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Energy related practices in Mediterranean low income housing.

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Abstract: The development of policies to improve energy efficiency and the retrofitting of the existing housing stock requires an adequate knowledge of the operation in practice and user needs. This becomes crucial when intervening in social housing, where household energy practices are likely to be confounded by energy affordability leading to outcomes that are distinct and sub-optimal when compared to those conventionally assumed. A field survey and analyses applied to more than 700 homes from collective social housing buildings in the south of Spain is reported here. The results show a clear stratification of energy consumption and ownership of household appliances and thermal systems. An austere self-imposed use of energy appears, coupled with normative adoption of certain energy efficient habits particularly with respect to laundry. An emergence of multimedia and computer equipment seems to be changing the overall balance of use of equipment in homes. A clear income level above which provision of thermal comfort using mechanical means became affordable was found. The work provides useful data of home habits and identify the main underperformance issues of this representative household-group, what may feed the design of upgrade policies and optimization of energy access for this housing stock.

Keywords: occupant behavior; energy practices; social housing; Mediterranean area; low income housing

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Introduction

Technical and regulatory advances over the last two decades have been a primary driver of increased energy efficiency in the new-build construction sector in contemporary cities. However, significant interventions will be needed to bring the existing building stock, particularly housing, up to the levels of energy efficiency required to achieve national and international CO_2 abatement objectives. The lower levels of energy efficiency that typifies existing housing stocks in European cities, much of which was built after WW II, also has an adverse impact on their ability to provide suitable living conditions (Bardhan, Jaffee, Kroll, & Wallace, 2014; Guerra-Santin & Itard, 2012; Hamilton, Steadman, Bruhns, Summerfield, & Lowe, 2013; Roufechaei, Abu Bakar, & Tabassi, 2014; Sendra, Domínguez-Amarillo, Bustamante Rojas, & Leon, 2013). Given their proportion in the stock, policies designed to reduce national emissions and energy consumption are unlikely to meet future targets without the development of appropriate, planned and comprehensive interventions in existing housing. This issue is prevalent in climate change policy in all member states of the European Union (González-Eguino, 2015).

Typical approaches to improve building performance are firstly concerned with retrofitting of the envelope and secondly extend to the upgrading the space conditioning and ventilation systems. In the overwhelming majority of cases the design and planning of interventions are based on data emanating from energy assessment tools that employ standardized, static and unidimensional users' profiles. This approach has largely persisted since the inception of the European Performance in

Buildings Directive (EPBD) despite numerous studies that have identified occupant behaviour as having a significant impact on residential building energy consumption (Cosar-Jorda, Buswell, & Mitchell, 2019; Gram-Hanssen, Georg, Christiansen, & Heiselberg, 2018; Harputlugil, Harputlugil, Pedergnana, & Sarıoğlu, 2019; Hu, Yan, Guo, Cui, & Dong, 2017; Lopes, Antunes, Reis, & Martins, 2017; Podkalicka, 2018; Yohanis, 2012).

Decisions to intervene in the stock should be planned to ensure that dwellings achieve an energy performance level that begins to approach that of the new build sector. However, this planning must be cognisant of the dwellings primary remit; namely of providing living spaces that meet appropriate minimum standards whilst allowing for the transition of household activities as demanded by inhabitants. In addition, the process must also take account of the costs of both interventions and operational energy, to ensure policy models are sustainable and address energy poverty issues and other market dysfunctionality (González-Eguino, 2015; Jafari & Valentin, 2017; Jenkins, 2010).

The development of successful policy in this area is hampered by both the lack of adequate information about the actual practices that underpin household energy use and how these actual practices impact on existing, standardised specification approaches (R Gupta & Chandiwala, 2009; Rajat Gupta & Chandiwala, 2010).

Whilst a point of contention, it could be argued that the use of standardised profiles to define expected inhabitant patterns and use-conditions may provide useful guidance for planning and design of new dwellings. However, they provide limited or no utility for estimating the energy consumption of existing dwellings, this requiring a more comprehensive understanding of user's energy practices in their environments. For instance, thermal control of dwellings is inherently variable, marking it is a dynamic process quite unlike the static process commonly assumed by official user profiles (Backlund, Thollander, Palm, & Ottosson, 2012).

These limitations in existing approaches result in significant discrepancies occurring between the forecasted and delivered impact of retrofit processes on the operational energy requirement of the dwelling. This creates substantial risk in policy development particularly where the capital costs of interventions have been justified by these forecasted operational energy savings. This inadequacy is a significant contributor to the energy efficiency gap and is one of the major concerns in the design of energy efficiency policy in Europe (European Commision, 2014; European Commission, 2014).

In addition, it has been postulated that ICT based user feedback techniques represent powerful approaches for modifying home-inhabitant energy practices, leading to increased efficiency in service delivery. These have been credited as providing a range of benefits to householders; for instance from assisting them in understanding static and often opaque billing data to provision of information to assist or encourage demand response. Previous studies show that feedback solutions can lead to savings in energy consumption for the users, often through the use of comparative statistics linking the candidate household with others are deemed to be similar (Anderson & White, 2009; Darby, 2006, 2010; Van Dam, Bakker, & Van Hal, 2010). However, creating an adequate environment for different users to be compared in such a manner as to make the information useful, would require prior information and knowledge of the circumstances of the involved users coupled with the computational capability to create different profiles in order to develop differentiated patterns (Delmas, Fischlein, & Asensio, 2013; Faruqui, Sergici, & Sharif, 2010; Fischer, 2008).

