see Figure 7) is similar but the consumption between 6 am and 10 pm in the case of NA homes is much higher. This high consumption throughout the day may be explained by the fact that, due to Covid-19, face-to-face work has been replaced in most cases by teleworking. This is mitigated in the consumption profile of the AP group since the percentage of dwellings with people with paid work is much lower.

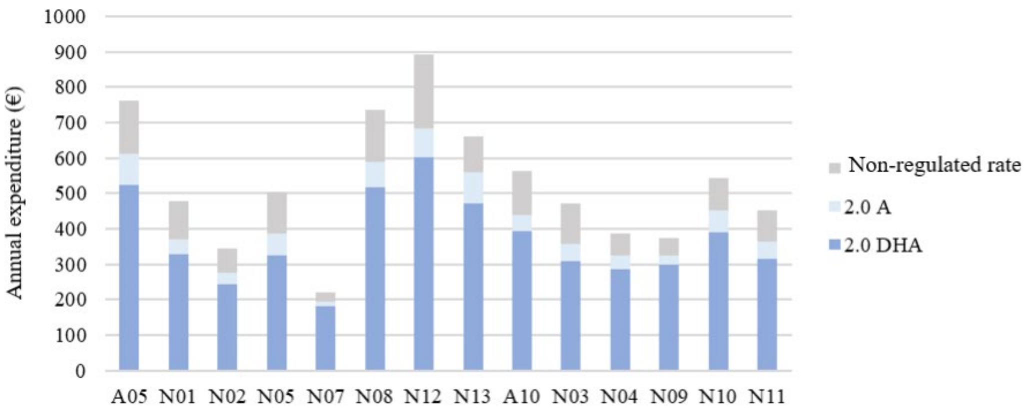
Contrarily to what was indicated by the average monthly summer consumption, the hourly consumption is reduced in both groups with respect to the winter hourly consumption and the profiles are much more similar, although different habits with higher consumption of AP group are distinguished between the 7am and 2pm and again from 6pm to 9pm.

Figure 7. Average hourly consumption in winter of AP and NA dwellings



The average annual expenditure on electricity for the AP group is €354.05 and for the NA group it is €454.11, 22% higher. Apart from the higher consumption during the winter months, another reason could be that all the NA households have contracted free market tariffs, on the contrary, 10 of the 12 AP homes studied have the PVPC tariff. The rates of all homes that do not have the PVPC rate have been analysed (see Figure 8) and the results show that, in all cases and for all consumption habits, the cheapest rate is the one regulated with discrimination of two periods, followed by the regulated one with 3 periods and finally those of the free market.

Figure 8. Comparison between tariffs in the case of dwellings out of the regulated market



On the other hand, the analysis of the expenditure of dwellings with electric heating in comparison with other methods shows that it is much higher, with an annual average of 493.45 € in the first case and 350.46 € in the second. It should be noted that in this analysis the annual expenditure has been calculated on the basis of the actual tariffs contracted by the volunteers and only for electricity, not knowing how much the households using non-electric heating systems pay for that.

With this data, the 2M and M/2 indicators are calculated. The first indicator affects to the 8% of the volunteers and only includes dwellings that indicate that they do not have any type of monthly income. On the other hand, the results of the M/2 indicator are very different, showing EP rates of 54%, affecting 50% of the AP dwellings and 46% of the NA ones.

4. Conclusions

First of all, the study highlights the great gender inequality in terms of involvement of the volunteers in the project, with female participation being 73%, which increases to 86% in the case of AP dwellings. This shows the great importance of the EmpowerMed project to achieve the empowerment of women in issues related to EP. Additionally, it is also important to highlight the great differences between the AP and NA groups in terms of educational levels, higher in the NA group than in the AP, average monthly remuneration for paid work, having the AP group 42% of the incomes of NA, and average equivalent monthly income of 500.5 € in the AP case in front of the 1,816.2 € in the NA group.

If the primary indicators provided by EPOV are calculated for the sample, remarkable differences between them are observed. The 2M indicator only considers 2 of the 24 houses analysed in the electrical study and they coincide with the two houses without any monthly income. On the other hand, when analysing the hidden poverty indicator, many cases come to light, both in AP and NA dwellings, which shows an equivalent energy expenditure much lower than the national median which was of 581 €/per/year in 2016.

Moreover, 30% of households report having suffered delays in the payment of bills during the last year, which corresponds to 57% of those affected and 70% report not being able to keep their homes at an adequate temperature during the winter.

In terms of the assessment of the volunteers on thermal comfort, it can be seen that it is worse in winter than in summer, with this difference being more marked in the AP group. This data is supported by the electricity consumption of the AP sample during the winter months, which is 53 kWh lower than the consumption of the NA group.

From the analysis of the measurements, it was found that, although there are several AP dwellings in very critical temperature conditions, there are also dwellings in the NA group that are in severe thermal comfort situations. It has also been concluded that butane stoves have a very negative effect on indoor air quality, with sensors becoming saturated and unable to collect real data on CO2 concentrations.

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Communication aligned with the Sustainable Development Objectives