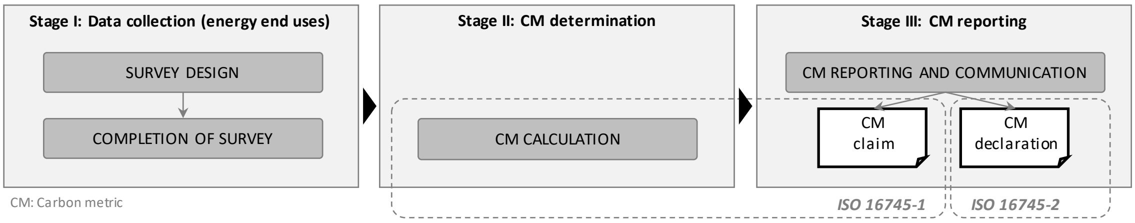
CARBON METRIC OF THE HOUSEHOLD SECTOR IN THE USE STAGE ACCORDING TO ISO 16745: A CASE STUDY

Abstract

The upward trend in the residential sector of energy use has significant consequences in terms of environmental impacts. Determining the carbon metric (CM), as part of the whole carbon footprint of a building, contributes to quantify the carbon emissions related to the building's use stage. Although many carbon footprint calculators exist in other sectors, none has been specifically designed and applicable to the building one. However, ISO 16745 provides guidelines for calculating and reporting the CM of existing buildings in operation. In this context, this work sets a methodology to measure the CM of existing households' use stage, based on ISO 16745 and split into three stages. The implementation of the methodology to a case study proved its applicability since it enabled the data collection task through the designed survey, and allowed the energy carriers and end-uses be disaggregated, quantified and clearly reported for user's knowledge. The study outlined that calculating the CM and, more specifically, reporting and making the results publicly available, help raise users' awareness about reducing greenhouse gas-related emissions, and provide new ideas for monitoring, benchmarking and proposing policies at individual member state and EU levels.

Keywords: ISO 16745; carbon metric; household sector; use stage; household survey

Graphical abstract



Highlights

- Carbon metric calculation and reporting of households’ use stage
- Methodology based on International Organization for Standardization 16745:2017
- Proposal of a survey for data collection and a disclosure report template
- Energy use data collection from household’s actual consumption
- Contribution to users’ awareness on reducing household emissions-related

1. Introduction

According to the latest Eurostat data, the residential sector represented 25.4% of the final energy use in the European Union (EU) in 2016 (Eurostat, 2018). Diverse factors can explain the upward trend in energy use in recent years, mainly due to an increased number of households, greater comfort demanded for heating and cooling spaces, domestic hot water (DHW), cooking and lighting, and also an increase in electrical appliances in homes to satisfy occupants' commodities (Eurostat, 2013). In environmental impacts and energy dependence terms, the consequences of this rising trend are relevant, and they also oppose the EU 2030 climate and energy framework to achieve 40% cuts in greenhouse gas (GHG) emissions from levels in 1990, increase by 27% the share of renewable energies and improve energy efficiency by 27% (EC, 2014).

In particular, the main energy use spent by households in the EU is for heating, which accounts for 64.7% of the final energy use. The electricity used for lighting and electrical appliances represents 13.8%, which is similar to that spent on heating water at 14.5%. Cooking services require 5.4% of energy end use, cooling spaces accounts for 0.3% and other end uses cover 1.3% (Eurostat, 2018). This use is produced in the operation stage of buildings, the most influential one which, in terms of the whole building's life cycle, typically accounts for 70% to 80% (ISO 16745-1, 2017). Therefore, the use stage of a building implies most GHG emissions and should focus on assessment, measurement and reporting.

In the past few years, different regulations in the building sustainability assessment field have come about (see Figure 1). By taking the methodological framework of the Life Cycle Assessment (LCA) methodology (ISO 14040, 2006; ISO 14044, 2006) as a reference, EN 15643-1 (2010) proposed the general framework for the sustainability assessments of buildings which, with EN 15643-2 (2011), EN 15643-3 (2012) and 15643-4 (2012), completed the principles for the environmental assessment and the socio-economic performance assessment, respectively.

Subsequently, 15643-5 (2017) extended the general framework to civil engineering works. At the building level, the calculation method for the sustainability assessment is proposed by EN 15978 (2011) for environmental performance, EN 16309 (2014) for social performance and EN 16627 (2015) for economic performance. In the present-day, a similar structure of standards is proposed at the civil engineering work level.

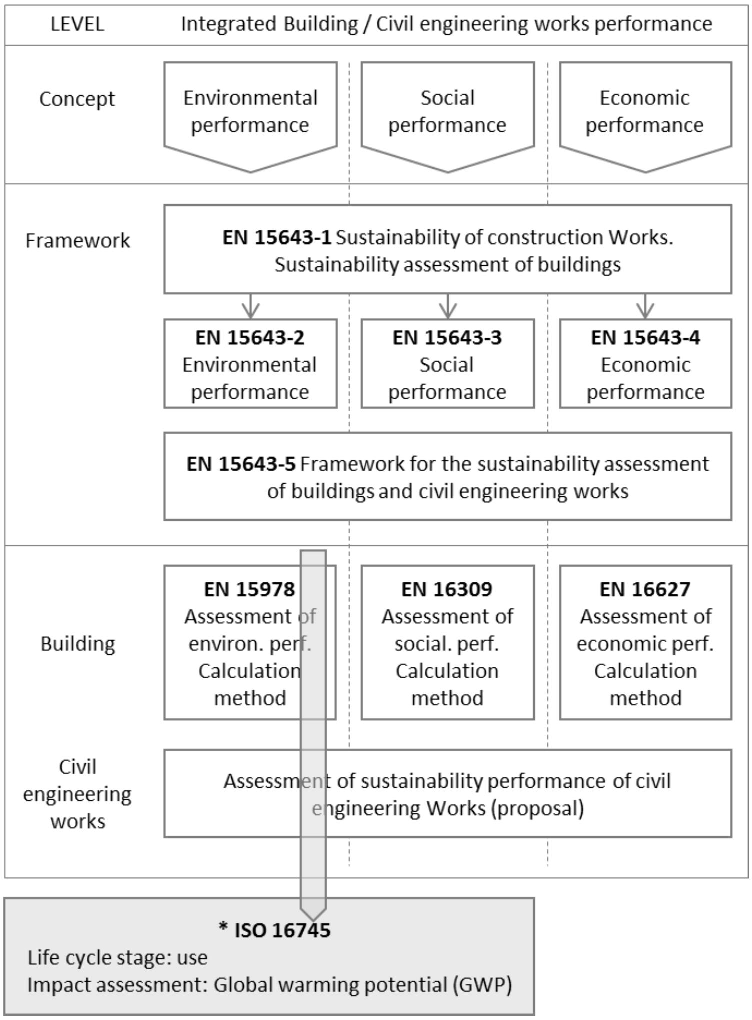


Figure 1. Business programme of CEN/TC 350 (based on UNE-EN 15643 (2012))

Particularly, and in relation to the environmental performance assessment of buildings, EN 15978 (2011) established the calculation method for the "cradle to grave" impact of buildings using LCA, and based on the modular structure of information from the Environmental Product Declaration (EPD) included in EN 15804 (2012). The modularity principle allows the building's environmental performance to be assigned during its life cycle to the module in the life cycle where it occurs. As shown in Figure 2, the system boundary is divided into the product, construction process, use and end-of-life stages, plus benefits and loads beyond the system boundary, each of which contains different modules.

BUILDING LIFE CYCLE STAGES														
PRODUCT			CONSTRUCTION PROCESS		USE					END OF LIFE				BENEFITS AND LOADS BEYOND
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse Recovery Recycling potential
					B6	Operational energy use								
					B7	Operational water use								

Figure 2. Modules for the building's different environmental performance assessment stages (adapted from EN 15978 (2011))

In this context, ISO 16745 (2017) focuses on evaluating the environmental performance of the use stage in terms of the building and its reporting as a carbon metric measurement (partial carbon footprint). Determining the carbon metric of an existing building or curtilage firstly implies obtaining energy use data, which derive from the building in operation. The use stage of buildings (module B6) covers the period from the practical completion of construction work to the time point when the building is deconstructed or demolished. The boundary in B6 includes impacts of the energy used by building-integrated technical systems during while the building was in operation. This implies determining the energy performance of a building on the basis of the calculated or actual annual energy used to meet the different needs associated with the building's defined uses, as covered by the Energy Performance of Buildings Directive (EPBD, 2010, 2002), which are: heating, DHW, air conditioning (cooling and humidification/de-humidification), ventilation, lighting, and auxiliary energy used for pumps, control and automation. As also required by EPBD, the energy supply by renewable sources should be taken into account so that all energy-generating units (e.g. photovoltaic cells, solar thermal panels, wind mills and ground- or air source-type heat pumps) located on the building's site are included in the assessment.

Beyond the boundary of buildings, the carbon footprint calculation has been widespread in recent years, based on protocols and standards such as the GHG Protocol (2004), PAS 2050 (2011), ISO 14064-1 (2006), EN ISO 14064-2 (2006), ISO/TR 14069 (2013) or ISO/TS 14067 (2013). This has led to the proliferation of carbon footprint calculators that focus on individuals' lifestyles (Birnik, 2013; Harangozo and Szigeti, 2017; Kenny and Gray, 2009; Padgett et al., 2008), corporations (Belkhir et al., 2017; Bermeo et al., 2018; Downie and Stubbs, 2013; Lam et al., 2018), agriculture (Colomb et al., 2012; Peter et al., 2017; Sykes et al., 2017; Whittaker et al., 2013), etc. However, none of these tools is especially designed and applicable to calculate the carbon footprint of a whole building or specifically of the use stage.

If we take this context into account, the present study aims to bridge this gap and presents a methodology to determine and report the carbon metric (CM) of the use stage of existing buildings. The method presented herein is based on ISO 16745 (2017). The paper is structured as follows: Section 2 describes the methodology for CM determinations, which is divided into three main stages: Stage I: data collection; Stage II: CM determination; Stage III: CM reporting. Section 3 addresses the description of the case study selected to implement the methodology, which is approached subsequently in Section 4 according to the three stages. The study finishes with the discussion of the results and conclusions.

2. Methodology for CM determination and reporting

The methodology used to determine the CM of the use stage of existing households is based on ISO 16745 (2017). This standard aims to set out a globally applicable common method of measuring associated GHG emissions (and removals) attributable to existing buildings by providing the requirements for determining, reporting, communicating and verifying a CM of a building related to the use stage. ISO 16745 (2017)(2017) applies to residential or commercial buildings, either individually or taking part of a building complex, but does not include provisions for regional or national building stocks. It should also be taken into account that it does not include any method to model the operational energy use of a building and is not an assessment method for evaluating a building's overall environmental performance as a building-rating tool does.

