18. Mixed method for determining the air-conditioning consumption in households. Application to Andalusia

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Abstract Energy characterization of the residential building stock is a main objective within the energy efficiency research field. The final-energy consumption profile in households represents the distribution of the actual energy consumed therein. Obtaining this profile from various sources and studies shows major differences depending on the methodology used in each case, when contrasting actual final-energy figures versus prediction based figures. In this research, we focus on the final-energy consumption fraction for household air-conditioning in Andalusia, where the higher cooling demand has become a typical distinctive feature of warm climates. To this end, a new mixed method has been developed as an alternative to other approximations, such as those of the final report of the SECH SPAHOUSEC project. As a result of its application, final-energy consumption in households is obtained by means of the integration of data from various sources: sectorial statistics of energy consumption, statistics of habitual use and domestic equipment or results of energy models simulations, representing the whole residential building stock of Andalusia.

Keywords Energy consumption; air-conditioning; households; energy efficiency; energy statistics.

1 Introduction

The final-energy consumption profile in households is a representative indicator of the actual use of the energy consumed therein. Obtaining this profile from various different sources and studies (Ayala, Galarraga and Spadaro, 2016; Castelli et al., 2015; Sendra et al., 2013; León et al., 2010) shows major differences

depending on the methodology used in each case. This work is focused on the fraction of energy consumption used for air-conditioning (heating / cooling) of housing in Andalusia.

The final report of the SECH SPAHOUSEC project (IDAE, 2011) is noteworthy when considering the background studies on the energy consumption profile in Spain in general, and particularly in Andalusia. To date, it could be considered the main reference for Spain.

The EU project, SECH (development of detailed Statistics on Energy Consumption in Households), was promoted in 2009 by Eurostat for the development of energy statistics in the residential sector by means of *bottom-up* methodologies, including monitoring and modelling techniques. The *Instituto para la Diversificación y Ahorro de la Energía* (IDAE) and the Government of Spain submitted to Eurostat the SPAHOUSEC Project (Analysis of the Energy Consumption in the Spanish Households) within the framework of SECH.

According to the final report of SPAHOUSEC, the study, developed in Spain, included live and telephone surveys about home appliances, behaviour and energy consumptions in households besides electricity consumption monitoring. As a result of the project, the determination of the aggregate energy consumption by services and applications, climate and housing building typologies throughout Spain zones is shown.

The results of residential consumption by the *bottom-up* approach were finally contrasted with the energy information available through procedures *top-down*, from studies such as the official energy statistics (MINETUR, 2013).

The SPAHOUSEC study shows an acceptable degree of affinity between its results and the derived from the official energy statistics, as stated in Table 1.

Table 1 SPAHOUSEC Energy consumption (IDAE, 2011) vs. 2010 final-energy balance (MINETUR, 2013) (Author's own)

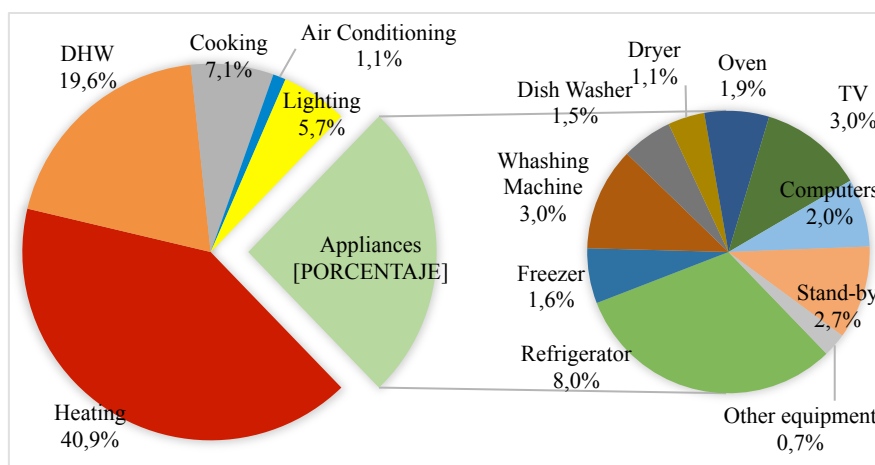FINAL-ENERGY CONSUMPTION IN SPAIN REPORT. RESIDENCIAL SECTOR.