In this context, it has been proposed that conventional methods of analysing dwellings (e.g. monitoring of physical parameters) should be complemented with (i) evaluation of users' energy practices, (ii) the derivation of actual patterns of consumption and (iii) the performance perception of users in their homes (Bordass & Leaman, 2005; Gram-Hanssen, 2010). Furthermore, this approach may be extended to include analysis of influencing socioeconomic and regional singularities to provide an overarching evaluation of housing energy performance. Datasets may emerge from this marriage of social, economic and technical factors that contribute towards discrete dwelling intervention strategies and comparative analyses that contain improved representative of actual performance of the dwellings. This approach has been promoted as an imperative in delivering a more comprehensive understanding of the existing housing stock (Stevenson & Leaman, 2010).

A principal aim of this paper is to contribute to the identification of actual users' energy habits and practices in large cities located in mild climates such as the European Mediterranean coastal area. A key research question addressed by the authors is the investigation of users' actions likely to have a material impact on dwelling energy consumption and a subsequent comparison of these findings with assumed values used in standardized energy assessment tools.

It draws on more detailed profiles of use and energy patterns of housing to provide an improved understanding of the characteristics and trends of social housing energy consumption. The analysis is based on a comprehensive study conducted in more than 700 inhabited dwellings in the city of Malaga (Spain), gathering information from different social housing neighbourhoods. The baseline data associated with energy practices may inform the design of future interventions and assist with methodologies used to disaggregate housing stock performance. The analyses had a twin focus; (i) to investigate ownership and usage of home appliances and (ii) to evaluate, primarily habitual and routine practices, i.e. those that are performed or repeated often and were associated with lifestyle choice.

Materials and Methods

Sample

Andalusia is the second largest but most populous geographical region in Spain. The residential neighborhoods taking part in this study were located in Malaga, the second largest city in Andalusia on the southern Mediterranean coast of Spain. The population density of the province of Malaga is higher than the Spanish average, making this study relevant to high density, European cities. The study locale has a prevailing, warm Mediterranean climate with dry and warm long summers and short mild winters -Köppen-Csa-(de la Flor, Domínguez, Félix, & Falcón, 2008).

The survey sample of 700 dwellings was drawn from 37 multi-family social housing blocks that each contained between 10 and 40 individual dwellings. The housing blocks were predominantly located in two areas in Málaga city, namely historic downtown and working-class neighborhood with a small proportion of dwellings located throughout the city in other scattered areas.

The surveyed residents were all home owners and presented a similar socioeconomic profile composed of low-income family households. One of the selection criteria was that homes were billed directly for water and electricity consumption.

The dwellings were all built between 1950 and 1979 by Government's public housing companies. A strength of the approach taken here was that the physical construction of surveyed dwellings was relatively consistent throughout the cohort allowing this variable to be excluded as a causal factor of energy consumption variation. This sample was representative of the buildings constructed prior to the implementation of the first Spanish energy demand regulations (NBE-CT-79 on Thermal Conditions in Buildings) and were constructed without any specific thermal insulation (Domínguez-Amarillo, Sendra, & Oteiza San José, 2016).

In southern Andalusia, multi-dwelling units prevail over single family homes, these being found more frequently in suburbs and metropolitan areas. Two periods of rapid housing construction can be identified in the stock; from 1940 to 1979 (particularly at the end of that cycle) and from 1990 to 2010, with these allowing the city to acquire it present appearance (Domínguez-Amarillo et al., 2016). Linear block and H-shaped block typologies are dominant among the multi-family buildings built after 1940. Tower block typology is more typical of developments built in the 1960's and 1970's (Domínguez-Amarillo, Sendra, Fernández-Agüera, & Escandón, 2017).

As a rule the façades in the sample have thermal transmittance values ranging from of 1.5 W/m^{2}K to 1.7 W/m^{2}K (Fernández-Agüera, Domínguez-Amarillo, Sendra, & Suárez, 2016). Wall construction method is either single wythe masonry typically attributed to block typologies built during or immediately after the war resulting in lower thermal mass and higher thermal transmittance. Later construction migrated to twin masonry wythes, comprising a thicker external leaf (normally 150mm) and a thinner inner leaf (40-70mm) with air cavities of 50mm. Reinforced concrete portal frames and structural floors constitute the prevailing structural approach. Most windows are single glazed and either hinged or horizontally sliding, with timber, steel or aluminium frames (from oldest to newest), depending on the date of construction (Domínguez-Amarillo et al., 2016).