According to ISO 16745 (2017)(2017), the CM is defined as the sum of annual GHG emissions and removals, which are expressed as CO_2 equivalents (CO_{2eq}) and are associated with a building's use stage. This is calculated from the energy delivered for each energy carrier, plus on-site energy, if any, produced without using the delivered energy and is used in the building, and/or for other energy use on the building's site multiplied by the respective GHG emission coefficient, as provided in the following formula:

$$m \cdot CO_{2eq} = \sum\left(E_{del,ci} \times K_{del,ci}\right) + \left(E_{site,ci} \times K_{site,ci}\right) \qquad \text{[eq.1]}$$

where, $m \cdot CO_{2eq}$ is the mass of GHG emissions as CO_2 equivalents; $E_{del,ci}$ and $K_{del,ci}$ are the delivered energy and the GHG emission coefficient for the delivered energy carrier, respectively; and $E_{site,ci}$ and $K_{site,ci}$ are the energy produced on site and the GHG emission coefficient for the on-site energy carrier, respectively.

The CM can also be reported by other indicators in the form of carbon intensity, which represents the CM expressed in relation to a specific reference unit related to a building's function. The CM is measured by $kgCO_{2eq}$/year and carbon intensity by, for instance, $kgCO_{2eq}/m^2$·year or $kgCO_{2eq}$/occupant·year.

The methodology proposed to determine and report the CM requires following a previous process to obtain data on household characteristics and household energy use. This is no easy process, rather a burdensome one as it requires accuracy and transparency to acquire reliable and evidence-based data. Figure 3 sets out the scheme for the proposed methodology, which is described below.

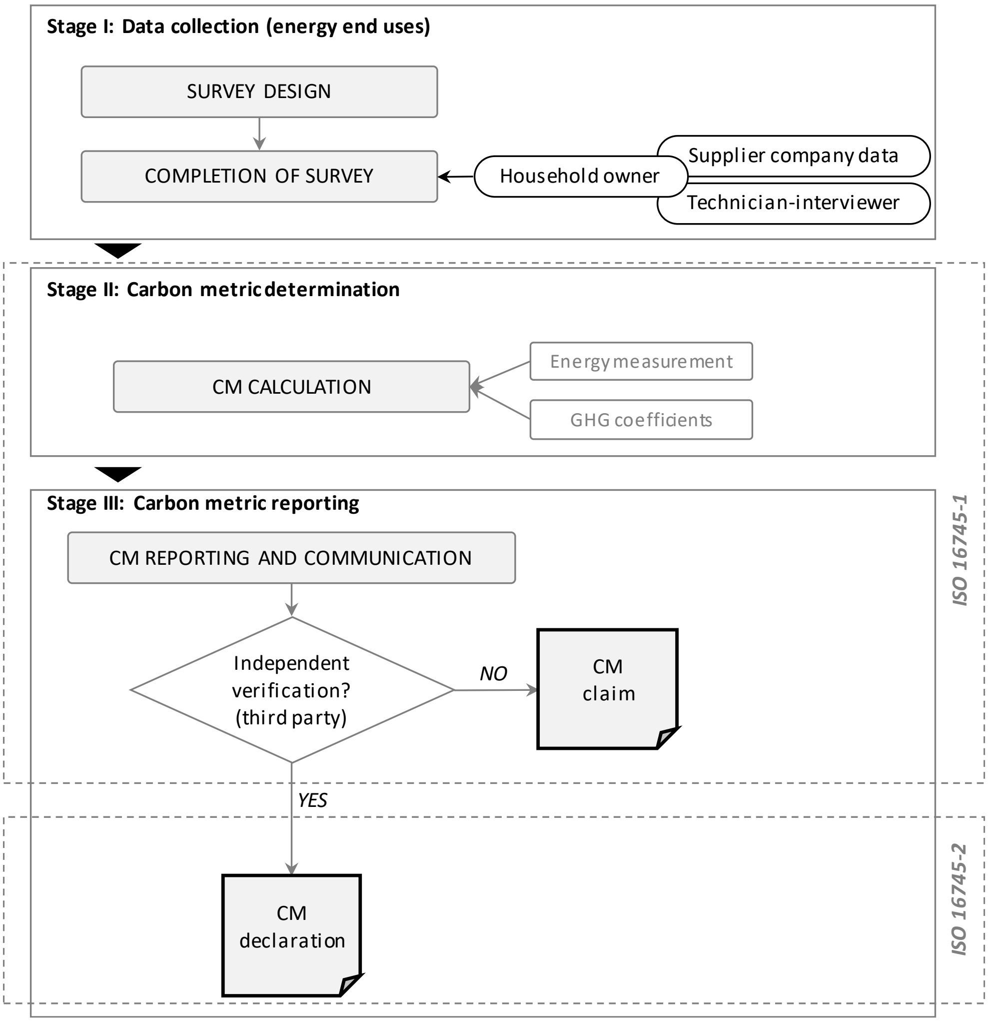


Figure 3. Methodology flow for CM determination and reporting

2.1. Stage I: Data collection method

As a first step, data collection involves measuring the energy carriers that account for all the sources delivered to, and generated within, the system boundary; e.g. electricity, fuels and imported cooling or heat. As ISO 16745-1 states (2017), these data can be retrieved from electricity bills, gas bills, invoices for fuel deliveries, utility provider reports, meter readings, pipeline measurements or energy management software. If applicable, on-site generated energy can be obtained from meter readings and measuring the amount of used biomass. Several methods allow these actual data to be acquired: business surveys, household surveys, use of administrative data and *in situ* measurements. They are all valid, but imply some advantages and disadvantages that make them appropriate for a particular or certain purpose. They are summarised in Table 1, which depicts the pros and cons of each one, where the *in situ* measurements provide the best quality data and enable energy use to be distinguished per individual household appliance, along with patterns of use. However, this method is quite expensive as it requires installing monitoring devices in each appliance and implies lengthy times and time- and human resource-timing tasks. In most cases, owners are not willing to participate in monitoring programmes given the technique's invasive implications. Generally, only small samples can be retrieved, which are poorly representative (Eurostat, 2013).

In contrast, administrative data contain many records, which allows using existing information and, thus, avoids duplication. However, permissions are usually required to access data and legal barriers are frequent. It also depends on third parties and available data do not always adapt to the requirements for collecting energy use data.

Halfway between both, business and household surveys can be found. Sometimes, energy providers are likely to know more up-to-date information on the amount of energy supplied to customers than customers themselves. They often distinguish billing information on tax rates applied to use, which differ for household, industrial and commercial customers, which makes business surveys a good option. Nevertheless, legal requirements about providing data exist, so response rates and quality can suffer if only voluntary data are collected. When relying on business surveys, some existing fuels might not be measured by meter (e.g., coal, oil, wood or butane) as customers can choose among many different energy suppliers, which makes data collection more difficult and less reliable. This does not occur with household surveys because comprehensive information on all used household fuels can be collected and data can be validated by an energy auditor who checks *in situ* the information that owners provide. It also allows data to be directly used as input for model calculations. This technique obviously implies a high respondent burden and time rates, but leads to a high data quality level.

Table 1. Advantages and disadvantages of household data collection methods (adapted from Eurostat (2013))

Data collection method	Advantages	Disadvantages
In situ measurements	• High quality data • Detailed information on individual appliances and patterns of use • Can be input data for modelling	• Invasive for households: difficult to find owners willing to participate • Much time and many human resources spent • Expensive: requires monitoring equipment • Small samples, less representativeness • Constraints in monitoring equipment: limitations in the number of metering devices and good probability of incidences
Household surveys	• Comprehensive information on all the energy carriers used • High data quality level • Data validation process (cross-checking by an energy auditor) • Results can be input data for modelling	• Resource- and time-consuming task • Expensive • High respondent burden
Business surveys	• Timeliness for data and results • Fewer respondents to consider compared to household surveys • Easy to acquire frequent headline consumption data • Use of constraining totals for other surveys and data collection	• Response rates can be low • Lack of detail • Lack of data validation • Reports of non-metered carriers • Inconsistency in the variables held by area-based energy suppliers
Use of administrative data	• Low survey burden • Many more records • Avoids duplication by using existing data • No sample error	• Requires substantial effort and may often be legal barriers to technicians • Dependency on third parties • Available data may not meet collection requirements

Among the above-mentioned methods, the household survey one was selected to conduct this study given its accuracy. So a survey template was designed, which consists of a questionnaire developed specifically to obtain information from the respondent's household. It was designed especially to be as simple and short as possible to reduce respondents' response burden in order to collect data efficiently with a minimum number of errors. The questions asked were accurately posed to be clear, concise and to provide answers suitably so they could be subsequently processed and analysed. The household survey is conducted by qualified technicians (architects and engineers) who act as energy auditors and interviewers, and is based on a face-to-face approach. This is a resource- and time-consuming task but, in turn, ensures that respondents answer questions truthfully, plus a validation by means of cross-checking conducted by a qualified technician. During face-to-face interviews, respondents are informed about the survey objectives and are persuaded to answer questions, which results in a greater involvement and motivation. It provides a higher potential on responding conceptually difficult topics as the technician can solve technical aspects.

The presentation form is easy to follow, and the questions themselves are clear, simple and easy to understand, which avoids ambiguity, and in understandable language to boost the respondents' interest. The survey designed for the purpose of this study accomplished the principles and requirements set by the MESH report (Garcia Montes, 2012) by being simple and specific, and by ensuring that questions were applicable and avoided misinterpretations.

The included information is based, on the one hand, on the recommendations set by Eurostat (2013) as input information for data collection and, on the other hand, on the mandatory requirements established in ISO 16745-1 (2017), taken as output information for reporting the CM, which will finally take part of a disclosure report. These items were considered to design the survey by considering all the relevant information to calculate the CM and to present the results. These are displayed in Table 2, where, they are grouped into four sections, the four that were taken into account to design the survey. Eurostat (2013) classified the items into three categories according to their relevance for understanding energy use in the household sector, as also for their usefulness for energy efficiency monitoring purposes in the household sector: highest (must have) and medium (nice to have) priority and additional information needs.