	Year 2010		SPAHOUSEC (ktep)	Final* (ktep)	% Deviation (SPAHOUSEC vs. Final)
Consumption by type of final-energy	**Carbon**	Coal & others	15	173	**-91%**
	Petroleum products	LPG	*1.032*	*1.386*	*-26%*
		Gasoil	*2.216*	*1.871*	*18%*
		Others	*0*	*112*	*-100%*
		TOTAL	3.248	3.369	**-4%**
	Gas	Natural & gas others	3.660	4.257	**-14%**
	Renewable energy	Solar thermal	*139*	*144*	*-3%*
		Geothermal	*12*	*9*	*33%*
		Biomass	*2.444*	*2.464*	*-1%*
		TOTAL	2.595	2.617	**-1%**
	ELECTRIC ENERGY		5.159	6.508	**-21%**
	TOTAL		**14.676**	**16.924**	**-13%**

(*) Actual Final-energy consumption in 2010. Source: MINETUR/IDAE

However, at SPAHOUSEC, an apparently underestimated consumption in the residential sector (-21% in electricity, -4% in petroleum products, -14% of gas) occurs regarding data obtained from energy supply companies (MINETUR, 2013), which may be due to the wide spread presence of consumption of small shops and businesses using domestic energy tariffs. Nevertheless, an overall 13% dispersion of the proposed values compared to those actually registered may be considered as technically acceptable.

SPAHOUSEC also provides a disaggregated energy consumption of households in Spain classified into various services and applications and is further segmented into climatic zones and housing typologies.

According to the aims of this work, in the Figure 1 the results are shown for households in the Andalusia region, which is included within the Mediterranean

 Fig. 1 Household energy consumption according to its use in Spain: Mediterranean area (IDAE, 2011).

area.

As stated in the final report of SPAHOUSEC, the energy consumption for indoor space cooling in household dwellings in Andalusia accounts for only 1.1%, compared with 40.9% for indoor space heating.

These percentages do not coincide with those in other social housing studies in the same region (Leon et al., 2010; Sendra et al., 2013), which have been obtained by means of surveys and monitoring of buildings in real use conditions.

In this paper, we will try to determine, through a bottom-up approach, the energy consumption of air-conditioning (heating + cooling) for the Andalusian residential building stock.

2 Initial data

The different information sources consulted for the determination of the energy consumption of air-conditioning of households in Andalusia are described below.

2.1 Energy demand for indoor space heating and cooling and water heating. CO2 emissions and primary-energy consumption

In order to establish the scale of energy efficiency labelling for existing dwellings in Spain, AICIA (2011) conducted a study to obtain a baseline adapted to the typology and climatic zone in each case. To this end, many simulations with several energy models, tested in various orientations and climatic zones, were performed in order to obtain the reference level which would be used in the energy labelling scale in each case. Each location's (provincial capital cities) climate file were taken into account and the standards for use and operational conditions were stablished.

The results themselves, summarized in Table 2, constitute a useful starting point for energy characterization of the Andalusian residential building stock, as they have been obtained by the energy simulation of typological and constructive models, which are representative of the whole set of buildings.

Table 2 Indicators of energy demand, consumption and CO_2 emissions of households in Andalusia, Ceuta and Melilla (Author's own from AICIA, 2011).

Single-family dwellings	Energy demand (kWh/m²)			Primary-energy consumption (kWh/m²)			Emissions (kgCO₂/m²)		
Location	Heat.	Cool.	DHW	Heat.	Cool.	DHW	Heat.	Cool.	DHW
Almería	44,7	46,8	16,6	87,4	47,8	26,1	21,4	11,7	6,3
Cádiz	50,7	36,1	16,7	94,7	36,8	26,2	21,9	9,1	6,3
Ceuta	75,2	14,2	17,2	134,2	18,6	28,4	35,9	5,4	7,7
Córdoba	78,8	54,4	16,9	176,4	55,4	26,5	41,6	13,7	6,4
Granada	127,5	29,9	17,6	240,8	30,5	27,6	56,9	7,4	6,7
Huelva	70,4	44,6	16,7	165,0	45,4	26,2	37,8	11,2	6,3
Jaén	104,8	53,7	16,7	198,1	54,7	26,2	46,9	13,5	6,3
Málaga	50,6	39,4	16,7	108,5	40,1	26,2	24,6	9,8	6,3
Melilla	45,0	35,5	16,7	97,6	46,3	27,6	26,8	13,3	7,5
Sevilla	64,4	56,4	16,7	141,1	57,6	26,2	34,0	14,2	6,3