Balconies are a common element with flatted construction in this locale. The relatively small floor area of the dwellings has resulted in many balconies becoming enclosed to increase habitable area. A substantial percentage of these flats also feature a laundry room adjacent to the kitchen, particularly those built after the enactment of ordinances on social housing design (Domínguez-Amarillo et al., 2016). These were initially constructed with open slats on the exterior façade. As in the case of the balconies many of these laundry rooms have been enclosed with joinery and glazing and incorporated into the kitchen. Domestic hot water heaters, typically gas-fired are located in these spaces.

Survey design

The purpose of the survey was to gather information from householders using a systematic approach and to then discretize the findings to reveal information concerning the following household knowledge and practices; (i) knowledge about their energy and water usage, (ii) energy and water using practices, and (iii) awareness and use of solutions, sources of information and support that is available to assist householders reduce their energy consumption.

A questionnaire survey was developed to collect this information. Surveys were hand delivered to a randomly selected set of dwellings with an instruction that completed surveys would be collected one week later. During the second visit, consultation was provided by a social worker to answer questions and assist householders in how to complete the survey. This process took approximately one hour per dwelling and served to maximize response rate. The 700 surveys were collected over a 12 month period.

The survey content included questions covering occupant and building information, ownership of energy consuming devices, occupant usage practices, energy consumption level and resident's attitudes toward energy-saving policies. A summary of the areas covered by the questionnaire is shown in Figure 1. For the sake of confidentiality, no individual sample was able to be identified or specifically located.

Billing data pertaining to energy and water consumption of each dwelling was collected. In a small number of dwellings (N=20), major household electrical appliance consumption was monitored. The results of these studies, whilst briefly reported here was largely used to verify household responses to the survey.

The user survey process was carried out in a single period for the whole group and included questions pertaining to both summer and winter occupation. A control group (N=20) received two surveys, one in the winter and the other in the summer season to investigate whether any bias could be discerned associated with the time of year surveys were conducted. No bias was found in the responses.

Results

Occupants information /Sample description

Family size, or inhabitants per house, is a well-documented precursor of household energy consumption with higher occupancy typically resulting in higher levels of end use equipment ownership and more cooking and domestic hot water usage (Hu et al., 2017). Furthermore, occupancy influences thermal conditioning energy demand with those with children having less predictable energy patterns compared to dwellings inhabited only by adults (Commission, 2018).

The average occupancy level in the survey sample was found to be 2.67 per household, slightly higher than the average, urban Spanish household size of 2.49 (Instituto Nacional de Estadistica, 2017). The mode household size was two people (28%), although dwellings with three or four inhabitants represent almost half of the sample (16% and 27% respectively) (Figure 2a). The number of single occupant dwellings was found to be 22%, marginally lower than the Spanish national average value (25.4%) (Instituto Nacional de Estadistica, 2017).

The marital status of the surveyed cohort was found to be consistent with national averages. Most respondents were either married (55.7%) or widowed (20%) with cohabiting individuals, those who are separated, single or divorced ranging from 4.1-7.5% (Figure 2b). 68% of households had no children in residence (Figure 2c), in contrast with the Spanish average of 55% (Instituto Nacional de Estadistica, 2017), lending the surveyed cohort a somewhat elderly profile. Households with children constituted less than a third of the total, with almost half of these corresponding to families with two children (17% of the total sample).

The average household net-adjusted disposable income in Spain was €1,400 per month in 2016 (€17,000 pa) (Instituto Nacional de Estadistica, 2016). The cohort were found to have a significantly lower income level than the national average, with more than half reporting less than average income and 7.8% of the survey reporting income of less than €500 per month. This places the cohort in the lower income strata of the city, making them potentially vulnerable to the risk of energy poverty, a situation common amongst social housing inhabitants. In Spain, those who were retired (above 65 years old) or widowed had a right to a pension with minimum income of €623 per month. Because 68% of tenants that live alone are more than 65 years old, the 75-percentile salary was approximated to be the minimum pension (Figure 3).

Housing information.

The floor area of surveyed dwellings ranged from 40 to 115 m^2 and varied with age of dwelling. Homes built between 1940 and 49 were found to have floor areas of 57-88 m^2. At the end of the 1940's social housing floor areas were substantially reduced due to the prevailing economic circumstances, associated with rises in the costs of both materials and construction labor coupled with constraints in government funding (Sambricio, 2003). Social housing built during the period 1950-1960 had a minimum floor area of 42 m^2 (Torres, 2000). Space standards were steadily increased from the start of the 1960's until the 1970's and have since remained relatively static (Domínguez-Amarillo et al., 2016) (Figure 4a). The study created three categories of dwelling by floor area, namely; (i) Small dwellings between 40-60 m^2 (5.7%), (ii) Medium dwellings between 60 – 85 m^2 (65.7 %) and (iii) Large dwellings between 85-115 m^2 (28.5%) (Figure 4b).

Electricity consumption

The average electricity consumption of housing in Malaga was determined using information gathered from two sources (Table 1). Total electricity consumption in the residential sector of Malaga City was provided by the local electricity distribution company (published by the Institute of Statistics and Cartography of Andalusia) and the total number of residential households was supplied by the City Council (Municipal Environmental Observatory of the City of Malaga).