Table 2. Recommendations for data collecting and CM reporting

	INPUT		OUTPUT		SURVEY DESIGN			
Aspect	(Eurostat, 2013)	Level of priority	(ISO 16745-1, 2017)	**ADDITIONAL INFORMATION**	**General identification**	**Building characteristics**	**Household characteristics**	**Energy information**
Owner/interviewee's name	●	✓✓✓			●			
Client being assessed			●		●			
Name of building			●		●			
Cadastral code				●	●			
Post address			●		●			
Climate zone			●		●			
Age of building	●	✓✓✓	●		●			
Date of assessment			●		●			
Auditor's name			●		●			
Existence of energy certificate				●	●			
Building type and use	●	✓✓✓	●			●		
Number of floors (above ground, underground)			●			●		
Total site area			●			●		
Building structure				●		●		
Building façade (type and insulation)	●	✓✓✓				●		
Building roof (type and insulation)	●	✓✓✓				●		
Building's windows	●	✓✓✓				●		
Building's conservation state				●		●		
Year of change in use (if any)			●			●		
Renovation works (if any)				●		●		
Year of latest major renovation (if any)						●		
Ownership type (owner or tenant)	●	✓✓✓					●	
Occupancy (number of persons)			●				●	
Occupancy (adults, children, retired people)				●			●	
Family income	●	✓✓✓						
Household size (number of rooms)				●			●	
Floor area (gross, net lettable)			●				●	
Free interior height (in metres)				●			●	
Facades' surface per solar orientation (in metres)				●			●	
Wall façade thickness (in metres)				●			●	
Solar protection (if any)				●			●	
Dwelling's windows (e.g. frame, glass, double-glazing, etc.)				●			●	
Operation schedule	●	✓✓✓	●					●
Inventory of energy carriers and use (electricity, natural gas, butane, etc.)	●	✓✓✓	●					●
Domestic hot water (type of boiler, power, fuel)	●	✓✓✓						●
Space heating (type of boiler, power, fuel, terminal units)	●	✓✓✓						●
Space cooling (type of system, power, fuel, terminal units)	●	✓✓✓						●
Cooking (type, fuel, equipment)	●	✓✓✓						●
Electrical appliances (type, number, age, energy efficiency eco-labels)	●	✓✓						●
Annual electricity use (kWh/year)	●	✓✓✓	●					●
- monthly				●				●
- contracted power				●				●
Annual natural gas use (kWh/year)	●	✓✓✓	●					●
- monthly				●				●
Annual butane use (kg/year)	●	✓✓✓	●					●
Annual diesel fuel use (kg/year)	●	✓✓✓	●					●
Penetration of renewable energy sources	●	✓						●

● it applies

✓✓✓highest priority, ✓✓medium priority, ✓additional information needs, according to Eurostat 2008 Task Force (Eurostat, 2013)

After drawing up a first survey draft, it was devised. This pilot survey was personally handed out to a small sample to verify that all the questions were easy to understand, relevant and comprehensible to interviewees. As in other similar studies (Orr et al., 2019), this task is an advisory one performed to obtain relevant initial opinions about the survey's structure and content. Feedback was positive and the survey that was finally run is shown in Supplementary Material 1. The questionnaire is divided into four main sections, from more general to more specific, where each addresses the following information:

- Section 1: general identification. Information about the building's owner, post address, year of construction and cadastral code, which contains relevant data such as built area, plot size or the horizontal division conditions of building's spaces. Whether the building or household has an energy efficiency certificate (EEC) is indicated, which provides important data about theoretical energy performance. Generally, few old households may have an associated EEC as the EPBD (2010) has been widely implemented lately for existing buildings.
- Section 2: building characteristics. It contains the climate zone where the building is located, the area and the typology (multi-family or single-family, detached or terraced, number of households, number of floors and use, among other features). The construction characteristics and the existence of insulation material on the structure, façade, roof and windows are also indicated here, as well as the conservation status and any conducted renovation works, if any.
- Section 3: household characteristics. The social-demographic characteristics, including ownership type (if owner or tenant), number of occupants and age range, and family income are compiled. The survey goes more deeply into the household constructive characteristics as they may vary from the global building ones. These address the length of façades by distinguishing between different solar orientations; number, size and type of frame, and glazing of windows; free interior height and exterior wall thickness; floor area

and number of rooms. Concerning technical building systems, space heating and or cooling and DHW systems are described, including kind of boiler, energy supply, what power fuels equipment and kind of terminal units (e.g., ducts, splits, fans, heat pump, radiators, etc.).

- Section 4: energy information. It approaches energy use information. It retrieves data about the operation schedule of occupants on weekdays and weekends separately; household appliances characteristics (power, year of purchase, energy label if any) and use pattern; cooking system (devices, kind of energy supply and use pattern). The survey ends by compiling the annual energy use data of different carriers over 12 months as a reference of the whole year (displayed monthly) based on supplier bills. These data are provided in kWh/year for electricity and natural gas, and in kg/year for butane, propane or gas. Whether the household or building is supplied by renewable energy and the kind of system are also indicated.

2.2. Stage II: Carbon metric determination

Once data have been collected, the CM can be determined. The CM should be measured by quantifying the direct and indirect GHG emissions and removals associated with a building in use. The system boundary includes all the areas associated with a building, both inside and outside the building, where energy is used or produced. According to ISO 16745-1 (2017), there are three types of CM of buildings, which are defined below:

- CM1: sum of the annual GHG emissions, expressed as CO_{2eq}, from the building-related energy use.
- CM2: sum of the annual GHG emissions, expressed as CO_{2eq}, from the building- and user-related energy use.
- CM3: sum of the annual GHG emissions, expressed as CO_{2eq}, from the building-and user-related energy use, plus other building-related sources of GHG emissions and removals.

Figure 4 is based on the scheme proposed by ISO 16745-1 (2017) for the system boundary and is described as follows. Outside the system boundary, it takes the energy delivered in the form of heat (gas, oil, coal, wood, etc.), or the electricity to supply the technical systems of the building directly or indirectly, the latter by means of district heating or cooling. Inside the system boundary, the energy transformed into the heating/cooling system or produced by renewable energies on-site is distributed to the building's different energy uses (CM1 and CM2). CM1 and CM2 consist of the equipment used to operate the building, which meet demand as energy end use and the technical building systems to deliver, convert, and generate energy for the energy end use. The system boundary includes all the energy-consuming and generating systems that are on the building's site (curtilage) and that support the building's operation. On the one hand, CM1 includes the heating, ventilating and air conditioning (HVAC) and DHW systems, lighting and plug-in (fixed lighting, plug-in lighting, plug-in heating/cooling) and other ultimate uses (indoor transportation, building auxiliary devices). On the other hand, CM2 involves lighting and plug-in (supplementary plug-in lighting, household/office appliances) and other special uses (cooking, refrigeration, devices in data centres and other specific functional devices). For CM3, the system boundary includes, whenever significant: maintenance (cleaning, repair, replacement and refurbishment), water use, waste treatment and disposal, and refrigerant emissions from the building's air cooling systems.

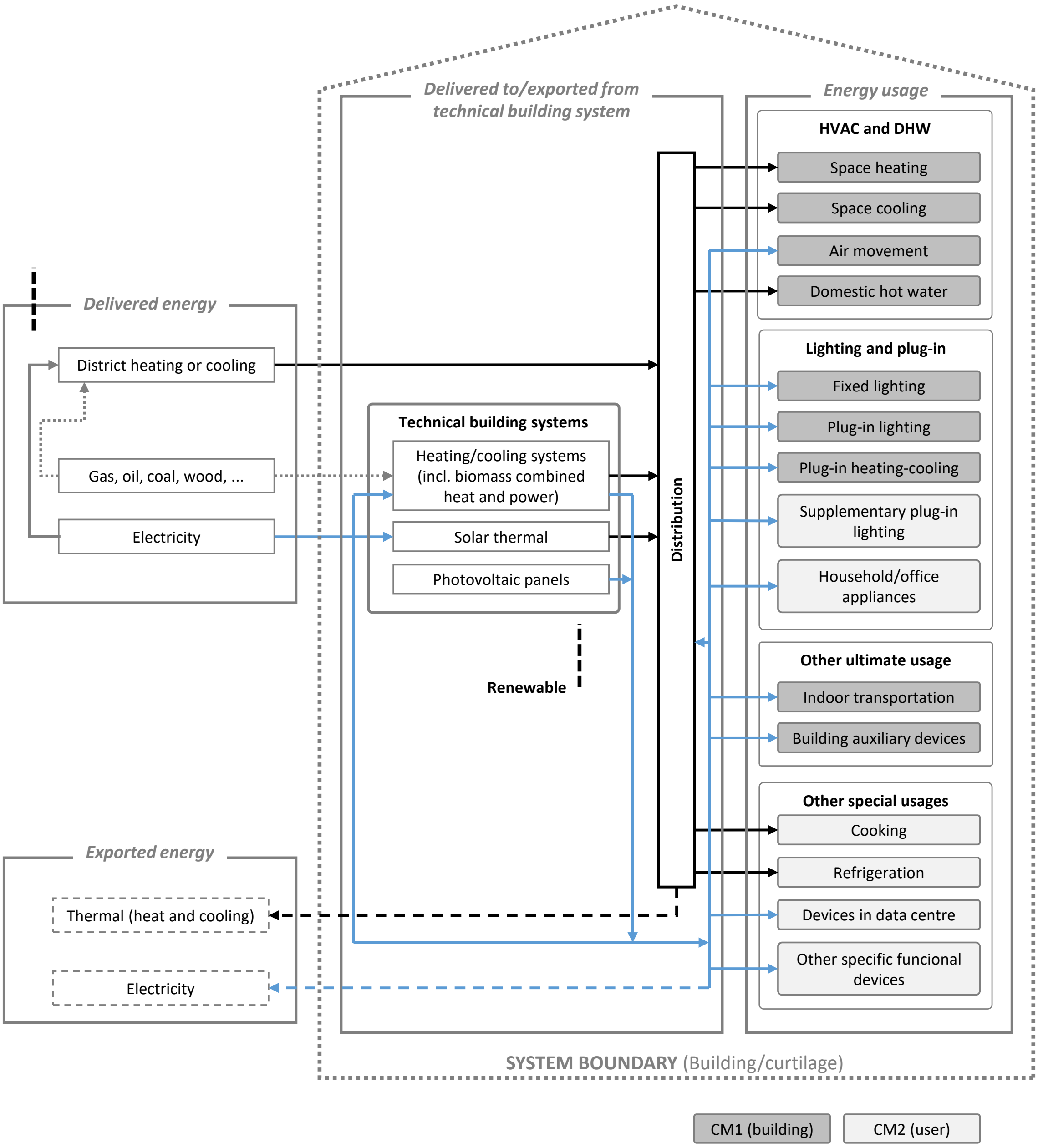


Figure 4. Boundary and energy flows for a building's energy use (adapted from ISO 16745-1 (2017))

Once the energy end uses have been determined, the GHG from energy use are quantified by using GHG emission coefficients, which characterise the amount of a specific GHG released from performing a certain activity, such as burning one tonne of fuel in a furnace (ISO 16745-1, 2017). Coefficients should be obtained from, and in the following order of priority: nationally agreed data, independently provided information or internationally agreed data. These shall include the following information: sources (if national or international), the GHG included, expressed as CO_{2eq} (following the corresponding GHG protocol), including elements in the supply chain (e.g.

on-site or on-site plus upstream processes), the time frame of environmental impacts (100 years), and the year of reference of the emission coefficient data.