Average	71,2	41,1	16,9	144,4	43,3	26,7	34,8	10,9	6,6

Multi-familiy housing build-ings	Energy demand (kWh/m²)			Primary-energy consumption (kWh/m²)			Emissions (kgCO₂/m²)		
Location	**Heat.**	**Cool.**	**DHW**	**Heat.**	**Cool.**	**DHW**	**Heat.**	**Cool.**	**DHW**
Almería	49,2	33,7	12,1	63,7	34,5	19,0	15,6	8,5	4,6
Cádiz	33,7	25,7	12,3	60,8	26,3	19,3	15,0	6,5	4,7
Ceuta	60,6	10,1	12,6	111,2	13,3	20,8	29,5	3,9	5,7
Córdoba	64,2	39,5	12,4	129,2	40,3	19,5	31,9	9,8	4,7
Granada	106,6	22,0	12,9	193,0	22,5	20,3	46,1	5,4	4,9
Huelva	43,0	32,2	12,3	101,8	33,0	19,3	24,8	8,1	4,7
Jaén	83,5	39,4	12,3	158,1	40,0	19,3	38,2	9,8	4,7
Málaga	41,4	28,4	12,3	84,0	28,9	19,3	20,4	7,0	4,7
Melilla	31,6	25,1	12,2	71,4	32,9	20,1	19,7	9,5	5,5
Sevilla	52,9	41,2	12,3	112,1	42,2	19,3	27,4	10,5	4,7
Average	**56,7**	**29,7**	**12,4**	**108,5**	**31,4**	**19,6**	**26,9**	**7,9**	**4,9**

2.2 Presence of equipment and cooling systems in Andalusia

Data of air-conditioning equipment in households is obtained from the "social survey 2008: Households and environment in Andalusia", conducted by *the Instituto de Estadística de Andalucía* (IEA), shown in Table 3.

Table 3 Presence of air-conditioning in households in Andalusia (IEA, 2008).

7.a. Households having air-conditioning (cooling systems) according to situation, type and habits for nocturnal use (Series by provinces with horizontal percentages).									
Instituto de Estadística de Andalucía CONSEJERÍA DE ECONOMÍA Y HACIENDA			Rooms with air-conditioning			Type of system		Nocturnal use habits	
Province	**Total households**	Air-conditioning presence	All	Most of them	Only one part	Individual	Central	Never turned off	Average T (ºC)
Almería	**234.101**	**52,2**	6,8	9,2	36,3	46,9	5,2	7,5	23,9
Cádiz	**414.684**	**46,6**	2,1	3,7	40,7	44,6	2,0*	2,2*	22,6*
Córdoba	**275.544**	**65,6**	11,5	5,4	48,7	58,7	6,8	4,8	23,1
Granada	**319.888**	**38,3**	2,3*	3,8	32,2	37,3	1,0*	1,5*	21,2*
Huelva	**183.775**	**51,6**	2,2*	5,6	43,8	47,8	3,6	2,3*	22,9*
Jaén	**219.618**	**62,4**	3,3	5,4	53,8	60,7	1,7*	11,8	24,5
Málaga	**554.688**	**44,8**	5,3	8,2	31,3	41,3	3,6	1,7*	25,3*
Sevilla	**614.360**	**84,4**	7,7	9,4	67,4	78,2	6,2	6,2	24,2
Total	**2.816.658**	**57,4**	**5,4**	**6,7**	**45,3**	**53,5**	**3,9**	**4,3**	**23,9**

SOURCE: IEA. Social survey 2008: Households and environment in Andalusia
* The underlying sample size is lower than 20 cases, so the statistical reliability of the estimation is scarce

In summary, it is worth noting that in the whole of Andalusia, 57.4% of all households have air conditioning. This is equivalent to consider that in Andalusia in 2008 there were already 1.617.761 dwellings with air cooling system available.