The average electricity consumption of the surveyed households was found to be 27% lower than that calculated for Malaga City households as a whole over the period 2015-2017 with relatively small annual variation. Average electricity consumption of the surveyed households was found to be 66% of the national Spanish average of 3,478kWh in 2016 (Instituto Nacional de Estadistica, 2017). It is interesting to note that this reduced consumption has been found where the associated dwelling energy efficiency rating was considerably lower than that of the national stock average. These consumption levels may reveal energy practices that suppress demand as a consequence of income levels.

The monthly average electricity consumption per dwelling was analyzed to investigate the extent to which a seasonal trend could be identified (Figure 5). For this, a seasonal decomposition of the series has been applied. The cycle-trend component was calculated when the temporal series data were softened with a mobile mean with k width equal to seasonality (12 months). The general pattern in the data obtained is mainly horizontal with some disruption in the initial period which slightly alters the base trend (red line) and slightly increases the trend in the final stages of the period.

The cycle-trend can be removed from the data after calculation, so that the calculations resulting from the seasonality-irregularity component are averaged and the irregular component is removed, leaving an estimator of the seasonal component. Seasonal indices (with 100% for the mean month) show how maximum electrical consumption is reached in January and August (117.9 and 118.01%), while the lowest consumption indices are obtained in April/June (78.95-81.7%).

Observation of the three years' worth of data (Figure 5b) shows higher absolute values for 2016. However, similar behaviour is also observed in the other years, as indicated by the general trend component, especially in the central part of the period.

This seasonal swing is less pronounced than that reported in studies that have evaluated households with a broader socio-economic status. It is likely to be reflective of the relative lack of space conditioning equipment and broad thermal comfort criteria found in the surveyed cohort. It is also interesting to note the similarity between the worst month of winter and summer, indicative of the almost exclusive dependence on electricity as an energy source.

Analysis of the detailed behaviours associated with submetering (Figure 6) shows this seasonal behaviour in dwellings with full families as well as in ones occupied by couples. It also shows the relatively low weight of mechanical thermal treatment in dwellings, resulting in low seasonality. These data, in keeping with the general results of the surveys, support the different findings identified for the general group.

Appliance ownership and use

The most common appliances found in homes was a fridge-freezer, washing machine and TV-sets, with ownership of each saturated at almost 100%. Washing machines, dishwashers and clothes dryers contribute significantly to residential energy and water consumption. Clothes washing practices were found to be particularly distinct in the surveyed cohort. Average temperature of a washing cycle in Spain was reported as being 33.9°C in 2011 (Gooijer & Stamminger, 2016), lower than the figure for Western-Europe as a whole (40°C) (Ramírez-Mendiola, Grünewald, & Eyre, 2017) and commensurate with findings that indicate a general tendency in Southern European countries for householders to use lower wash temperatures than the rest of the continent (Gooijer & Stamminger, 2016). Almost all survey respondents (95%) indicated that only cold-water wash cycles were used. The number of wash cycles reported by the cohort was between one and four per week which when combined with household occupancy levels presented an average number of cycles of 1.5 loads per week per occupant (Figure 7). As a consequence of the decisions made by householders regarding wash cycle temperature, the average consumption of a washing machine among the cohort was 35 kWh per year, significantly below the national average.

These washing practices, stimulated by fiscal concerns have a significant impact on the knowledge of and participation in schemes designed to encourage uptake of energy efficient appliances. This is reflected by the finding that only 3% of respondents owned an A+ class washing machine. This represents an under-reported barrier to household participation of such schemes, distinct from acknowledged barriers that include; (i) information deficit, (ii) low priority assigned to energy efficiency, (iii) purchasing stimuli favoring capital over operating cost (Dupret & Zimmermann, 2017).

Ownership of clothes dryers and dishwashers was not universal in the surveyed dwellings in common with ownership statistics for social housing in Spain. For instance, only 30.7% of respondents reported owning a dishwasher; this compares to national averages of 40%, 46% and , 59% in Spain, UK and France respectively (Dupret & Zimmermann, 2017; Jones & Lomas, 2016; "The statistics portal," 2018). Those households that did own a dishwasher reported carrying out between one and three loads during a typical week. Almost all (95%) had purchased their dishwasher in the last five years meaning that the stock as a whole was relatively energy efficient.

The most prevalent household appliance was the television; with 98 % of households having at least one television set (Figure 8) and with several sets often being present per home. Of these, 33.6%

and 49.2% of households had one and two TV sets respectively. Energy consumption is driven by not only the number of units built also the total hours of use (Sekar, Williams, & Chen, 2016), with this likely to ensure it has a significant influence on total consumption (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013; Jones & Lomas, 2016; Meyers, Williams, & Matthews, 2010).

It is noticeable that the majority of households (66.4%) declared ownership of some form of home computer equipment (i.e. desktops, laptops, or tablets). This was below the national average home ownership of computers for Spain (75.9% in 2016) ("The statistics portal," 2017) perhaps indicative of the age and income profile of the cohort. Current trends of penetration of home computing equipment continue to rise towards saturation and largely prevalent in all income groups (Marszal-Pomianowska, Heiselberg, & Kalyanova Larsen, 2016; Ramírez-Mendiola et al., 2017; Widén & Wäckelgård, 2010).