2.3. Stage III: CM reporting

After calculations, the CM should be reported and displayed in a disclosure report. According to ISO 16745-1 (2017), the disclosure report is a tool to communicate the CM of an existing household. It should contain both the information of the results on GHG calculations and the assumptions made (mandatory), plus any other additional information on the household's owner, along with some technical information depending on the purpose of measurements (voluntary). Thus it includes the items established for the CM study report, as indicated in Table 5, plus the following information:

- A disclaimer stating the relevant limitations of various potential uses
- Disclosure and justification of the used methods

Finally, the CM should be communicated through a claim or a declaration. The CM claim is the mandatory supporting document for communicating the CM, while the CM declaration is voluntary. The former does not need to be verified by an independent third party, but should be available upon request. The latter has, instead, to be verified by an independent third party in accordance with ISO 16745-2 (2017).

Supplementary Material 2 proposes a valid disclosure report template for communicating the claim or declaration. It was designed according to the guidelines and requirements set out in ISO 16745-1 (2017).

3. Description of the case study

A household was selected to implement CM calculation and reporting. The field study was performed for 12 months, from January to December 2016. The household corresponds to a dwelling unit as part of a multi-family terraced building built in 2006, located in Castellón de la Plana, on the Spanish east coast, which corresponds to climate zone B3 according to the Spanish Building Code (CTE, 2013). It covers a gross area of 141 m^2 and a net lettable area (conditioned) of 116 m^2, and is placed on the fourth floor of a building that corresponds to a penthouse. The users are the owners of the household and are a family with five members, made up of two adults and three children. Figure 5 displays the dwelling's floor plan.

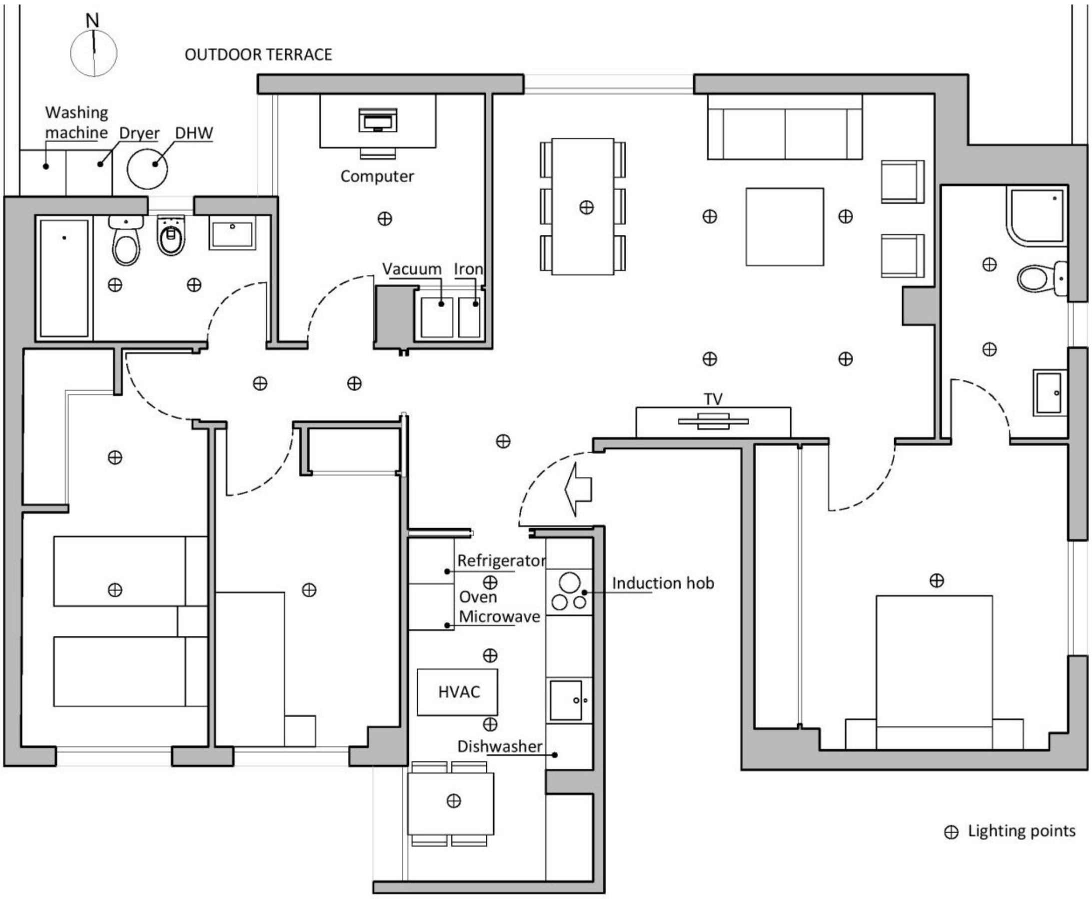


Figure 5. Dwelling's floor plan

Regarding the construction characteristics, the building's structure consists of reinforced concrete porticoes and slabs, brick walls for façades with thermal insulation, a flat roof also with thermal insulation, and aluminium double-glazing windows, where the conservation state is good. The building's configuration and the envelope's thermal features affect energy performance (Braulio-Gonzalo et al., 2016), as does the occupants' influence, and how they operate the technical building systems and appliances play an important role in the final energy performance of households (Terés-Zubiaga et al., 2013). So a description of the household's system boundary, including delivered energy, technical building systems, operating energy end-uses and electrical appliances, provides a better understanding. Figure 6 graphically outlines the household's system boundary.

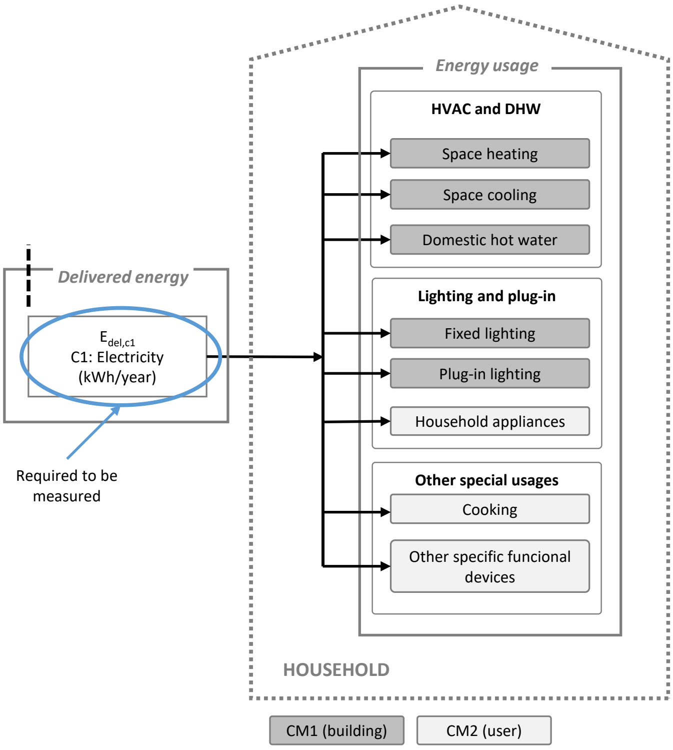


Figure 6. Household boundary (based on ISO 16745-1 (2017))

The household's energy end-uses are supplied entirely by electricity. The technical building systems are formed by a DHW system with an electrical boiler and combined ducted space heating and cooling supplied by electricity. Since B3 corresponds to a mild climate, space heating was used only 3 months per year (from December to February) and space cooling only sporadically on certain days with hot weather, especially in July. August was not operational as the family was on holidays and not in the household, when only the refrigerator-freezer and stand-by appliances were operating. On a typical week, the occupants' operation schedule varies depending on weekdays (activity from 19:00h on) and on weekends (activity during the whole day).

Household equipment includes refrigerator, freezer, dishwasher, dryer, electrical oven, induction hob, microwave, iron, vacuum, TV and computer, for which the technical characteristics are provided in Table 3. Figure 5 displays the position of household appliances, HVAC and DHW systems and lighting points.

Table 3. Detailed inventory of household appliances and comparison to the equipment rate in the Spanish Mediterranean

Household appliance	**Power (W)**	**Year of purchase**	**Energy label**	**Use**		**Equipment rate in the Spanish Mediterranean**
				Times/week	**Hours/week**	
Refrigerator-freezer	200	2007	A+ (a)	N/A	168	99.4%
Dishwasher	2,500	2000	A (a)	6		54.1%
Washing machine	2,500	2000	A (a)	4		92.5%
Dryer	2,000	2000	C (a)	2		34.9%
Oven	1,300	2006	N/A		1	77.1%
Induction hob	4,000	2006	N/A		5	n/a
Microwave	800	2007	N/A		5	89.9%
Iron	1,000	2000	N/A		1.5	n/a
Vacuum	1,300	2000	N/A		1	n/a
TV	150	2012	N/A		25	100%
Computer	150	2015	N/A		168	48.9%

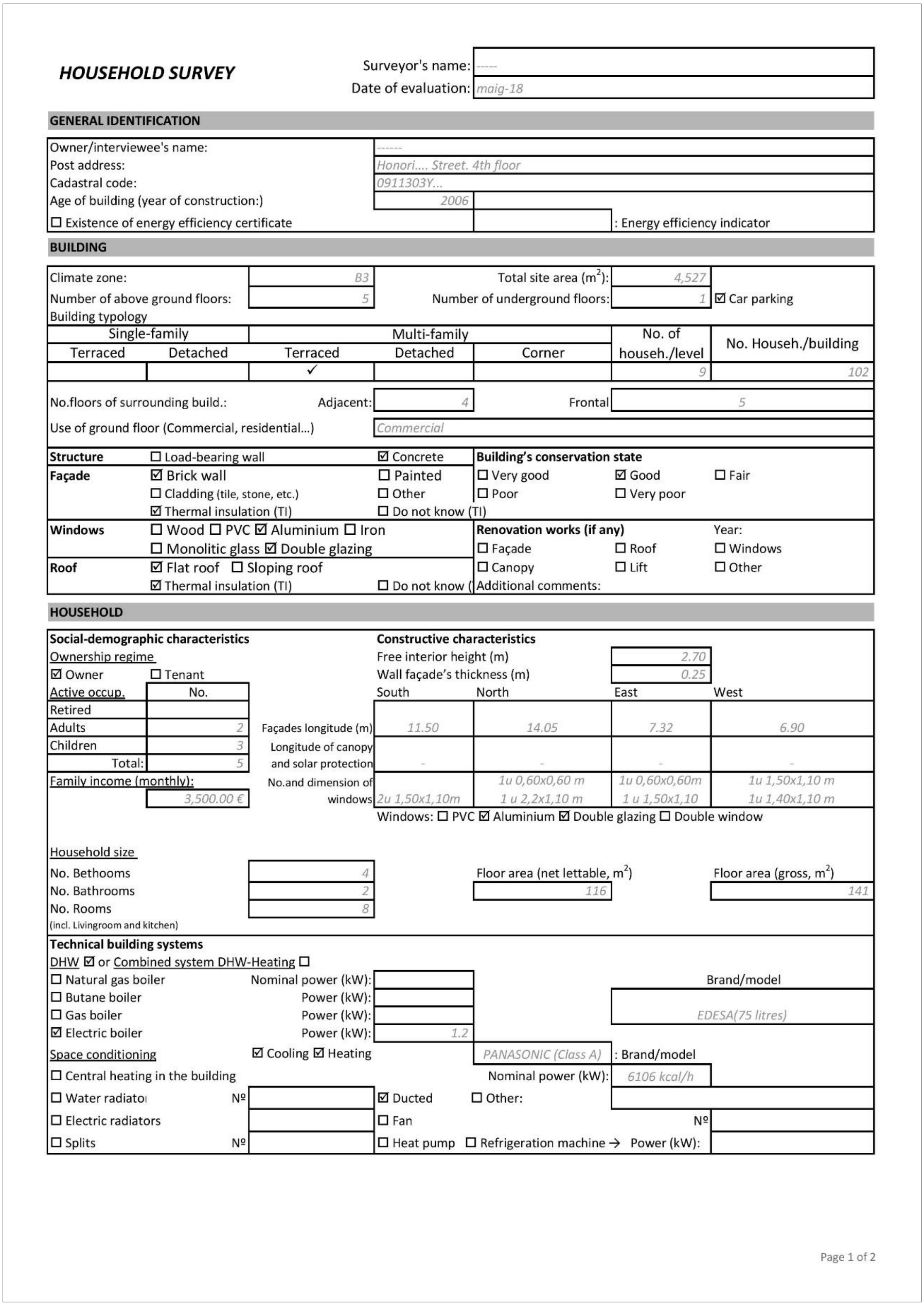
N/A: Not applicable; (a)Eco-labelling according to (Directive 2009/125/EC, 2009)

