Sustainability of non-residential buildings and relevance of main environmental impact contributors' variability. A case study of food retail stores buildings

Beatriz Gimeno-Frontera[a], María Dolores Mainar-Toledo[a], Aitana Sáez-de-Guinoa[a], David Zambrana-Vasquez[a], Ignacio Zabalza Bribián[*b]

[a] Research Centre for Energy Resources and Consumption (CIRCE), CIRCE Building – Campus Río Ebro, Mariano Esquillor Gómez, 15, 50018 Zaragoza, Spain

[b]Research Centre for Energy Resources and Consumption (CIRCE) – University of Zaragoza, CIRCE Building – Campus Río Ebro, Mariano Esquillor Gómez, 15, 50018 Zaragoza, Spain

ABSTRACT

European tertiary sector represents about 13% of EU-28 final energy consumption. As an example, food retail stores sector amounts about 3% of EU members' electricity consumption. Furthermore, currently, fluorinated gases, which are the most used refrigerants for space conditioning and refrigeration systems, involve 2% of EU emissions, having risen since 1990 by 60%. Specifically, commercial refrigeration is responsible for 35% of EU-27 CO_2-eq emissions related to refrigerants.

A methodology based on Life Cycle Assessment standards is presented in this study to assess the energy and environmental implications of non-residential buildings, adapted to particularities of food retail stores buildings, in terms of Primary Energy Demand, carbon footprint and water demand. Relying on a reference building, constructive improvements are tested and evaluated. Then a sensitivity analysis of several configurations of food retail stores are studied considering their building location, refrigerant typology and schedule. Results show that electricity and refrigerants are the main contributors and sensitive to potential improvements. In fact, static calculations reveal that a food retail store may involve, in terms of Global Warming Potential, about 800 kgCO_2- eq/m^{2}year, more than 20 times higher than a regular building. Thus, future scenarios are estimated through a dynamic calculation methodology. Due to optimal dimensioning and configuration of the refrigeration system, together with refrigerant replacement, an 80% of Global Warming Potential minimization can be reached. Furthermore, temporal dynamic assessment can present a variability of environmental impacts estimation from static Life Cycle Assessment of more than 15%, by considering a wider approach towards sustainability assessment of non-residential buildings.

KEYWORDS

Life Cycle Assessment, non-residential buildings, food retail stores buildings, energy efficiency, refrigeration systems, Global Warming Potential, Dynamic Life Cycle Assessment.

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* Corresponding author: izabal@unizar.es

Phone: +34976761863; Fax:+34976732078

NOMENCLATURE

Acronyms

ALR- Annual Leakage Rate

CED- Cumulative Energy Demand

DHW- Domestic Hot Water

DLCA- Dynamic Life Cycle Assessment

DX- Direct Expansion

EMAS- Eco-Management and Audit Scheme

EOL- End of Life

EPD- Environmental Product Declaration

EU- European Union

EU-27- European Union 27 Member States (from January 2007 to June 2013)

EU-28- European Union 28 Member States (from 1 July 2013)

F-gas- Fluorinated gases

GHG- Greenhouse Gas

GSHP- Ground Source Heat Pump

GWP- Global Warming Potential

HFC- Hydrofluorocarbon

HVAC&R- Heating, Ventilation, Air Conditioning and Refrigeration

IIR- International Institute of Refrigeration

LCA- Life Cycle Assessment

LCI- Life Cycle Inventory

MH- Metal Halide

MT- Medium Temperature

MS- Member State

MW- Mineral Wool

RSL- Reference Service Life

SCOP- Seasonal Coefficient of Performance

SEER- Seasonal Energy Efficiency Ratio

UN- United Nations

1. INTRODUCTION

Non-residential buildings represent 25% of European building stock, whereof about one third of useful floor space is represented by wholesale and retail buildings [1]. Commerce and public services represent about 12.5% of EU-28 final energy consumption, accounting for more than 150 Mtoe in 2016 [2]. More in detail, at Spanish level, services sector emitted in 2015 almost, 15.5 MtCO_2- eq related to energy consumption [3] and represented about 30% of national electrical intake [4], whereof commercial sector accounted one third. In fact, retail sector has been pointed as one of the priority sectors according to Regulation 1221/2009 of the European Parliament on the voluntary participation by organisations in a Community Eco-Management and Audit Scheme (EMAS) [5], detailed by the Commission Decision 2015/801 [6].