2.3 Conversion factors of final-energy, primary-energy and CO_2 emissions

For the conversion operations between final-energy, primary-energy and CO_2 emissions it is necessary to deduce the final- energy consumption from the primary-energy obtained from Table 2. For this purpose, the conversion factors that will be used throughout the process are listed in Table 4.

Table 4 Conversion factors of primary-energy for indoor space heating and cooling to final-energy according to the consumption framework of Andalusia (Author's own from IAE-2008 survey)

	Final-energy	% Type of fuel over total *	General conversion factor** (kWh Primary E./ kWh Final E.)	Andalusia conversion factor (kWh Primary E./ kWh Final E.)
Cooling	Electricity	100%	2,61	2,61
Cooling factor				**2,61**
Heating	Electricity	53%	2,61	1,38
	Natural gas	8%	1,07	0,09
	Gasoil	7%	1,12	0,08
	Heat pump	9%	2,61	0,23
	Others	24%	1,05	0,25
Heating factor				**2,03**

(*) Source: Table 3.a. Households according to heating system presence by dwelling characteristics in Andalusia. Year 2008. (IEA,2008).
(**) Source: Recognized document (RITE, 2016), p.16.

2.4 Features of the Andalusian residential building stock and its air conditioning.

In Table 5, a synthesis is shown of the assumed starting conditions to conduct the energy consumption calculation. These conditions were used in a former study for the characterization of residential building stock in Andalusia, developed by the *Agencia de Vivienda y Rehabilitación de Andalucía* (AVRA) in 2012.

Table 5 Basic characterization of the Andalusian residential building stock. (MARIE Study,

Households in multi-family buildings / percentage they represent	1.806.302	71 %
Households in single-family buildings / percentage they represent	745.136	29 %
Total households	2.551.438	100 %
Surface of average household in multi-family housing building (m²)	75	
Surface of average household in single-family dwelling (m²)	100	
Surface of the *average household* in Andalusia (m²)	82,3	
Heated surface (m²) & (%) in the *average household*	61,73	75 %
Cooled surface (m²) & (%) in the *average household*	41,15	50 %

AVRA, 2012)

3 Methodology

As a methodological alternative to aforementioned approaches, for the determination of the air-conditioning consumption of households, a new mixed-type (*bottom-up* and *top-down*) estimation method is proposed, starting from a previously expressed data series. The method includes applying values from the average simulations results of energy models (AICIA, 2011) that represent the whole national residential building stock, for its subsequent extrapolation after corrections to the Andalusian residential buildings stock. This mixed-type method can contribute to fine tune certain results which have hitherto been indirectly obtained through surveys or monitoring, as in SPAHOUSEC. This methodology could also be applied to other Mediterranean European regions or even other countries with an equivalent energy scenario.

In this section, is explained the calculation process that is used to obtain the values for space heating and cooling energy consumption of households in Andalusia through a *top-down* approach, starting from the sources mentioned in section 2.

The operating procedure is shown in Table 6, which essentially consists the following steps:
1. Values are expressed in rows of each province and the total.
2. In columns B to E, the distribution of the number of households per province is indicated and the presence of heating and cooling system in each case.
3. Columns F to I include data of annual primary-energy consumption for indoor space heating and cooling for single-family and multi-

family typologies expressed in kWh/m², obtained from the simulation of energy models (AICIA, 2011).

4. The values of annual primary-energy consumption (columns F to I) are converted into annual energy consumption per household (columns J to M), by adopting the values of 75 m² and 100 m² for multi-family housing buildings and single-family dwellings, respectively.

5. The N and O columns express annual consumption values by weighted housing, taking a 71% to 29% ratio for multi-family and single-family homes respectively, for the whole of Andalusia.

6. In the P and Q columns, the proportion of households in the considered province with respect to the total is assigned to the preceding values (multiplied by the factors in column C). Thus, a total value is obtained as the sum of the unit values of each province weighted by their proportion of the overall weight. The total corresponds to the average value of primary-energy consumption for space heating and cooling, assuming that all surfaces of the household are thermally conditioned, and all dwellings have heating and cooling equipment available.