According to the building's year of construction, which is prior to the introduction of mandatory requirements for the EEC of buildings in Spain (CTE, 2006), the global building did not have any EEC. The same can be stated for renewable energy use because its implementation in new buildings became mandatory in 2007 in Spain.

4. Implementing the methodology

4.1. Stage I: data collection

The data collection process was done as follows. The evaluator technicians previously contacted the household owner and agreed on a date for an on-site meeting. On the date the meeting was held, the evaluator presented the study to the owner and then conducted the interview. The evaluator made some *in situ* measurements and checks (e.g. built area of household; façade, floor, roof and window surfaces; solar orientation; kind and specifications of technical building systems) and the owner also took part in the process by thoroughly answering the survey questions on aspects such as occupancy, user behaviour or timetable. The owner provided energy bills for a whole year, disaggregated monthly. This household survey was supported by business data provided by the company supplier, which allowed to break down use into different time periods, weekly and one-day hourly, to provide a better understanding. Figure 7 displays the completed survey.



HOUSEHOLD SURVEY

Surveyor's name: -----
Date of evaluation: maig-18

GENERAL IDENTIFICATION

Owner/interviewee's name: ------
Post address: Honori.... Street. 4th floor
Cadastral code: 0911303Y...
Age of building (year of construction:) 2006
☐ Existence of energy efficiency certificate : Energy efficiency indicator

BUILDING

Climate zone: B3
Total site area (m^2): 4,527
Number of above ground floors: 5
Number of underground floors: 1
☑ Car parking

Building typology

Single-family		Multi-family			No. of househ./level	No. Househ./building
Terraced	Detached	Terraced	Detached	Corner		
		✓			9	102

No.floors of surrounding build.: Adjacent: 4 Frontal 5
Use of ground floor (Commercial, residential...) Commercial

Structure	☐ Load-bearing wall	☑ Concrete	**Building's conservation state**		
Façade	☑ Brick wall	☐ Painted	☐ Very good	☑ Good	☐ Fair
	☐ Cladding (tile, stone, etc.)	☐ Other	☐ Poor	☐ Very poor	
	☑ Thermal insulation (TI)	☐ Do not know (TI)			
Windows	☐ Wood ☐ PVC ☑ Aluminium ☐ Iron		**Renovation works (if any)**		Year:
	☐ Monolitic glass ☑ Double glazing		☐ Façade	☐ Roof	☐ Windows
Roof	☑ Flat roof ☐ Sloping roof		☐ Canopy	☐ Lift	☐ Other
	☑ Thermal insulation (TI)	☐ Do not know (	Additional comments:		

HOUSEHOLD

Social-demographic characteristics

Ownership regime
☑ Owner ☐ Tenant

Active occup.	No.
Retired	
Adults	2
Children	3
Total:	5

Family income (monthly): 3,500.00 €

Constructive characteristics

Free interior height (m) 2.70
Wall façade's thickness (m) 0.25

	South	North	East	West
Façades longitude (m)	11.50	14.05	7.32	6.90
Longitude of canopy and solar protection	-	-	-	-
No.and dimension of windows	2u 1,50x1,10m	1u 0,60x0,60 m 1 u 2,2x1,10 m	1u 0,60x0,60m 1 u 1,50x1,10	1u 1,50x1,10 m 1u 1,40x1,10 m

Windows: ☐ PVC ☑ Aluminium ☑ Double glazing ☐ Double window

Household size
No. Bethooms 4
No. Bathrooms 2
No. Rooms 8
(incl. Livingroom and kitchen)

Floor area (net lettable, m^2) 116
Floor area (gross, m^2) 141

Technical building systems

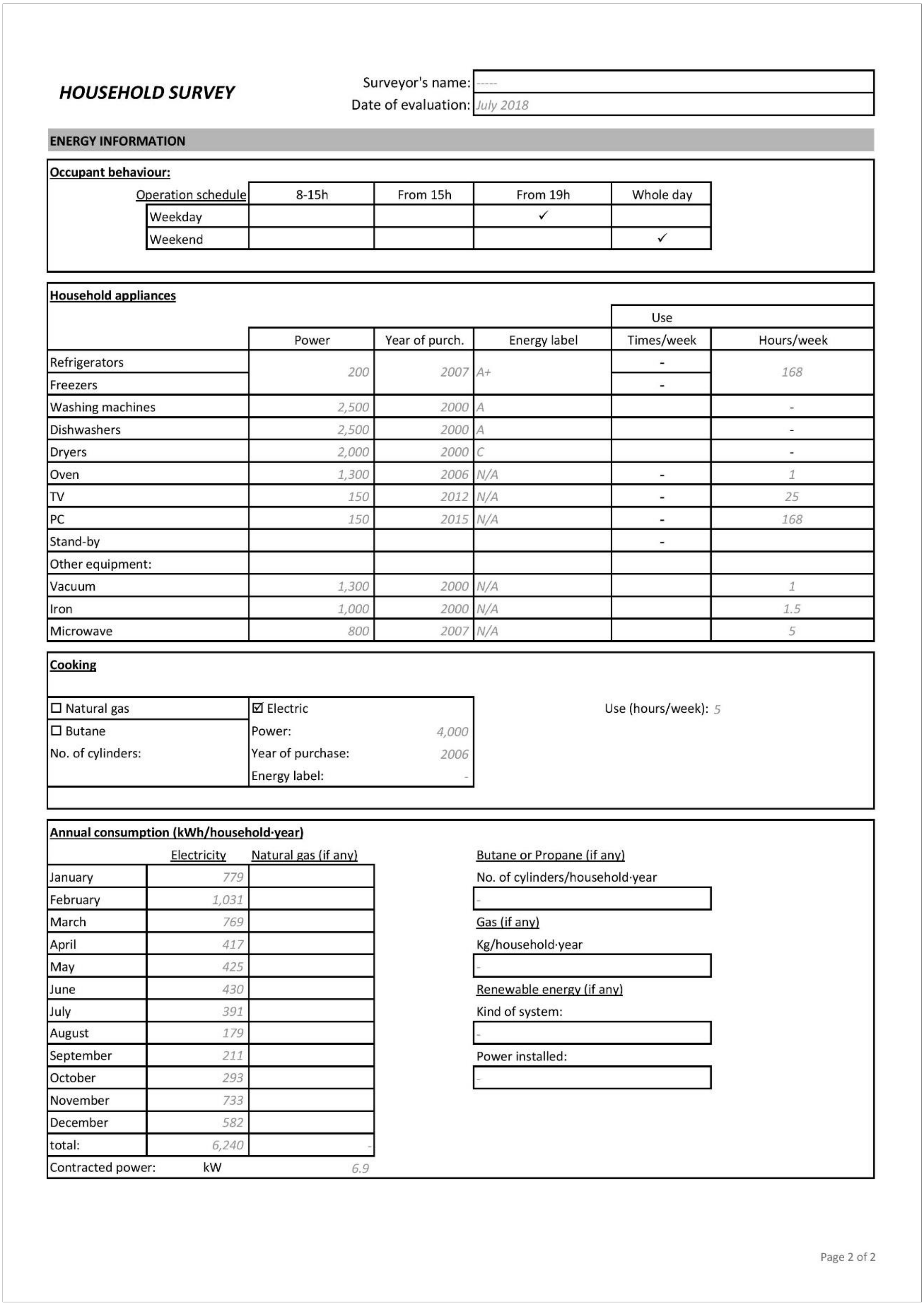
DHW ☑ or Combined system DHW-Heating ☐

☐ Natural gas boiler	Nominal power (kW):		Brand/model
☐ Butane boiler	Power (kW):		EDESA(75 litres)
☐ Gas boiler	Power (kW):		
☑ Electric boiler	Power (kW):	1.2	

Space conditioning ☑ Cooling ☑ Heating
PANASONIC (Class A) : Brand/model
☐ Central heating in the building
Nominal power (kW): 6106 kcal/h
☐ Water radiator Nº ☑ Ducted ☐ Other:
☐ Electric radiators ☐ Fan Nº
☐ Splits Nº ☐ Heat pump ☐ Refrigeration machine → Power (kW):

Page 1 of 2

Figure 7. Completed household survey



HOUSEHOLD SURVEY

Surveyor's name: -----
Date of evaluation: July 2018

ENERGY INFORMATION

Occupant behaviour:

Operation schedule	8-15h	From 15h	From 19h	Whole day
Weekday			✓	
Weekend				✓

Household appliances

				Use	
	Power	Year of purch.	Energy label	Times/week	Hours/week
Refrigerators	200	2007	A+	-	168
Freezers				-	
Washing machines	2,500	2000	A		-
Dishwashers	2,500	2000	A		-
Dryers	2,000	2000	C		-
Oven	1,300	2006	N/A	-	1
TV	150	2012	N/A	-	25
PC	150	2015	N/A	-	168
Stand-by				-	
Other equipment:					
Vacuum	1,300	2000	N/A		1
Iron	1,000	2000	N/A		1.5
Microwave	800	2007	N/A		5

Cooking

☐ Natural gas	☑ Electric	
☐ Butane	Power:	4,000
No. of cylinders:	Year of purchase:	2006
	Energy label:	-

Use (hours/week): 5

Annual consumption (kWh/household·year)

	Electricity	Natural gas (if any)
January	779	
February	1,031	
March	769	
April	417	
May	425	
June	430	
July	391	
August	179	
September	211	
October	293	
November	733	
December	582	
total:	6,240	-

Contracted power: kW 6.9

Butane or Propane (if any)
No. of cylinders/household·year
-

Gas (if any)
Kg/household·year
-

Renewable energy (if any)
Kind of system:
-

Power installed:
-

Page 2 of 2

Figure 7. Completed household survey (Continued)

4.2. Stage II: CM determination

The GHG coefficients for CM determinations were obtained by using the nationally agreed data from Spain, were the household is located, and which are presented in Table 4. Each provided value includes the corresponding bibliographic source. Alternatively, values from energy providers companies including fuel mixes for energy generation can be selected.