Regarding retail sector, food retail stores are considered the main electricity consumers [7]. Moreover, according to Galvez-Martos, J. L., 2013, food retail stores buildings may, at least, duplicate other commercial buildings' final energy intensity, such us office buildings which account for 100-200 kWh/m^2 year [8]. The main energy-consuming facilities in food retail stores are perishable food refrigeration fixtures, being usually responsible for around half of the total electricity use, followed by illumination equipment that stands for about 20% of total energy consumption [9]. On the other hand, commercial refrigeration represented 13% of 2012 EU-27 refrigerant bank in terms of weight and was responsible for 22% of total EU-27 refrigerant emissions, with the release of more than 16,000 tonnes of refrigerants; furthermore, it accounted for 45,000 ktCO_2- eq, which implied 35% of EU-27 CO_2- eq emissions related to refrigerants [10]. Hydro-fluorocarbon (HFC) refrigerants R404a and R134a, according to the nomenclature specified in ANSI/ASHRAE 34-2013 [11], represented, by the year 2012, 66% and 13%, respectively, of the refrigerant bank for commercial refrigeration, having become the most commonly used refrigerants in commercial refrigeration sector as of R22 and R12 were banned. Nowadays, several alternatives such as hydrocarbons, natural refrigerants or lower GWP HFC and HydroFluoroOlefin (HFO) fluids are being assessed. Paradoxically, ammonia has been the most used refrigerant in food processing industry for 100 years [12] and hydrocarbons were common refrigerants between the late XIX century and 1930 [13]. Natural refrigerants such as R744 (CO_2) and R717 (ammonia) represented 4% of the bank in 2012 [10]; but it has been noted that, for example, between 2012 and 2015 the number of CO_2-based stores in Europe has almost trebled, according to market trends [14].

Spanish retailers' environmental impact related to refrigerant leakages, per sales area, has been in a steady decline in recent years. According to the annual reports disseminated by the main hypermarket companies operating in Spain, they have decreased the direct impact related to refrigerants refill from more than 300 $kgCO_2$- eq/m^2year during 2010 to less than 150 $kgCO_2$- eq/m^2year in the year 2015 [15]. It should be noted that according to Galvez-Martos, J. L., 2013, refrigerant refill quantity can be read as equal to leakage [8]. Instead, retailers who mainly own smaller stores, such as supermarkets, still report over 200 $kgCO_2$-eq/m^2year direct impact in terms of annual refrigerant refill [15]. Against stand-alone commercial refrigeration, where Annual Leakage Rate (ALR) can account for between 1% [16] and 5% [17], supermarkets' direct and indirect systems ALR can range from 18% and 12 % respectively [17], or even reach 30% [16]. Refrigerant leakages during building operation cannot be completely avoided, although minimization can be achieved.

Current trends are encouraging non-residential buildings' managers and more specifically retail stores managers to adapt their outlets to low energy buildings and rethink their running patterns. On the one hand, worldwide environmental situation has been promoting, in terms of regulation: i) international agreements, such as Montreal protocol [18]; ii) European decarbonisation directives towards 20-20-20 goals achievement, like 2012/27/EU regarding energy efficiency [19]; iii) EU Circular Economy Strategy facing 2030 [20]; iv) Best environmental management practices for commercial retail sector, consolidated by the voluntary participation by organisations in a EMAS Community, as defined in the Commission Decision (EU) 2015/801[6] and v) European F-gas regulation to reduce high Global Warming Potential (GWP) refrigerants, among other issues [21]. On the other hand, consumers' awareness has encouraged food retail companies to develop environmental friendly strategies [22]. As a result, for example, six of the principal food retail enterprises that operate in Spain have enrolled Global Compact initiative fostered by United Nations (UN), undertaking their social and environmental responsibility and facing innovative commitment plans [23]. As an example, the food retailer with the biggest market share in Spain declared to provide energy efficiency training to staff in every supermarket [24], which, according to Carbon Trust [25], can lead to higher CO_2- eq potential savings than other solutions such as doors on cabinets and LED lighting technology. At building level, there are many types of building certifications, such as Building Research Establishment Environmental Assessment Methodology (BREEAM) or Leadership in Energy and Environmental Design (LEED), contributing to the energy management improvement and the minimization of Greenhouse Gas (GHG) emissions, e.g., BREEAM certification achieved by Lidl Växjö in Sweden [26]. LEED certification has similar mandatory requirements to current European legislation regarding refrigerants and as an optional criterion, the use of environmental-friendly refrigerants can account for about 2% of total score [27].

Even so, available studies related to the application of global methodologies for environmental impact assessment of particular non-residential buildings, such as food retail stores buildings, have restricted scope and/or approach. In 2011, Target Zero programme published five guides in order to give advice on the 'Design and construction of sustainable, low and zero carbon buildings in the UK'. One of them focused on supermarkets, investigating operational carbon, modelled according to National Calculation Methodology (NCM), BREEAM assessments and embodied carbon, calculated following LCA Standards ISO 14040 and 14044 [28]. Nevertheless, this approach left out food refrigeration energy implications and refrigerants direct and indirect impacts. In terms of operational energy consumption, there are comprehensive studies, empirical and simulated, such as Braun et al., 2014 [29] and Spyrou et al., 2014 [30]. Furthermore, refrigeration fittings and refrigerants have been deeply analysed by specialized groups like the International Institute of Refrigeration (IIR), developing further assessment methodology [17].

Hence, this article presents a methodology based on LCA standards in order to estimate environmental implications of particular non-residential buildings, such as food retail stores buildings. The approach considers potential typological, temporal and spatial variables relevance evaluation in order to gauge the role of electricity consumption and refrigerant leakages. Thus, it is possible to perform a sensitivity analysis of environmental impact calculations of non-residential buildings and ease decision support towards their sustainability assessment, considering the relevance of the main impact contributors' variability within a dynamic approach.