7. In the R and S columns the previous unit values are diminished by the percentage of heating and cooling availability in each province, thereby obtaining the total value weighted with the actual presence of the air-conditioning equipment.

8. The T and U columns show the proposed final values obtained by weighting the previous columns with the percentage of the thermally conditioned surface in each household. For the whole of Andalusia 2.334,73 kWh and 943,65 kWh annual values of primary-energy for heating and cooling consumption are obtained respectively.

9. In the V and W columns, after correcting their percentage over the total value, unitary values per household for each province are shown.

10. At the bottom of the table the final-energy for space heating and cooling consumption values is calculated by applying the conversion factors formerly registered in Table 5.

Table 6 Auxiliary and intermediate calculations for the determination of the annual final-energy for indoor space heating and cooling consumption (Author's own).

A	B	C	D	E
Pr.	Number of households	Proportion over total (%)	Heating availability (%)	Cooling availability (%)
AL	234.101	8%	23,38	52,21
CA	414.684	15%	42,22	46,9
CO	275.544	10%	59,59	65,62
GR	319.888	11%	40,24	38,30
HU	183.775	7%	68,60	51,56
JA	219.618	8%	44,84	62,43
MA	554.688	20%	32,12	44,82
SE	614.360	22%	47,02	84,41
Tot.	2.816.658	100%	43,11	57,44

A	F	G	H	I	J	K	L	M
	C_{ep} (kWh/m²)				C'_{ep} (kWh)			
	Heating		Cooling		Heating		Cooling	
Pr.	S.F.	M.F.	S.F.	M.F.	S.F.	M.F.	S.F.	M.F.
AL	28,7	63,7	47,8	34,5	2.870	4.778	4.780	2.588
CA	24,9	60,8	36,8	26,3	2.490	4.560	3.680	1.973
CO	55,5	129,2	55,4	40,3	5.550	9.690	5.540	3.023
GR	81,1	193,0	30,5	22,5	8.110	14.475	3.050	1.688
HU	31,2	101,8	45,4	33,0	3.120	7.635	4.540	2.475
JA	57,9	158,1	54,7	40,0	5.790	11.858	5.470	3.000
MA	35,1	84,0	40,1	28,9	3.510	6.300	4.010	2.168
SE	40,5	112,1	57,6	42,2	4.050	8.408	5.760	3.165

A	N	O	P	Q	R	S	T	U	V	W
	$C'_{ep.}$ (kWh)									
Pr.	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.	Heat.	Cool.
A	4.220	3.228	351	268	82	140	62	70	740	843
CA	3.955	2.471	582	364	246	170	184	85	1.253	576
CO	8.481	3.758	830	368	494	241	371	121	3.790	1.233
GR	12.616	2.085	1.433	237	577	91	432	45	3.808	399
HU	6.316	3.078	412	201	283	104	212	52	3.250	793
JA	10.086	3.721	786	290	353	181	264	91	3.392	1.162
MA	5.485	2.706	1.080	533	347	239	260	119	1.322	606
SE	7.135	3.923	1.556	856	732	722	549	361	2.516	1.656
Total C'_{ep}			7.031	3.116	3.113	1.887	2.335	944		
Total C'_{ef}							1.162	362		
Total final-energy for air conditioning consumption (kWh)							**1.523,41**			

4 Results and discussion.

The values obtained in this paper versus the SPAHOUSEC project values are expressed in Figure 2. Since the results of the latter are based on statistical approaches, using surveys and monitorings, the outcomes of this study were obtained from energy demands under standard use and operational conditions, although corrected by the degree of equipment and the percentage of actual conditioned surface described in specific statistics of households and environment in Andalusia.

The results of this study show that there is a theoretical average energy demand of similar magnitude for cooling and heating (Figure 2), which carries a similar proportion of energy consumption for such purposes.