Table 4. GHG coefficients to determine the CM

Energy carrier	GHG coefficient	Source of information	GHG included in CO_2 equiv (Procotol)	Elements in supply chain	Time frame	Year of reference
Electricity (national average)	0.357	(a)			100	2016
Electricity (peninsular average)	0.331	(b)			100	2016
Electricity (extrapeninsular avg)	0.833	(b)			100	2016
Electricity (Balearic Islands)	0.932	(b)			100	2016
Electricity (Canary Islands)	0.776	(b)			100	2016
Electricity (Ceuta and Melilla)	0.721	(b)			100	2016
Heating diesel	0.311	(c)			100	2016
LPG	0.254	(c)			100	2016
Natural gas	0.252	(c)			100	2016
Coal	0.472	(c)			100	2016
Non-densified biomass	0.018	(c)			100	2016
Densified biomass (pellets)	0.018	(c)			100	2016

(a) Values approved by the Spanish Commission for the Energy Certification of Buildings, 27 June 2013 (CEE, 2013)
(b) Based on the report "CO_2 emission factors of final energy sources in the building sector in Spain" (IDAE, 2016)
(c) Based on "Well-to-Tank Report, version 4.0, Joint Research Centre (European Commission)" (Edwards et al., 2013)

As the energy data were collected annually from energy bills for all the end uses included in the household, it was necessary to disaggregate them in Spain, and according to the SECH-SPAHOUSEC study (IDAE, 2011) and Garcia Montes (2012). When all the energy uses are supplied by electricity, the disaggregation of a household's end uses in a multi-family building results in the distribution of percentages reported in Figure 8. The greatest use was due to household appliances, which corresponded 61.8% of the global use in a typical household. This was followed by lighting (11.74%), cooking (9.29%), DHW (7.47%), space heating (7.37%) and space cooling (2.33%), ordered from the strongest to the least impact. The use due to household appliances was split as follows with its related percentages: refrigerator (18.91%), TV (7.53%), washing machine (7.32%), stand-by (6.62%), oven (5.10%), PC (4.59%), freezers (3.74%), dishwashers (3.74%), other equipment (2.18%) and dryers (2.07%).

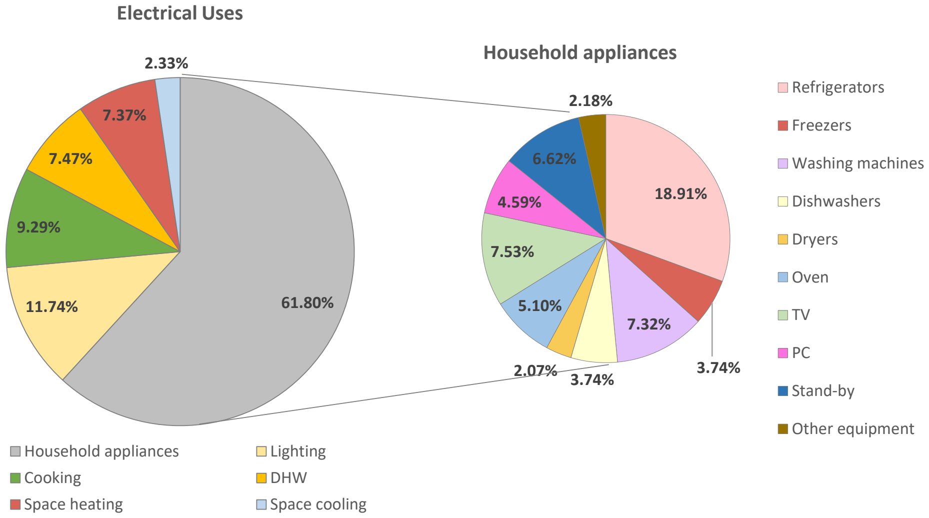


Figure 8. Use of households as electrical end uses in a multi-family building (adapted from SECH-SPAHOUSEC (IDAE, 2011))

The household's measured annual energy use was 4,631.661 kWh/year, distributed throughout the year as seen in Figure 9. This figure also displays the distribution of a typical week in winter (Monday 18 – Sunday 24 January 2016) and in summer (Monday 18 – Sunday 24 July 2016), and the distribution of the use on a typical day in both these seasons (Wednesday 20 January and Monday 18 July), which corresponded to an average day of January and July, respectively.

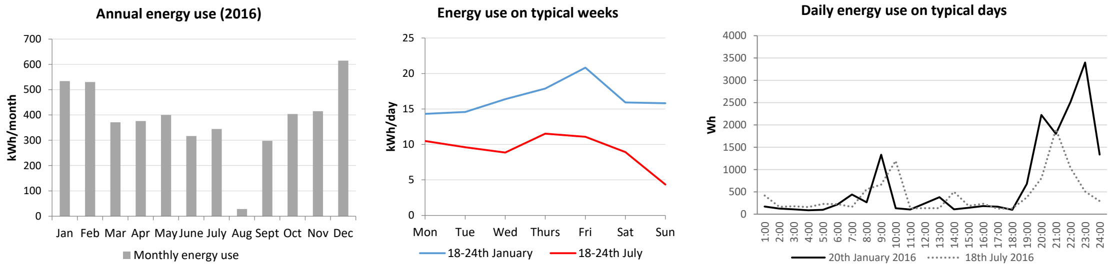


Figure 9. The household's energy use displayed annually (left), weekly (middle) and daily (right)

The disaggregation of the household's global energy use was based on the distribution of the energy end uses referred to in Figure 8. This disaggregation resulted in the data presented in Table 5, split into building- and user-related energy uses (CM2), and structured according to ISO 16745-1 (2017) requirements

Table 5. List of the energy end uses included in the CM for CM2 (adapted from ISO 16745-1 (2017))

Energy use-related building service			Present in building[a]	Included in the CM[b]	Separately metered[c]	Measured or estimated[d]	Energy carrier if known[e]
1	Building-related energy use	Space heating*	P	I		M	341.353
2		Space cooling*	P	I		M	107.928
3		Air movement*					
4		Domestic hot water*	P	I		M	345.985
5		Lighting for basic building function (fixed lighting, etc.)*	P	I		M	543.757
6		Auxiliary energy (e.g. for heat pumps)*					
7		Indoor transportation*					
8		Building auxiliary devices*					
9	User-related energy use	Plug-in supplementary lighting*	P	I		M	
10		Household/office appliances*	P	I		M	1,986.519
10.1		Freezers	P	I		M	173.224
10.2		Washing machines	P	I		M	339.038
10.3		Dishwashers	P	I		M	173.215
10.4		Dryers	P	I		M	95.875
10.5		Oven	P	I		M	236.215
10.6		TV	P	I		M	348.764
10.7		PC	P	I		M	212.593
10.8		Stand-by	P	I		M	306.616
11		Refrigerator*	P	I		M	875.847
12		Devices in data centre*					
13		Other specific functional devices*	P	I		M	100.970

* Included in ISO 16745-1; (a)Use "P" to indicate if building services are present in the building; (b)Use "I" to indicate if the energy end use for the building service is included in the CM; (c)Use "X" to indicate if the energy end use for the building service is separately metered; (d)Use "M" or "E" to indicate if the delivered energy end use is based on either measurement or estimation; (e)Report may indicate the energy carrier for each energy end use, if known

Having measured and disaggregated the global energy use, CM ($m \cdot CO_{2eq}$) can be calculated according to eq.1 by applying the GHG emission coefficient (0.331, as depicted in Table 4 for the peninsular average electricity carrier in Spain) to the sum of the energy carriers related to building services of the household, resulting in 1,553.080 kg CO_{2eq}/year. The results are presented in Table 6. The carbon intensity per area and per occupant was 13.389 kg $CO_{2eq}/m^2 \cdot$year and 306.616 kg CO_{2eq}/occup·year, respectively.

Table 6. Inventory of energy carriers and the CM calculation (based on ISO 16745-1 (2017))

		Energy carrier (electricity)
1	Energy delivered	4,631.661 kWh/year
2	GHG emission coefficient for delivered energy	0.331
3	Mass of GHG emissions (as kg CO_2 equivalent) for delivered energy	1,533.080 kg CO_{2eq}
4	Energy generated and used on-site	-
5	GHG emission coefficient for energy produced and used on-site	-
6	Mass of GHG (as CO_2 kg equivalent) for energy produced on-site	-
7	Total (CM1 and CM2)	1,533.080 kg CO_{2eq}

NOTE 1 The quantity of the energy carrier can be described "N/A" if its GHG emission coefficient is zero
NOTE 2 The energy carrier type is identified according to the GHG coefficient

The CMs disaggregated by end use are graphically described in Figure 10, and are presented in kg CO_{2eq}/year along with their respective percentages in relation to the household's overall CM.