2. METHODOLOGY

Standards ISO 14040:2006 [31] and 14044:2006 [32] stablish LCA framework, which has been adapted to buildings' specific evaluation through CEN/TC 350, developing EN 15643-1[33], -2[34], -3[35], -4[36], EN 15804 [37] and 15978 [38]. According to building stages standard classification, this study develops a cradle to grave approach. A methodological proposal for non-residential buildings' life cycle stages, adapted to food retail stores particularities, is described in Figure 1. From the stages shown in Figure 1, the following aspects have been considered: i) building materials (including thermal envelope and structure), HVAC&R system and refrigerant's A1-A4 modules; ii) estimated resources consumption of construction process regarding module A5; iii) annual refrigerant leakages and consequent refrigerant refill within modules B1 and B2; iv) building materials and HVAC&R systems replacement by products with the same features and technical specifications, in B4; v) operational energy and water use, in B6 and B7, respectively; vi) building materials and HVAC&R systems EOL transport and processing within C2 and C3 modules and vii) EOL refrigerant leakages in C4. Figure 2, appends externalities and variables affecting building's performance in order to conduct calculations over the methodological approach proposed in Figure 1.

2.1. Goal and scope definition

This study aims to evaluate the environmental implications and potential relevance of variability among the current main impact contributors to food retail stores buildings, e.g., electricity and refrigerant leakages. The food retail store building becomes the functional unit considered and it is assessed for 50 years of Reference Service Life (RSL), fulfilling the design, space thermal conditions and edible refrigerated food conservation requirements for the year 2016. In order to obtain comparable results, calculations are presented related to sales area surface (m^2), the usual unit for indicators comparison in retail trade sector.

2.2. Reference building selection and energy modelling

The methodology described is deemed appropriate for non-residential buildings, particularly for food retail stores. A hypothetical representative stand-alone, single storey supermarket has been developed as reference building, relying on current building regulation and practices. The reference building has been modelled in Design Builder[1] software (v.4.7) [39] in order to

[1] Design Builder Software Limited, www.designbuilder.co.uk

perform the energy simulation through Energy Plus[2] engine [40]. It should be noted that total energy consumption corresponds to electricity. The operational energy consumption breakdown (kWh/m^2year) has been obtained: i) refrigeration fittings and electronic devices, ii) lighting, iii) space heating, iv) space cooling and v) Domestic Hot Water (DHW). In order to achieve reliable results on energy loads considering the variables involved and heat transfer related, simulations have been performed and the values obtained verified with enterprises' reports and scientific literature consulted for further analysis. Moreover, the reference building simulation has enabled to test the improvement opportunities potential.

2.3. Boundaries of the system

In accordance to the methodological approach presented in Figure 1, this study considers the main building materials, the heat pump and DHW boiler, refrigerant charge and leakages and the illumination system, as well as, operational energy and water consumption. Due to the variability and abundant literature available regarding refrigeration and air conditioning configuration systems, e.g., Cecchinato (2012) [41], this study does not accomplish a comprehensive study on HVAC&R layout or configuration. Consequently, it assumes the minimization of heating and cooling demand, as well as, refrigeration thermal losses and the improvement of the lighting equipment, leaving out specific considerations on HVAC&R configuration. In addition, related to display cabinets, it has been assumed a potential reduction of 20% of refrigeration thermal losses, which could be achieved reducing air infiltrations, e.g., through optimum air curtains [42] or even better results could be met with glass doors on vertical multi-deck shelves [43]. Refrigerated cabinets and shelves' embodied carbon, between 280 and 620 kgCO_2- eq/m regarding length of display case [44], is not taken

[2] www.energyplus.net

into account in this study due to: i) it has been demonstrated that their use phase represents more than 90% of their environmental impacts (approx. 93% [45], 95% [46]) and ii) they may represent less than 0.04% of building's total GWP. Furthermore, the embodied primary energy corresponding to the addition of glass doors would possibly represent less than 2% of the energy savings related [43]. There are other solutions to reduce refrigeration energy consumption, e.g., evaporative condenser, floating head pressure, suction pressure control, among others [25], but they are not included in the boundaries of the system. In a similar way, pipe network and other conditioning systems have been omitted.

Related to the lifespan, a report conducted on British supermarkets' service life, resulted that the average age of supermarkets demolished studied was under 25 years old; some of them were just 15 years old and none of them had reached design buildings' life span (50 years). In fact, from almost 600 existing, and still trading, supermarkets analysed, only a 2% were over 45 years old [47]. Still, this study considers reference building's service life optimization in accordance to design life span: 50 years. However, some products installed have a shorter expected lifespan, and consequently their replacement will be considered. In this sense, in general terms, it is assumed that facilities and installations have an expected service life of 20 years, while, most part of building materials may operate 50 years, except for some products, such as gypsum coating and windows, which have an expected service life of 25 years [48].

2.4. Life Cycle Inventory (LCI) and quality data

A food retail store building is a complex product composed by construction materials and fittings. The materials inventory is developed relying on European averages of the Ecoinvent v2.0 database (2007), one of the available databases, which best accomplishes expected features according to [49]. Specific fittings or components, that are not available in Ecoinvent v2.0 database (2007), are assessed relying on EN-15804-compilant Environmental Product Declarations (EPD) which include products' cradle to gate and, in some cases, cradle to grave impact divided into life cycle stages covered. With regard to refrigerant, in terms of GWP, direct emissions relative to CO_2-eq for 100 years integration are based on "*IPCC Fourth Assessment Report/IPCC07/ and Scientific Assessment/WMO10/*" as contained in 2010 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee [50]. Furthermore, refrigerant manufacturing impacts refer to [51] in accordance with [50].