Digital tablets were only found in 3% of households. The high rate of ownership of desktop computers (45.9%) may be questionable. It may reflect legacy purchases coupled with the income levels of the cohort, but it may also be a misinterpretation in the survey form, with the Spanish term for "computer" able to be applied to both desktops and laptops. This issue should be reviewed in future work when developing surveys. Caution should also be applied to this dataset when converting ownership/usage data to energy consumption data to ensure that it does not result in an overall bias being applied to home computing ownership.

A significant aspect of both television and home computing equipment is the impact of standby load on both baseload and overall consumption. It has been estimated, for instance that it is responsible for approximately half of the annual energy consumption of these appliances (De Almeida, Fonseca, Schlomann, & Feilberg, 2011). In this cohort survey responses indicated a significant awareness of the problem, with almost half of the users (54.1%) stating that devices were disconnected when not in-use over-night, a higher response rate than found in similar studies (Grottera et al., 2018; Prudenzi et al., 2011). It may be indicative of energy-saving practices among the cohort, it being an easy user-controllable action with immediate visualization.

Patterns of use of domestic hot water

Among households in Southern Spain centralized space heating systems are extremely rare and the only thermal system likely to be present throughout the stock is a individual water heater (Sendra et al., 2013). The results from the cohort surveyed here were consistent with this finding. Domestic hot water (DHW) was mainly provided by gas-fired instantaneous water heaters or electric-direct cylinders with the former being the most prevalent (92%) (Figure 9a). System selection was reported as being predicated on operating cost. Despite delivering increased convenience and the assurance of uninterruptable supply, only 20% of DHW systems were found to be connected to the gas network. These operational benefits were outweighed by the higher capital cost of attaining a network connected system and the running costs. DHW provision from solar water-heating systems was reported as being cost competitive in 2013 compared to the incumbent systems found in the surveyed households. This is leading to increased uptake nationally of installations in single-family homes and at district-level serving multiple homes (Sendra et al., 2013). Despite this, uptake among the demographic described in this survey was found to be non-existent. This may have been associated with adoption barriers quoted elsewhere that include installation difficulties and investment cost (Eicker, Demir, & Gürlich, 2015). The principal use of DHW in the cohort was for satisfying human cleanliness with average figure for weekly showers is 5.6 per inhabitant (Figure 9b), similar to the Spanish average(Instituto Nacional de Estadistica, 2017).

Patterns of thermal control

Malaga's subtropical-Mediterranean climate results in it having one of the warmest winters in Europe, with average temperatures of 17 °C (62.6 °F) during the day and 7–8 °C (45–46 °F) at night in the period from December through February. This largely negates the requirement for space conditioning using standardized thermal comfort metrics. Nominally, the cooling season extends to the eight month period from April to November. Most respondents in the surveyed cohort reported having neither a cooling nor a heating system, with causal factors likely to be the benevolent climate and the socio-economic status of the cohort. Therefore, space conditioning represented only a small fraction of the total household energy consumption of the cohort. Respondents reported that their principal space conditioning requirement was for heating with under-heating of the dwelling described as a main cause of discomfort. The main energy source used to provide space conditioning was electricity, with other energy forms of negligible importance. For example, only 3.3% of respondents reported using butane or propane gas as their main source of heating (Figure 10a).

Heating is provided chiefly by a combination of electric resistance heaters (39.3%), and heat pumps (31.1%). Heat pumps are of an individual direct expansion (DX) type —with these systems being capable of providing both space heating and cooling as required. They are predominantly installed to provide space conditioning to a single room. More than a fifth of the cohort (26.3%) reported having no heating system in their home. A small number of respondents (5.7%) reported the use of blankets as an active heating system. In this sample, blankets are widely used as a measure against the cold, as is discussed later on (Figure 10a). The finding that more than a quarter of dwellings have no mechanical heating systems is higher than data found for the overall Spanish stock and significantly higher than for comparable studies carried out elsewhere in Europe.

A clear relationship has been reported between over-heating of dwellings during the summer months and health conditions with excess summer deaths becoming an increasingly acute concern particularly among low income households (Ahrentzen, Erickson, & Fonseca, 2016). Given these issues, it was perhaps surprising the cohort perceived summer over heating to be a lesser concern than winter under-heating.

16.4% of respondents reported not using any mechanical methods to cool the home. Among those respondents that did report use of mechanical cooling systems, the most prevalent technology used was portable-fans (37.7%) (Figure 10b). Whilst air-conditioning systems were present in almost the half of the dwellings, these were predominantly single room systems (33.6% of the total sample) located in the main living space or bedroom (DX split systems). Only 12.3% of the total sample reported having all-dwelling air conditioning units (Figure 10b). The relative absence of whole house space cooling systems is typical of housing where systems are installed as a retrofit measure. Limited access to capital and installation constraints encourage the use of local equipment, in which only one space of the house is conditioned during the winter/summer (Figure 11), this typically being the space around which the home activity orbits.