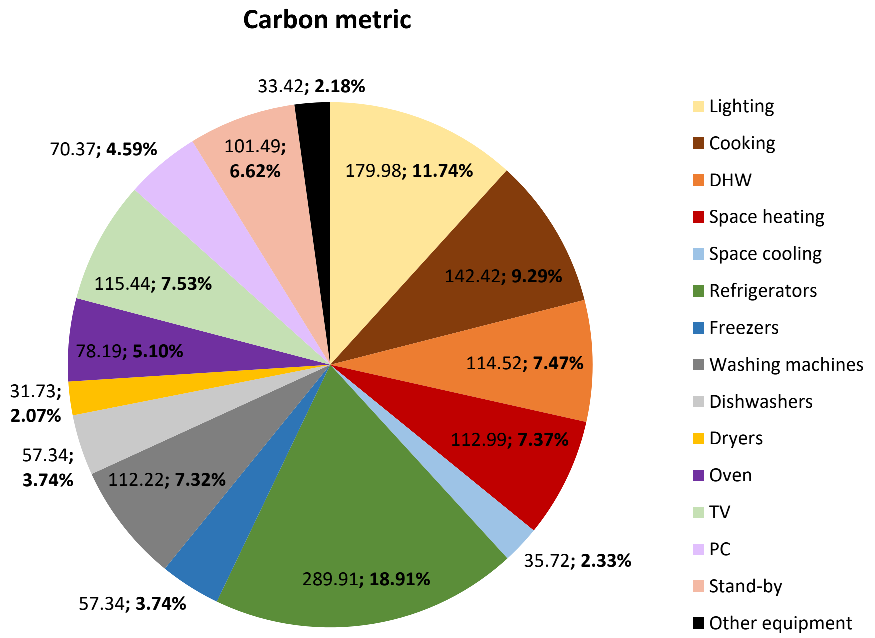
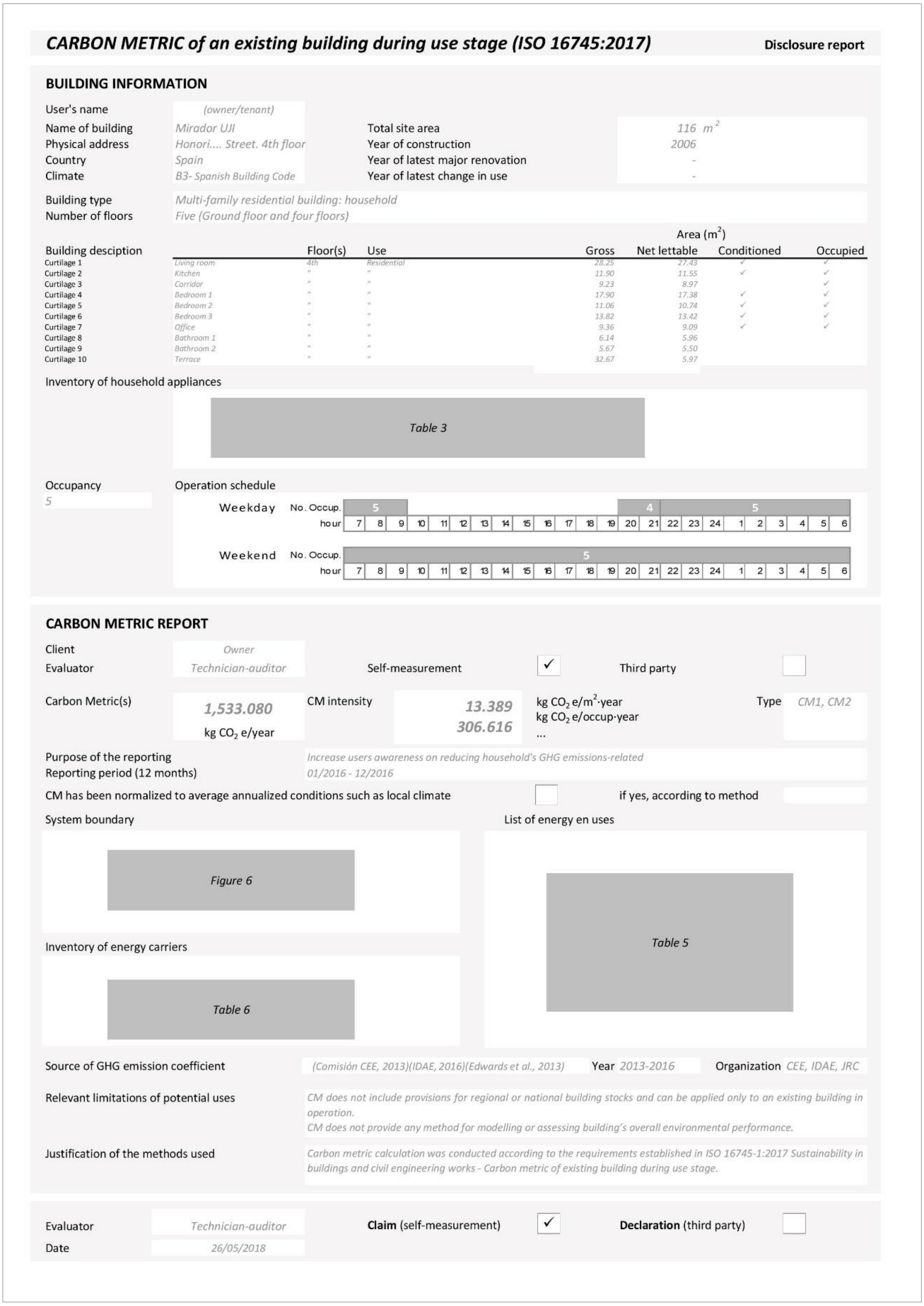


Figure 10. Household's CM disaggregation per energy end uses (kg CO_{2eq}/year; **%**)

4.3. Stage III: CM reporting

The results previously obtained when calculating the CM should be included in the corresponding sections of the disclosure report, as seen in Figure 11.



CARBON METRIC of an existing building during use stage (ISO 16745:2017) — **Disclosure report**

BUILDING INFORMATION

User's name	(owner/tenant)		
Name of building	Mirador UJI	Total site area	116 m^2
Physical address	Honori.... Street. 4th floor	Year of construction	2006
Country	Spain	Year of latest major renovation	-
Climate	B3- Spanish Building Code	Year of latest change in use	-

Building type	Multi-family residential building: household
Number of floors	Five (Ground floor and four floors)

Building desciption		Floor(s)	Use	Area (m^2) Gross	Net lettable	Conditioned	Occupied
Curtilage 1	Living room	4th	Residential	28.25	27.43	✓	✓
Curtilage 2	Kitchen	"	"	11.90	11.55	✓	✓
Curtilage 3	Corridor	"	"	9.23	8.97		✓
Curtilage 4	Bedroom 1	"	"	17.90	17.38	✓	✓
Curtilage 5	Bedroom 2	"	"	11.06	10.74	✓	✓
Curtilage 6	Bedroom 3	"	"	13.82	13.42	✓	✓
Curtilage 7	Office	"	"	9.36	9.09	✓	✓
Curtilage 8	Bathroom 1	"	"	6.14	5.96		
Curtilage 9	Bathroom 2	"	"	5.67	5.50		
Curtilage 10	Terrace	"	"	32.67	5.97		

Inventory of household appliances

Table 3

Occupancy

5

Operation schedule

Weekday	No. Occup.	5													4		5								
	hour	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6
Weekend	No. Occup.	5																							
	hour	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6

CARBON METRIC REPORT

Client	Owner				
Evaluator	Technician-auditor	Self-measurement	☑	Third party	☐

Carbon Metric(s)	1,533.080 kg CO_2 e/year	CM intensity	13.389 306.616	kg CO_2 e/m^2·year kg CO_2 e/occup·year ...	Type	CM1, CM2

Purpose of the reporting	Increase users awareness on reducing household's GHG emissions-related
Reporting period (12 months)	01/2016 - 12/2016

CM has been normalized to average annualized conditions such as local climate ☐ if yes, according to method

System boundary

Figure 6

List of energy en uses

Table 5

Inventory of energy carriers

Table 6

Source of GHG emission coefficient	(Comisión CEE, 2013)(IDAE, 2016)(Edwards et al., 2013)	Year	2013-2016	Organization	CEE, IDAE, JRC

Relevant limitations of potential uses	CM does not include provisions for regional or national building stocks and can be applied only to an existing building in operation. CM does not provide any method for modelling or assessing building's overall environmental performance.
Justification of the methods used	Carbon metric calculation was conducted according to the requirements established in ISO 16745-1:2017 Sustainability in buildings and civil engineering works - Carbon metric of existing building during use stage.

Evaluator	Technician-auditor	**Claim** (self-measurement)	☑	**Declaration** (third party)	☐
Date	26/05/2018				

Figure 11. The household's CM disclosure report

5. Conclusion and Policy Implications

Calculating and reporting the CM of buildings or part thereof allows the GHG emissions to be displayed, which are associated with the use stage of a building in operation. According to EN 15978 (2011), the CM is considered to be the building's partial carbon footprint as it focuses on the energy use strictly used in module B6 of the whole building's environmental life cycle stages. This section describes the policy implications derived from the study.

Within the ISO 16745 framework (2017), this study proposes a methodology that sets specific guidelines and materials for following the process of determining and reporting the CM of the use stage of residential buildings. The application of the proposed survey to the case study proved its applicability because it enabled and simplified the data collection task, not only for measuring the energy carriers related to the system boundary, but also for including other aspects that help better understand the building's operation, whose causes underlie its performance. The survey can be applied to any type of household and climatic zone, since it includes a wide range of options regarding construction, technical systems, fuel sources and other building's features. Completing the household survey by a face-to-face interview held between the owner and a qualified technician allowed truthful and evidence-based information to be acquired, which was supported by bills and the online disaggregated information available from the company supplier. As a drawback, it should be considered that the completion of the survey implies time and effort, due to the movement of the technician to the household and the necessary interview period (which takes about one hour), but ensures the veracity of the information collected.

The application of the proposed disclosure report template to the case study was useful for presenting the results as either a claim or a declaration, depending on the nature of the verifier party. The on-page report was accurately designed to be short, intelligible and transparent, with no misleading, but only the relevant information set out in ISO 16745 (2017), plus some additional information suggested in Eurostat recommendations (2013). It contributes, thus, to inform users where the highest potential to reduce GHG-related emissions lies, and provides new ideas for monitoring and proposing policies at individual member state and EU levels.

From the case study results, it can be concluded that the highest proportion of CM is due to the household's refrigerator, which runs 24 hours a day, all year round and accounts for 18.91%. Space heating has a medium impact (7.37%) since the household is located in a mild climate where the use of space conditioning is necessary only at specific time of the day when occupants return home from 6:00 pm. This is reflected in the daily energy use distribution graph in Figure 9 for a typical day in winter. Energy use in a typical summer week is 44% lower than it is in winter, mainly due to the air conditioning system for space cooling that is limited to far fewer cases of heat peaks, and accounts for only 2.33%. Accordingly with the Eurostat data stated in the Introduction, the household's space heating is below the European average, while its space cooling is above this average, as evidenced by the specific climate conditions in Spain (temperate winters and hot summers). Household DHW use amounted to half the European average, with 7.47% and 14.5%, respectively. Electrical appliances were 53% of the CM, which represents the highest percentage of end uses and is well above the European average. As Table 3 reflects, most are old and lack an energy label due as they predate Directive 2009/125/EC on eco-design requirements for energy-related products (Directive 2009/125/EC, 2009). Besides, the household's high occupation (5 members against 2.49 for the Spanish household average (INE, 2018), clearly increases the electrical use and explains this fact. Stand-by and other equipment amounted to 8.8%, lighting accounted for 11.74% and cooking for 9.29%, all of which are higher than the European average. Thus the household's global CM value was 1,553.080 kg CO_2 e/year.