A comprehensive analysis on food retail stores average features has been performed relying on: i) the public 'Sustainable Development report' and 'Annual report' released by the main Spanish food traders, as well as, ii) national statistics, iii) existing regulation, iv) future market expectations and v) scientific bibliography on food retail stores. According to actual data consulted, it has been found that hypermarkets, in Spain, may have an average energy intensity between 350 [52] and 500 kWh/m^2year [15] whereas, supermarkets can amount about 610 kWh/m^2year [15].

2.5. LCI Impact Assessment

The impact categories evaluated in this study have been chosen in accordance with European 2020 targets, regarding energy consumption and environmental concerns. Thus, this study considers: i) Primary energy demand (MJ- eq), ii) Global Warming Potential (GWP) (kgCO_2-eq) and iii) Water demand (l). Primary energy demand is evaluated following Cumulative Energy Demand (CED) methodology v1.08 [53], which assesses demand related to production, use and disposal of a product, in this case the food retail store building. GWP indicator is calculated relying on IPCC v.1.02 characterisation factors with a time horizon consideration of 100 years [53]. For water demand throughout the complete life cycle, despite of the lack of methodology for desiccation potential integration into LCA, this study considers freshwater extractions (rivers, lakes, soils and wells) and excludes water used in turbines in hydraulic power production. Building components calculations of life cycle impacts have been conducted through the software tool SimaPro v7.3.2 [54]. It has to be highlighted that electricity mix emission factors used in this study, cover, besides energy generation direct emissions, other stages such as raw material acquisition, facilities manufacturing, transport, construction and dismantling [55]. In detail, for the reference building, Spanish electricity mix has been calculated in accordance to Ecoinvent v2.0 database (2007), corresponding to the year 2000.

3. CASE STUDY DESCRIPTION

European food retail accounted for almost 100,000 km^2 of sales area by the year 2011, 44% more than in 2000 [56]. These can be located in stand-alone buildings or business premises. According to Galvez-Martos, J.L., 2013, energy intensity (kWh/m^2 year) is higher in smaller shops because bigger sales areas have lower refrigerated fittings density, 2 to 5 m and 6 to 12 m of display case per 100 m^2 of sales areas in large supermarkets and small supermarkets, respectively [8], which are the most energy consuming items in food retail stores [57]. In addition, there can be defined three main refrigeration systems according to their configuration: i) stand-alone or plug-in systems, ii) condensing units and iii) centralized systems, which can be direct or indirect. In turn, food refrigeration fittings can be classified in terms of temperature provided: i) Medium Temperature (MT) and ii) Low Temperature (LT), which may have a length display cases ratio of 2:1 (MT: LT) [8]. There may be also variations on stores' energy consumption profile depending on services provided, such as, cafeteria, additional food preparation services, bakery and non-edible goods supply, among others. It has to be highlighted that all the processes involved in supermarket buildings are closely related to each other, e.g., lighting contributes to heat loads, refrigeration fittings density has consequences on heat recovery rates, just as, building's geometry and enclosures design, e.g., skylights affect Heating, Ventilation and Air Conditioning (HVAC) and lighting consumption. Furthermore, inappropriate or insufficient maintenance and cleaning works concerning refrigerant leakages can also entail rise on building's energy consumption.

The case study is based on a hypothetical building, located in Zaragoza (Spain) with a gross surface of 2,500 m^2 and a sales area of 1,625 m^2. It is assumed a sales area containing Medium Temperature (MT), multi-deck open shelves, with night curtains, and storage coolers connected to a centralized system, with a refrigerated fittings density of 5 m per 100 m^2 [8] and refrigeration heat released to sales area of -25 W/m^2. It must be noted that space thermal loads implications caused by refrigeration fittings may have significant variations regarding sales distribution, goods restocking and general thermostat location, among others. Stand-alone retail buildings are usually light-weighted with poor insulated enclosures. Traditionally, only roofs contain insulating materials. In addition, they hardly have any interior partitions, except for private areas. While a common dwelling may have a Partition surface: Gross surface rate of 1:1 [58], a relation 1:3 is considered for a food retail store, even though it has a greater height. Table 1 shows the main characteristics considered for the reference building, including the Seasonal Energy Efficiency Ratio (SEER) of the HVAC system.

Figure 3 displays the building's layout considered. The model has been defined considering habitual construction systems observed in current Spanish retail buildings and building regulation [59], (materials are detailed in Table 2), in order to evaluate environmental thermal loads related. In addition, it has been elaborated an occupation profile regarding current shopping habits and schedule perceived. Moreover, internal gains within, illumination and fittings are considered, including plausible programming for each type of space inside the food retail store. This is, the heat release caused by the illumination technology and electric devices, such as computers and cash registers (e.g., 5 W/m^2 in sales area and 12 W/m^2 in the office area), and refrigeration heat release previously mentioned (e.g., -25 W/m^2 within sales area and -5 W/m^2 in the warehouse).