The survey included monitoring the internal temperatures of a representative group of dwellings (N=20). According to the findings, most households in the sample were unable to maintain indoor temperatures that are commensurate with standardised comfort indices, particularly in the summertime. Based on average internal temperatures, the dwellings were able to achieve adequate thermal comfort levels during the winter months. However, persistent periods of both low internal temperature and high humidity did occur, predominantly during the night. These may give rise to discomfort and conditions that would promote condensation and mould growth. In summer, in contrast, internal temperatures were found to be higher than the thermal comfort ceiling for nearly 24 hours of the day. The implications are particularly acute at night when high temperatures are likely to adversely impact occupants' sleep with widely accepted impacts on their overall quality of life (Basu & Samet, 2002; Díaz et al., 2015).

Energy poverty *(according International Energy Agency, IEA)* is the inability of a household to meet minimal energy services for their basic needs, such as keeping housing in suitable climate conditions for health (20 to 17°C in winter and 27 to 25°C in summer). Results from this sub-sample of the cohort indicate that this inability was present, particularly in the summer (Figure 12).

The survey returned information regarding the number of weeks per year the householder used space conditioning systems to heat or cool the dwelling (Figure 13). Whilst cooling systems were found to operate for longer than heating systems, the difference was not reflective of the relative duration of heating and cooling seasons in Malaga. This finding has also been found in other similar surveys (de la Flor et al., 2008; Sendra et al., 2013).

Regardless of the space conditioning systems present in the dwelling, the habitual practice of householders plays a critical role in the actual energy balance of homes. Survey responses indicated that energy affordability played a significant role in how these practices develop. Respondents indicated that 59% did not use any type of heating system during winter and 51% no cooling system in the summer. When this response is compared to system ownership, it indicates that some respondents both own and do not use heating and cooling systems.

The extent to which this is a function of affordability, governed by income level can be discerned by comparing the responses of the wealthiest proportion of the surveyed cohort. Responses from this proportion indicated that they made regular use of space conditioning equipment, with practices similar to those expected of residents seeking to achieve standardised thermal comfort standards (Sendra et al., 2013). For instance, 6% and 11% of respondents reported using the heating system and cooling system respectively for more than 12 weeks a year, with these respondents all being found within the wealthiest percentile of the survey cohort.

From a thermal comfort perspective, three distinct groups emerge. A group (10%) who both own and are willing to pay for the use of appropriate space conditioning systems to achieve standardized thermal comfort conditions throughout the year. A second group (63.7%) that used space conditioning only during extreme periods, estimated cumulatively to be for around four weeks per year. Although these homes do not usually maintain indoor environments within conventionally accepted thermal comfort bands, they do use systems to avoid excessive exposure to thermal stress situations. Finally, a third group (26.3%) who live in free-running dwellings who resort to non-fiscal adaptive measures in response to the found dwelling temperatures. The second and third groups represent different pictures of energy poverty.

Returning to the issue of practice and system ownership it is evident that equipment does not suppose operation. Nor is expected energy-demand a precursor of actual consumption, and that the reality for a sizeable proportion of the cohort is a circumstance dominated by energy poverty, nuanced by ability (or absence of ability) to react to extreme events that is substantially larger than that previously estimated.

Where heating systems are commonly used, the most representative group — all be it only representing 29.5% of the cohort — selected a temperature set-point in the 21-25 °C band. A similarly sized group (23.8% of respondents) were unaware of the temperature set-point used by their heating system. Residents who used winter set-points outside conventional thermal comfort bands were relatively rare; for instance 1.6% and 2.5% preferring under 20 °C and above 25 °C respectively. 94% of residents who reported use of a cooling system chose temperature set points in the 21^{O}C to 24 ^{O}C temperature band.

Patterns of cooling control measures

Tenants were asked to rank the actions they would take to keep cool during summer with the aim being to create a comprehensive sequence of practices for each tenant. A key finding was the direct relationship that emerged with where use of cooling systems was placed in this sequence of actions and household income. Switching on the cooling system only appeared as the primary adaptive response in respondents with salaries above €1100 per month (Figure 14). Among surveyed users whose incomes fell below this level, all indicated that they implemented passive adaptive measures prior to the use of space conditioning systems. In this context, the most common passive adaptive practices was found to be window opening followed by removal of clothing with these carried out prior to resort to mechanical systems (either fan or air conditioning depending on ownership).

Similar income dependency was found among response to low temperatures in the winter. People with salaries lower than €500 per month didn't resort to the use of any mechanical systems. Only people with a salary above €2200 per month used centralized heating systems as their primary response to cold temperatures. In winter, the most popular passive actions were closing all doors and windows and wearing warm clothing (Figure 15).

Considering the cohort in its entirety and considering only a narrow energy conservation perspective the data indicates that a clear majority of residents adopt passive adaptive actions as a habitual practice (Figure 14 and 15). However, this may be a somewhat quixotic outcome as a key causal factor in the adoption of these passive practices is affordability, with clear evidence of these practices being in effect unlearned when income levels rise above a threshold value. In effect, these practices are more indicative of suppressed energy demand triggered by affordability.