Fig. 2 Compared results of annual final-energy for heating and cooling consumption in households (Author's own).
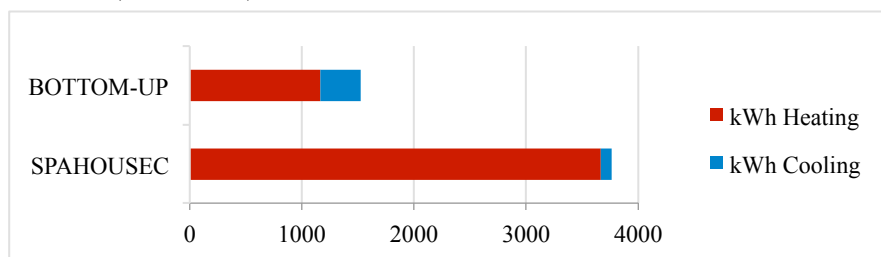
The fact that this mixed-method obtains an annual consumption for air conditioning (heating + cooling) of 1532 kWh per household, compared to 3763 kWh predicted in the SECH-SPAHOUSEC Project, demonstrates the large differences (more than double) between the application of one or another method.

The annual final-energy for heating and cooling consumption is, once corrected, shown in Table 7. These deducted consumption values will represent a new cast (22,5% for air-conditioning) for the contributions of the various types of energy consumption source in households, compared to that offered by SPAHOUSEC (42% for air-conditioning) for Andalusia.

Table 7. Distribution of the annual energy consumption in households calculated for Andalusia versus the obtained in SPACHOUSEC (Author's own).

Annual final-energy consumption by application in households. Mediterranean region, SPAHOUSEC				
Energy appli-cation	kWh/m^2	kWh	%	
Heating	44,52	3.664,23	41%	
DHW	21,34	1.755,96	20%	
Cooking	7,73	636,09	7%	
Home-appliances	27,87	2.293,50	26%	
Lighting	6,20	510,66	6%	
Cooling	1,20	98,55	1%	
Average total consumption	108,86	8.959,00	**100**	
Annual final-energy consumption by application in households in Andalusia (Author's own)				
Energy appli-cation	kWh/m^2	kWh	%	
Heating	14,12	1.161,86	17%	**
DHW	21,89	1.801,60	27%	**
Cooking	7,73	636,09	9%	*
Home-appliances	27,87	2.293,50	34%	*
Lighting	6,20	510,66	8%	*
Cooling	4,39	361,55	5%	**
Average total consumption	82,20	6.765,27	**100**	

(*) Final-energy consumption values adopted from SPAHOUSEC
(**) Final-energy consumption values obtained from the *bottom-up* mixed-method

5 Conclusions

From the results of the application of the proposed mixed-method, a set of representative values of energy for air-conditioning (heating and cooling) consumption is obtained. This outcome is much more consistent with the actual greater availability of air-conditioning equipment and with the standard use profile than those obtained by other *top-down and bottom-up* mixed methods.

The method involves the application of average values obtained by simulation of energy models representing the national residential building stock, for their extrapolation to cover the whole set. This could contribute toward the fine tuning certain results that have hitherto been indirectly studied through surveys and monitorings.

The outcomes of the study forecast a higher final-energy for heating consumption than for cooling consumption, although this difference (the former two to three times greater than the latter) is not as dramatic as that obtained by SPAHOUSEC.

Overall, an average annual final-energy for air-conditioning (heating + cooling) consumption per household of 1532 kWh is obtained, compared to the 3673 kWh stated in SPAHOUSEC for the Mediterranean area (which is more than double the previous figure).

These outcomes underline the noticeable differences obtained between applying the methodology described in this study, which uses energy demand (under standard conditions of use and operation) estimations, corrected by the availability of equipment and the percentage of area actually conditioned as described in specific statistics for households and environment of Andalusia, and other more general studies, such as SPAHOUSEC.

A contrast of these results with studies of a more specific nature, including monitoring and individual energy consumption metering of different uses, could contribute to a better adjustment of the proposed method.

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7 Abbreviations used

C_{ep}.	Annual primary-energy consumption
C'_{ep}.	Annual primary-energy consumption per household.
C'_{ef}.	Annual final-energy consumption per household.
Cool.	Cooling
DHW	Domestic hot water
Heat.	Heating
M.F.	Dwellings in multi-family housing buildings
Pr.	Province
S.F.	Single-family dwellings
T.	Temperature

8 Acknowledgements