The main LCI for Production, Construction and Use phases are specified in Table 2, Table 3, Table 4, respectively. The EOL inventory has been elaborated considering transport of solid waste products by 20-28 tonnes-truck to the treatment plant located 26 km far from the building site. The main part of the materials is assumed to be landfilled, except for openings and metal items, which around 80-90% of their components may be separated and recycled.

4. RESULTS

Table 5 summarizes the LCA results obtained for the reference building, disaggregated by phases regarding CED, GWP and Water demand. Due to the high-energy intensity of food retail stores and the refrigerants typology used thus far, use phase accounts more than 90% of total impacts, as detailed in Table 5, but energy efficiency current practices will enlarge production phase significance. Furthermore, it must be highlighted that, consequently, the use phase results obtained for the reference building involve between 20-100 times Global Warming Potential of habitual building's LCA results. Figure 4 presents production phase breakdown for the reference building. Refrigerant manufacture, considering use phase refilling, may exceed roofing embodied carbon, while total refrigerant leakages may double electricity consumption's environmental impact during operational use phase. In fact, within use phase, refrigerant may stand for more than 60% of GWP, whereas electricity consumption represents one third. The fact that, in terms of energy consumption, electricity is the main contributor to the food retail sector's buildings, is evidenced in the environmental impacts (mainly CO_2- eq), which are highly influenced by the supply mix's characterisation factor considered, in this case, 0.60 kgCO_2- eq/kWh, from Ecoinvent v.2.0 for Spanish electricity mix. Consequently, given the importance of electricity as input and the dependency of its environmental impact to the supply mix, results are sensitive to the assumptions considered, e.g., from the same database, French characterisation factor may imply, in terms of GWP, less than half of the environmental impact related, mainly due to high contribution of nuclear power in this country.

4.1. Scenario assessment

Even though the broad variability of stores attributes precludes the definition of a unique profile type, an approach to these types of buildings' performance has been developed in relation to the following main variables: geometry, construction systems, fittings technology and schedules. In this sense, improvement opportunities and prioritisation criteria can be evaluated in accordance with results. In addition, the scenarios proposed allow to estimate and/or evaluate potential variations on the results obtained.

Hence, in order to validate the methodology, as well as, evaluate the potential scatter of environmental implications, the study is articulated within three types of scenarios as summarized in Figure 5. From a static point of view, three improvement proposals are raised in line with EMAS criterion in order to evaluate improvement potential. Besides, in order to conduct a sensitivity analysis of the building typology selected, three scenarios compare: i) different location of the food retail store, ii) schedule and iii) different refrigerant options and management. Table 6 summarizes the variables considered for building typology sensitivity analysis. Beyond these scenarios, a dynamic approach is also proposed to evaluate prospective results accuracy and potential spatial and temporal variability. Due to the relevance of refrigerant and electricity in terms of GWP, sensitivity analysis at building and dynamic levels is conducted with regard to this impact category.

4.1.1. Energy consumption optimization

Commission Decision (EU) 2015/801 of 20 May 2015 defines a benchmark of excellence [6], that applied to the reference building would imply an averagely total consumption under 300 kWh/m^2year. In order to build up decision support for the implementation of environmental management practices, three improvement proposals have been developed based on the reference building. The variables considered for the improvement proposals calculations are detailed in Table 7. They have been defined following a progressive improvement, regarding energy consumption and building materials choice, in order to achieve HVAC consumption excellence benchmark defined in Best Environmental Management Practices in Retail Trade Sector and halving operational energy consumption when reaching Proposal 3.

The results for the improvement proposals considered, in terms of Primary Energy Demand, Global Warming Potential and Water demand, are presented in Table 8 as the environmental net benefits of the subsequent scenarios, based on the methodology described by Dylewski et al., 2014 [60], translated to this specific case studies conditions; this is, the reduction of the impacts associated to the minimization of the energy demand taking into account the resulting environmental load in other stages e.g. product stage and transportation. These benefits are presented with regard to the reference building.

In terms of CED, the improvement achieved by the development of the scenarios proposed, can almost reach 50%, in accordance with building's energy intensity reduction. In addition, the decrease of energy consumption can lead to almost 40% of water demand minimization without intervening on operational water demand. Nevertheless, GWP mitigation accomplished stands for 20% of reference building's environmental impact inasmuch as refrigerant charge and leakages represent more than 60% of this impact. Consequently, proposal 3 involves throughout the reference service life assessed around 3,500 MJ eq/m^2year, implying less than 600 kgCO_2- eq/m^2year of GWP and almost 10 m^3/m^2year of water demand.

4.1.2. Location of the store alternative

Table 9, unlike Table 8, presents the results regarding GWP of a food retail store located in a premise integrated in a larger structure, instead of the potential benefits regarding the scenarios proposed for the reference stand-alone building presented in the latter. Towards

LCA results for a supermarket located in a premise, it has been developed and fully modelled with Energy Plus engine a food retail store maintaining the same internal layout and adapting its enclosures and environmental conditions to a feasible situation of a commercial premise. It has been assumed a commercial place located on the ground floor of a block, remaining the central part of the supermarket's hood as the block's courtyard (with dimensions 40.0 x 32.5 meters). In addition, it has been considered to be located within the urban fabric with 20 meters street width delimiting two of its sides.