Ventilation

Typically, design of social housing in southern Spain incorporates features that ensure average to good natural ventilation (Barbosa, Vicente, & Santos, 2015; Mavrogianni, Taylor, Davies, Thoua, & Kolm-Murray, 2015). None of the surveyed dwellings had mechanical ventilation systems, it rather being provided by window and door opening. A distinction should be drawn between two possible ventilation routines: brief, room-by-room opening during the heating season and lengthy (often nearly all day), flat-wide opening during the cooling season.

In the absence of mechanical systems that are able to deliver more consistent ventilation, heating season practices are restricted to purge ventilation for short periods during the day, which may have concomitant implications for indoor air quality depending on dwelling infiltration rates. The survey indicated that during the period when windows are closed most of the time, 98.4 % of homes are aired once or at most twice per day (Figure 16). Whilst airing of homes was found to be a near universal and established practice, the intensity and duration was found to vary. The majority of the surveyed population aired their dwelling once per day, for a short time period by opening all the windows in the flat. Unlike standard housing in other climates, these dwellings normally have vertically hinged or sliding windows which resulted in them being either fully open or fully closed, and only rarely in intermediate positions (Domínguez-Amarillo et al., 2016). The length of time that the dwelling was aired was found to vary, with nearly 45 % of users ventilating for less and the remaining 55 % for more than 30 minutes per day. Significantly, users ventilating just once a day tend to open windows for longer than 30 min, whereas those ventilating twice do so for less than that each time.

Significant scatter in the total length of time windows were opened per day was found, with the expected increase in duration in summer compared to winter. Analysis revealed some patterns that suggested window opening practices in the heating season were primarily associated with household composition and occupancy duration. Ventilation time was found to be longer in dwellings with higher daily presence. This included older occupants (potentially retirees who spend more time at home) and those of medium age with lower per capita income (possibly part-time workers or the unemployed who would likewise spend more time in their homes). In the latter case this may also be related to the presence of women not working outside the home who typically are responsible for domestic affairs, that may include household airing (Álvarez & Miles-Touya, 2016; Floro, 1995; Gutiérrez-Domènech, 2010). In contrast, working age occupants with higher incomes who spent less time at home were more likely to practice shorter and more fragmented ventilation. These profiles are consistent with socio-economic analyses such as found in (Gimenez-Nadal & Molina, 2014; Scanlan, Bundy, & Matthews, 2011). These findings would imply that ventilation during the heating season is perceived by occupants not as an energy-cost issue but as an indoor comfort problem, i.e. its impact on household energy consumption are either overlooked or considered less important than indoor air quality.

Another finding of interest was the higher prevalence of routine ventilation among older than younger users. This may suggest that this cultural practice has not been inherited by the younger population.

These socio-economic patterns were not observed during the cooling season, when windows remain open for much longer, averaging five hours per day with values of ten hours not uncommon.

Patterns of use of lighting

The project of which the survey was a part provided energy saving light bulbs to participating households improving lighting energy consumption by an average of 60%. Prior to the distribution of energy saving light bulbs, 87% of dwellings had incandescent bulbs and only two cases were found where LEDs bulbs were used throughout the dwelling. From the perspective of reducing energy consumption, the survey results indicated predominantly good lighting practices with for instance, 78% of respondents reporting lights being turned off when the room was not in use, 87% turning off lights when they leave left the home and 98% turning off lights when they went to bed.

4. Discussion

The large-scale survey reviewed here provided a comprehensive picture of household systems, practices, capacities and situations of a representative social housing cohort, located in Southern Spain linked to their use of energy. The survey was conducted among 700 residents of broadly similar housing construction and was therefore able to reflect on energy practices that arose as a consequence of lifestyles, i.e. financial, age-group, household formation and cultural. Electricity was found to be the main source of energy for this housing group, in line with the national data for Spain. This was complemented with bottled butane and to a lesser extent networked natural gas usage, with usage of diesel-oil (more typically used in larger dwellings) not found within this stock. Gas (LPG or Urban Gas distribution) was typically used for Domestic Water heating and cooking, but only rarely for heating, where electricity use was found to be dominant. Thermal-solar or photovoltaic energy systems were not found among the surveyed stock in alignment with national data for social housing.

The income level of respondents was found to be a dominant factor that affected actual energy consumption. A sizable portion of perceived demand —or the energy use expectation— was not actually converted into actual energy consumption. Users traded energy affordability for sub-optimal thermal comfort compared to conventional standards. The prevalence of suppressed demand resulted in the normative adoption of passive adaptive practices for achieving some level of thermal comfort in both the winter and summer seasons. Interestingly, these practices were discarded above a certain level of household income with occupants then resorting to use of mechanical systems for delivering improved thermal comfort outcomes, again emphasizing income led suppression of demand.