Within the European framework, the MESH Report (Garcia Montes, 2012) provided guidelines to develop new ideas in the household sector, and the study presented herein falls in line with it because it is inspired in the methodology proposed for energy data collection through household and business surveys. CM calculations and, more specifically, reporting and making the results publicly available in a final disclosure report raise users' environmental awareness, regardless of them being household occupants, technicians, verifiers, administration staff or legislators.

This work aimed to be practical for many stakeholders, and not only those involved in the building profession, who are expected to use a household's CM as a reference for decision making in their business activities or governmental policies. The CM can be used for a wide variety of purposes, but is especially useful as a baseline for benchmarking in, for instance, developing a post-occupancy evaluation, setting energy management systems or contracts, or establishing investment strategies when listing targets or property management strategies. It can even be useful for educational purposes in environmental fields and as a policy information asset. The CM can also be used for monetising international carbon trading in building-related sectors.

On the other hand, the renovation of housing stocks to reduce primary energy consumption is a key strategy to reduce the carbon footprint of the built environment (Ballarini et al., 2014). The use of retrofitting measures intended to store carbon in construction elements, such as the incorporation of optimal insulation materials in the building's envelope to reduce energy demand or the inclusion of bio-based materials used in façades, roofs and interior walls, can compensate the GHG emissions related to the use stage of the building, neutralising the carbon balance and accelerating the transition to a zero-carbon society. For instance, wood-based components were found as a valid solution to improve the building's energy performance and the aesthetic of the exterior elements (façades and roofs), since the biogenic carbon embedded in the mass is fixated for as long as the building is in use (Pittau et al., 2019), acting as a carbon sink. In this context, the calculation and reporting of the building's CM according to the methodology proposed herein can facilitate setting the target for the estimation of the necessary carbon storage in construction components, in order to compensate the GHG emissions derived from the use stage of the building's life cycle.

However, some limitations should be mentioned and considered within the ISO 16745 framework (2017). The calculation method of the CM does not include provisions for regional or national building stocks, and can be applied only to an existing building, which can be either residential or commercial, or a building complex. Moreover, it does not provide any method for modelling or measuring the operational energy use of the building or part thereof, which was instead provided in the context of this work. The fact that the assessment method is restricted to stage B6 should be taken into account, that is, the operational energy use, of the building's overall life span and cannot, therefore, be considered an assessment method to evaluate a building's overall environmental performance like a rating tool does. This means, in turn, that it can be integrated into a more wide-ranging assessment tool specifically for the operational use assessment as part of it in the form of, for example, a calculator. Finally, the fact that it does not include a benchmarking or weighting system for value-based interpretations of the CM, which would allow comparisons among buildings to be made, should also be considered.

As a further research line, different ideas for continuing the present research line can be proposed. The comprehensive data collection process allows aspects that influence a household's energy performance to be explored, such as façade surface, orientation, proportion of window surfaces, type of installations or fuel used. In line with this, the data collected from the household's actual energy use can be compared with an estimated one, obtained from a building's energy performance software or energy models, which would enable to investigate the energy gap between both, and to discover which factors are more relevant in the dispersion. Finally, a tool for automating the CM calculation process can be developed based on the proposed methodology, which is useful for household users, building designers, legislators and public administrations.

Acknowledgments

The authors are grateful to Universitat Jaume I, Convocatòria d'ajudes postdoctorals per a la incorporació a grups d'investigació de l'UJI (Spain). (Contract POSDOC-A/2017/17).

References

Ballarini, I., Corgnati, S.P., Corrado, V., 2014. Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. Energy Policy. https://doi.org/10.1016/j.enpol.2014.01.027

Belkhir, L., Bernard, S., Abdelgadir, S., 2017. Does GRI reporting impact environmental sustainability? A cross-industry analysis of CO2emissions performance between GRI-reporting and non-reporting companies. Manag. Environ. Qual. An Int. J. 28, 138–155. https://doi.org/10.1108/MEQ-10-2015-0191

Bermeo, J., Rodríguez, V., Alvarez, M., 2018. Carbon footprint in corporate logistics operations in the food sector. Environ. Qual. Manag. in press. https://doi.org/10.1002/tqem.21535

Birnik, A., 2013. An evidence-based assessment of online carbon calculators. Int. J. Greenh. Gas Control 17, 280–293. https://doi.org/10.1016/j.ijggc.2013.05.013

Braulio-Gonzalo, M., Juan, P., Bovea, M.D., Ruá, M.J., 2016. Modelling energy efficiency performance of residential building stocks based on Bayesian statistical inference. Environ. Model. Softw. 83, 198–211. https://doi.org/10.1016/j.envsoft.2016.05.018

CEE, 2013. Valores aprobados en Comisión Permanente de Certificación Energética de Edificios. Madrid.

Colomb, V., Bernoux, M., Bockel, L., Chotte, J.L., Martin, S., Martin.Phipps, C., Mousset, J., Tinlot, M., Touchemoulin, O., 2012. Review of GHG Calculators in Agriculture and Forestry Sectors

- A Guideline for Appropriate Choice and Use of Landscape Based Tools.

CTE, 2013. Orden FOM/1635/2013, de 10 de septiembre, por la que se actualiza el Documento Básico DB-HE Ahorro de Energía del Código Técnico de la Edificación, aprobado por Real Decreto 314/2006, de 17 de marzo. España.

CTE, 2006. Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación. España.

Directive 2009/125/EC, 2009. of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. Official Journal of the European Union.

Downie, J., Stubbs, W., 2013. Evaluation of Australian companies' scope 3 greenhouse gas emissions assessments. J. Clean. Prod. 56, 156–163. https://doi.org/10.1016/j.jclepro.2011.09.010

EC, 2014. 2030 Climate & Energy framework https://ec.europa.eu/clima/policies/strategies/2030_en (accessed 10.1.18).

Edwards, R., Larivé, J.-F., Rickeard, D., Weindorf, W., 2013. Well-to-Tank Report Version 4.0. Luxembourg. https://doi.org/10.2788/40526

EN 15643-1, 2010. Sustainability of construction works -Sustainability assessment of buildings - Part 1 : General framework.

EN 15643-2, 2011. Sustainability of construction works - Assessment of buildings - Part 2 : Framework for the assessment of environmental performance.

EN 15643-3, 2012. Sustainability of construction works - Assessment of buildings - Part 3 : Framework for the assessment of social performance.

EN 15643-4, 2012. Sustainability of construction works - Assessment of buildings - Part 4 : Framework for the assessment of economic performance.

EN 15643-5, 2017. Sustainability of construction works. Sustainability assessment of buildings and civil engineering works. Framework on specific principles and requirement for civil engineering works.

EN 15804, 2012. Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products.

EN 15978, 2011. Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

EN 16309, 2014. Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology.

EN 16627, 2015. Sustainability of construction works. Assessment of economic performance of buildings. Calculation methods.

EN ISO 14064-2, 2006. Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.

EPBD, 2010. European Directive 2010/31/UE on the energy performance of buildings.

EPBD, 2002. European Directive 2002/91/EC on the energy performance of buildings.

Eurostat, 2018. Energy consumption in households http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households (accessed 7.6.18).

Eurostat, 2013. Manual for statistics on energy consumption in households. Luxembourg: https://doi.org/10.2785/45686

Garcia Montes, J.P., 2012. MESH: Production of a manual for statistics on energy consumption in households.

GHG Protocol, 2004. A Corporate Accounting and Reporting Standard. World Resources Institute and World Business Council for Sustainable Development.

Harangozo, G., Szigeti, C., 2017. Corporate carbon footprint analysis in practice – with a special focus on validity and reliability issues. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2017.07.237

IDAE, 2016. Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España. Madrid.

IDAE, 2011. PROYECTO SECH-SPAHOUSEC. Análisis del consumo energético del sector residencial en España. Informe final. Ministerio de Industria, Energía y Turismo.

INE, 2018. Spanish Statistical Institute http://www.ine.es/inebaseweb/hist.do?L=1 (accessed 7.10.18).

ISO/TR 14069, 2013. Greenhouse gases - Quantification and reporting of greenhouse gas emissions for organizations - Guidance for the application of ISO 14064-1.

ISO/TS 14067, 2013. Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication.

ISO 14040, 2006. Environmental management - Life Cycle Assessment - Principles and Framework.

ISO 14044, 2006. Environmental Management- Life Cycle Assessment. Requirements and Guidelines.

ISO 14064-1, 2006. Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.

ISO 16745-1, 2017. Sustainability in buildings and civil engineering works - Carbon metric of an existing building during use stage. Part 1: Calculation, reporting and communication.

ISO 16745-2, 2017. Sustainability in buildings and civil engineering works - Carbon metric of an existing building during use stage. Part 2: Verification.

Kenny, T., Gray, N.F., 2009. Comparative performance of six carbon footprint models for use in Ireland. Environ. Impact Assess. Rev. 29, 1–6. https://doi.org/10.1016/j.eiar.2008.06.001

Lam, W.Y., Van Zelm, R., Benítez-López, A., Kulak, M., Sim, S., King, J.M.H., Huijbregts, M.A.J., 2018. Variability of greenhouse gas footprints of field tomatoes grown for processing: interyear and intercountry assessment. Environ. Sci. Technol. 52, 135–144. https://doi.org/10.1021/acs.est.7b04361

Orr, J., Drewniok, M.P., Walker, I., Ibell, T., Copping, A., Emmitt, S., 2019. Minimising energy in construction: Practitioners' views on material efficiency. Resour. Conserv. Recycl. 140, 125–136. https://doi.org/10.1016/j.resconrec.2018.09.015

Padgett, J.P., Steinemann, A.C., Clarke, J.H., Vandenbergh, M.P., 2008. A comparison of carbon calculators. Environ. Impact Assess. Rev. 28, 106–115. https://doi.org/10.1016/j.eiar.2007.08.001

PAS 2050, 2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. United Kingdom.

Peter, C., Helming, K., Nendel, C., 2017. Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – A review of carbon footprint calculators. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2016.09.059

Pittau, F., Lumia, G., Heeren, N., Iannaccone, G., Habert, G., 2019. Retrofit as a carbon sink: The carbon storage potentials of the EU housing stock. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2018.12.304

Sykes, A.J., Topp, C.F.E., Wilson, R.M., Reid, G., Rees, R.M., 2017. A comparison of farm-level greenhouse gas calculators in their application on beef production systems. J. Clean. Prod. 164, 398–409. https://doi.org/10.1016/j.jclepro.2017.06.197

Terés-Zubiaga, J., Martín, K., Erkoreka, A., Sala, J.M., 2013. Field assessment of thermal behaviour of social housing apartments in Bilbao, Northern Spain. Energy Build. 67, 118–135. https://doi.org/10.1016/j.enbuild.2013.07.061

UNE-EN 15643, 2012. Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework.

Whittaker, C., McManus, M.C., Smith, P., 2013. A comparison of carbon accounting tools for arable crops in the United Kingdom. Environ. Model. Softw. 46, 228–239. https://doi.org/10.1016/j.envsoft.2013.03.015