Measures regarding HVAC, such as façade insulation or heat recovery systems implemented in Proposals 2 and 3 may have minor consequences on total energy consumption, as shown in Table 9. Production phase result does not reveal significant changes in absolute terms, but the distribution of the impacts related to each building component does. On the one hand, external walls surface is reduced, as well as, the branding metal top of the walls avoided, while adiabatic walls surface is increased. On the other hand, aerated concrete slabs with acoustic insulation to separate the premise with upper spaces substitute part of the metal deck roofing. In terms of total LCA, the reference building located in a premise involves around 1% less of the impacts, while the benefits of energy efficiency strategies developed in the scenarios are gradually less effective and even involving greater impacts than stand-alone building when analysing scenario 3.

4.1.3. Schedule alternative

Opening hours is a tool that food retail companies use to differentiate themselves from competitors [61] and to attract additional demand when these are closed [62]. Thus, where there is deregulation of opening hours some retailers are extending their schedule. Due to perishable refrigerated goods require of continuous refrigeration, extended opening hours, may become a cost-effective decision in terms of energy consumption, when energy-consuming items are optimized through energy efficiency solutions. Results in terms of GWP for the scenarios related to opening 24 h a day-7 days a week are presented in Table 10. This variation, although extends opening hours, does not increase working hours regarding other services such as office work or food preparation. It should be noted that the energy consumption is not just a multiplying factor applied to the overall consumption. The energy consumption resulted from the simulation of the building has been adapted to the expected activity, schedule and fittings modifications. Spaces attached to sales area are assumed to become voided and their illumination and electric devices turned off after regular opening hours. In addition, commercial area occupation profile is adapted to the schedule, as well as, HVAC setting.

Analysing the results, regarding opening hours, the reference building could involve a 25% energy intensity increase and meet a GWP benefit of 0.1 kgCO_2- eq/m^2 per opening hour. Applying energy efficiency measures within the scenarios assessed, GWP net benefit may almost duplicate.

4.1.4. Refrigerant charge alternative

Lately, the environmental impact regarding refrigerants has become a major issue, overcoming at times GWP associated to operational energy consumption. It can be constrainted: i) reducing refrigerant charge due to the refrigeration system configuration, e.g., decreasing refrigerant charge, from R404a 4 kg/kW in direct centralized systems to 0.4 kg/kW for indirect configurations with R404a/R744 [57] ; ii) minimizing leakage rates, e.g., annual (from 20% to 15%) and End-Of-Life (EOL) (from 15% to 10%), [17]; and iii) by the refrigerant choice – e.g. R404a involves 3,700 kgCO_2- eq/kg, whereas R744 1 kgCO_2- eq/kg [17]. According to HVAC&R equipment suppliers [63], similar energy efficiency values to DX systems, running with R404a, can be achieved within R404a/R744 cascade layout. Consequently, this study's scenario only focuses on the refrigerant charge and not on energy consumption implications related. Table 11 presents the GWP results of three approaches suggested to reduce the environmental impact.

Developing a more exhaustive control over leakages, can lead to 10% GWP minimization. Furthermore, the partial or total substitution of HFCs by environmental friendly refrigerants involve the reduction of more than half of total building's CO_2- eq emissions. Consequently, within use phase, electricity consumption becomes the main impacting issue, accounting more than 90% of the emissions. As a result, the combination of improvement proposal 3 and the refrigerant replacement achieves an 80% of GWP reduction throughout the complete building's life span.

4.1.5. Dynamic assessment of relevant impact contributors

Buildings' long lifespan intensifies time-related variability [64]. These uncertainties and potential changes can be coped with a dynamic modelling approach [65]. Hence, in order to address potential running patterns and systems changes and/or spatial variability, a dynamic life cycle assessment is conducted in this study. DLCA approach is modelled from a double perspective, evaluating time-dependent and spatial variations regarding buildings' main environmental impact contributors (energy consumption and refrigerant leakages) figured in static LCA. For this purpose, beyond static LCA approach, [64] proposes a simplified mathematical model for temporal variations considering four parameter categories for buildings, namely: i) *building operations*, as for example, changes in energy consumption; ii) *supply chain dynamics*, such as, changes in efficiency of the electricity grid; iii) *inventory dynamics*, as the effect of environmental regulation on efficiency and emissions, among others, and iv) *environmental system dynamics*, like emission fates affected by changes in environment conditions. Supply chain functions have been accounted without time gap; this is, no time differences have been assumed between processes and emissions. In line with these parameters, the dynamic proposal in this paper considers: i) influence of refrigerant leakages on energy consumption, ii) electricity mix variation and iii) change on refrigerant choice.

Table 12 compiles, based on [64] DLCA parameters, the variables proposed for the scenario. Regarding DLCA parameters for buildings classified by [64], variations on building operations, supply chain dynamics and inventory dynamics are considered according to EU trends. Nevertheless, possible changes in background environmental systems are not taken into consideration, therefore characterization factors are not time-adjusted. Figure 6 represents variables and main causes related within building's life cycle. It has to be noted that future scenarios approach is always uncertain, due to: i) internal variables, such as actual operation, and ii) external variables, like the background [64]. However, these scenarios present sensitivity to future time-depending changes. Changes regarding site do not refer to building's displacement, but allow comparing environmental impacts differences between the same building with different electricity supply mix.