Practices relating to household ventilation were only found to be linked to income levels, in so much as they were a determinant of household formation and duration of occupancy. Critically, ventilation practices were found to be wholly counter to those assumed in standardised energy assessment tools used in Spain and typical of those used in national calculation methodologies throughout Europe. Household ventilation was intermittent throughout the year, extending to substantially longer periods during the cooling season. This compares to a constant ventilation air change rate of 0.63 r^{-1} used in standardised tools in Spain (CSIC & IDAE, 2015). Clearly, these assumptions do not capture either occupant driven or seasonal practices and further research is required on the timing of ventilation, to ensure that these standardised approaches better reflect householder's adaptive behavior.

Appliance ownership mirrored the conventional model of Southern Europe, with households purchasing in-unit appliances, rather than relying on communal facilities (e.g. building laundry). This permits self-controlled energy practices to emerge and with respect to laundry, these were heavily influenced by discrete energy affordability concerns.

Washing machines owned by the respondents typically belonged to lower efficiency classes despite them being perceived as being a household appliance that had a high energy impact by householders. This gave rise to the development of energy practices, i.e. the generalized choice of cold-water programs, which resulted in actual energy consumption that was significantly lower than national levels. The lack of correlation between ownership of energy efficient appliances and household energy consumption has been reported elsewhere, and emphasizes the importance of considering washing and laundry practices when estimating energy intensity (Ramírez-Mendiola et al., 2017). They also have policy implications, casting doubt on the importance of promoting energy labelling schemes for washing machines to households whose laundry practices result in such a disparity between actual and expected levels of energy consumption. Survey responses indicted very low ownership of clothes-drying appliances, as well as low usage in dwellings which owned a system, with users primarily relying on natural drying. This should be considered in housing planning and design process, for both new build and existing dwellings to provide for drying spaces and opportunities to allow this practice to continue.

The increasingly widespread presence of informatic, entertainment and multimedia equipment, as well as its extending use that can be glimpsed in national surveys is reflected in survey response, emphasizing its increasing importance in determining household energy intensity, even for social housing. For instance, in this survey this equipment type was found to have displaced other appliance groups such as home-lighting and laundry that have traditionally been viewed as being primary contributors to household energy consumption.

The clear evidence of this displacement should serve to raise awareness concerning energy consumption of informatics appliances, which are not perhaps currently perceived as key policy targets in addressing household energy intensity. One of the most striking findings is the progressive loss of importance in the energy use of white goods compared to brown goods, which will disrupt typical forecasting models. This trend has been indicated previously by other authors (see for instance (De Almeida et al., 2011), but an acceleration and expansion of this phenomenon can be seen in the cohort surveyed here.

The work identifies the existence of different levels of energy poverty with various causal factors. Inefficient building envelopes and thermal systems are unable to permit adequate thermal comfort to be affordably achieved in social housing. The buildings pre-date 1979 and therefore lack the envelope energy efficiency levels and buildings energy control capacity defined in building regulations imposed since that date. The envelope heat load coefficient is higher than that recommended by current regulations for the specific climate zone (generally 1.38 W/m^2K as opposed to a limit of 0.94 W/m^2K (Fomento, 2013)). HVAC equipment is inefficient and generally found only in individual rooms. These technological discrepancies are magnified by social factors caused by the post -2007 economic crisis which particularly affects residents of social housing of the type surveyed here. Energy affordability has also been impaired by increases in residential electricity tariffs in Spain during this period.

The greatest inefficiency identified in the study was in the achieved thermal control of the house environment. Even in an area with a climate as benign as the southern coast of the Iberian Peninsula, indoor conditions were usually unfit compared to conventional thermal comfort standards with a significant proportion of households effectively living in free-running environments. Inadequate thermal comfort provision particularly at night during the cooling season is likely to have a direct impact on occupant health. During the heating season, the free running performance of the buildings was exacerbated by inadequate ventilation provision, likely to give rise to impaired indoor air quality and conditions that promote mould growth, particularly significant in coastal areas.

Conclusions

The design of European residential energy policy is predicated on the output from various standardised modelling and calculation processes. The survey of this population group revealed energy practices that differ markedly from those that are typically used as an input to these standardised approaches. In order for policy to become more effective it is imperative that the actual practices that underpin residential energy use, particularly among socio-economic groups who face energy poverty and affordability issues, with less capacity for technology-led adaption is better understood.

This disparity between actual energy practices and those assumed by models that are used to construct energy policy is a widely reported issue. New energy assessment tools may need to be envisaged that place more emphasis on linking practices to household and dwelling meta-data, of the type reported here that allow remedial actions and policy to be brought forward that is redolent of found rather than assumed situations.

Usually home energy control and the related potential for energy conservation is typically a function of both an improvement in efficiency of the technological component and modification of household energy practices. However, in this survey cohort energy profligate habits were generally not prevalent as a consequence of energy affordability. The sub-optimal thermal outcomes being achieved by the survey cohort are likely to be indicative of the wider social housing stock in Spain and cannot be used as an energy baseline for planning, as correcting the iniquities of energy poverty is likely to lead to a release of the demand suppression found here. Caution should be exercised in the development of new policies to address this sub-optimality, formed cognizant of the associated risk of rebound effect and attendant increased energy intensity. Concepts of energy efficiency that consider both practice and technology should guide policy such that it delivers improved user outcomes, keeps energy use under control and addresses actual affordability.

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