Within HVAC&R systems, refrigerant leakages effects can be classified as direct and indirect impacts. Direct impacts refer to the consequence on climate change of the release of refrigerant substances to the atmosphere due to their Global Warming Potential. Indirect impact may have a double dimension. On the one hand, it refers to refrigerants embodied impacts, such as, manufacturing impacts [17]. On the other hand, it relates to systems' energy consumption [17]. Furthermore, undercharged systems may incur on electricity consumption rise and cooling capacity reduction [16]. Carbon Trust (2012) [25] estimates that energy consumption can escalate between 10% and 15% due to refrigerant-undercharged systems; less refrigerant flowing into the evaporator, reduces saturated evaporating temperature and so, efficiency. As an example, in a small system with no liquid receiver, electricity consumption increases by 2-4% as evaporation temperature drops of 1ºC [16]. In addition, in some cases, system overcharging can become counterproductive too. Hence, annual refrigerant leakages cause energy consumption rise if not efficiently refilled. Several studies have previously been conducted to evaluate the impacts of refrigerant charge on heat pumps performance at small-scale systems, such as residential air conditioners as summarized in Table 13 [66], [67], [68], [69]. It has to be noted that CO_2 systems are expected to be more sensitive to undercharged situations. In order to compare long term effects of not refilling of losses, static LCA, which considers energy consumption is not affected by leakages, is contrasted with every two years refilling works. This means, as reflected in Table 14 that the first year finishes with 80% of refrigerant charge and the following year at 60%. No further undercharge is considered possible, in this case, due to cooling capacity required for perishable food conservation may not be achieved or compressor failure may occur. Energy consumption increase has been explored based on previous experiences and averages considering leakages as a continuous and successive process that affect energy efficiency progressively. Besides, the study does not cover potential energy consumption increase due to other materials and facilities deterioration or loss of performance.

On the other hand, electricity relevance among buildings' life cycle is sensitive to electricity generation mix. Significant differences can be found due to location. Furthermore, carbon intensity indicators are expected to be improved towards 2050 being averagely reduced by 80% for EU-28 considering 2000 as base year and reaching 88% in some countries like Spain [70]. Even so, from an LCA approach, electricity generation emission factor may double 2050 regular characterisation factors forecast. Figure 7 presents calculated LCA emission factors for electricity generation in accordance to expected gross electricity generation by source [71] and life cycle GHG emissions of each source expressed as $kgCO_2$-eq per kWh, as estimated by [55] and summarized by [72].

Additionally, EU aims to reduce by 60% Fluorinated gases (F-gases) emissions by the year 2030 [24]. F-gas regulation will encourage the use of more environmental friendly refrigerants. As an example, as performed in Scenario 2 of the static analysis devoted to refrigerant substitution, CO_2 will be considered involving higher energy consumption rise due to leakages.

DLCA results are presented in Table 15. Despite of dynamic approach considers energy consumption rise due to refrigerant leakages, long-term improvement on electricity mix reduces life cycle environmental impact calculations.

4.1.6. Sensitivity analysis

Food retail stores buildings' GWP present a wide variation of figures, as observed in Figure 8, from more than 800 kgCO_2-eq/m^{2}year to less than 200 kgCO_2-eq/m^{2}year. The improvement proposals can achieve a GWP reduction of about 150 kgCO_2-eq/m^{2}year on the reference building and almost 200 kgCO_2-eq/m^{2}year in the case of opening 24h-7d per week. From a static point of view, the major difference is observed on refrigerants choice.

It can be appreciated that electricity mix, from a spatial approach, has a significant relevance, accounting, in this case, for an environmental impact difference between Spanish and EU-28 average of about 10% (Figure 9 ii). Introducing temporal dimension, the scenario compares Spanish electricity mix obtained from Ecoinvent v2.2 towards Spanish calculated LCA emission factor evolution unto 2050. Figure 9 iii and iv present results obtained. It can be observed the influence of energy efficiency loss due to inappropriate refill works, the influence of refrigerant and expected variations within electricity mix. If R404a is used, results differ about 20% with regard to reference static LCA. Despite of energy consumption rise due to inadequate maintenance, electricity consumption environmental impact may be halved. If environmental friendly refrigerant is considered for complete building's life cycle, electricity consumption becomes the main contributor to environmental impact, representing more than 90% of total impact. Hence, energy efficiency loss due to refrigerant leakages may represent about 18% of total impacts, almost doubling energy consumption increase of DLCA with R404a. Furthermore, the difference between the static and dynamic approach of R744 case stands between 20 and 30%.

5. DISCUSSION AND CONCLUSIONS

Food refrigeration has a significant role, both in terms of energy consumption and refrigerant emissions. Furthermore, the habitual lightness of stand-alone food retail buildings together with the high operational energy demand confers use phase the major part of the environmental impact. Nevertheless, they present noteworthy cost-effective improvement opportunities, underscoring thermal loads, fittings performance and refrigerant choice. However, due to long lifespan of buildings and desired future changes on electricity generation, DLCA approach reveals significant changes on figures obtained, reaching a difference between 15-30% of final environmental impact. As electricity weight is increased with regard to total environmental impact, more sensitiveness to electricity consumption and/or generation mix variations is expected. Furthermore, the role of energy managers and energy management systems becomes relevant in order to optimize energy efficiency strategies and/or obtain real-time impact assessment data.

According to static results obtained, combining the use of environmental friendly refrigerants, together with energy efficiency measures regarding lighting and HVAC&R systems there can be achieved environmental impact savings of 80%. Moreover, heat recovery systems, can sometimes meet total heating demands or even recover excess heat, enabling to sell the extra heat in a city district network. Regarding opening hours, extension of commercial schedule may lead to better exploitation of energy consumption, due to the habitual main energy-consuming system in a food retail store, refrigeration fittings, requires continued power supply. However, it should be noted, that in terms of economic and social impact of commercial schedule, other variables may be taken into account, such as night shift implications.

Analysing dynamic approach, when high-GWP refrigerants are used, electricity consumption and so, energy efficiency strategies, loose their relevance towards refrigerant leakages impact. In fact, it moves from a estimated Electricity:Refrigerant impact rate of 2:3 to 2:4.6 rate. However, when low-GWP refrigerants operate, specifically CO_2 whose leakages involve higher loss of performance, electricity consumption becomes the main contributor to environmental impact.

Then, it can be concluded, that non-residential buildings, and particularly food retail stores buildings, demand a LCA temporal and spatial dynamic apporach. The fact that electricity and refrigerant emissions involve most part of these building typology's environmental impacts in terms of CO_2-eq together with its sensitiveness to spatial and/or temporal variations, illustrates the relevance of taking into consideration potential future scenarios regarding electricity mix improvement, energy consumption increase due to refrigerant undercharge conditions and refrigerant substitution. In addition, as refrigerant emissions are reduced due to F-gas regulation, energy consumption acquires a mayor role. Hence, the methodological approach proposed results suitable for non-residential buildings environmental evaluation and, furthermore, it is able to gauge environmental implications of the particular case of food retail stores buildings.

Future research may be conducted on different refrigeration systems configuration and other non-residential buildings typologies, such as offices. Also, temporal variations with regard to climate change characterization factors or energy costs may be considered. In addition, towards sustainability assessment, environmental impact results should be aggregated to economic and social dimensions evaluation in order to obtain a holistic approach. Certainly, on the road to sustainability, a structured a comparable system is required, taking into account stakeholders' perception and form of interaction within the building from environmental, social and economic point of view, and including building management issues.

ACKNOWLEDGMENTS

This contribution has been developed in the framework of the SuperSmart project'Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel', funded by the EU under the H2020 Innovation Framework Programme, project number 696076.

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TABLE CAPTION

FIGURE CAPTION

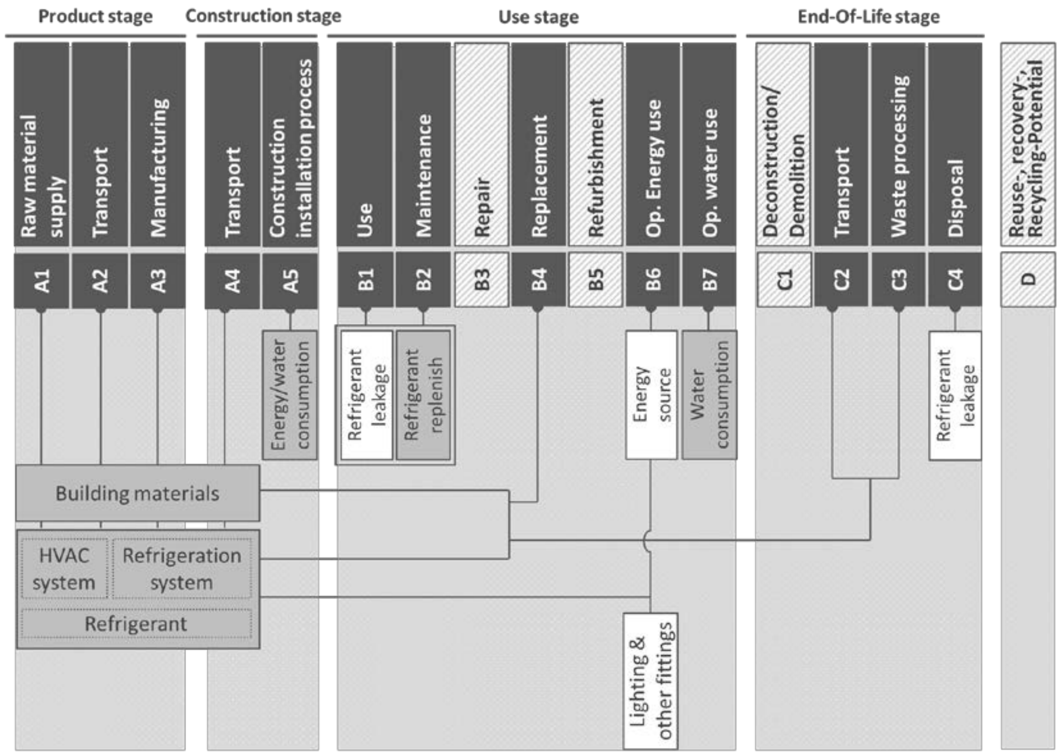


Figure 1. LCA methodology proposed

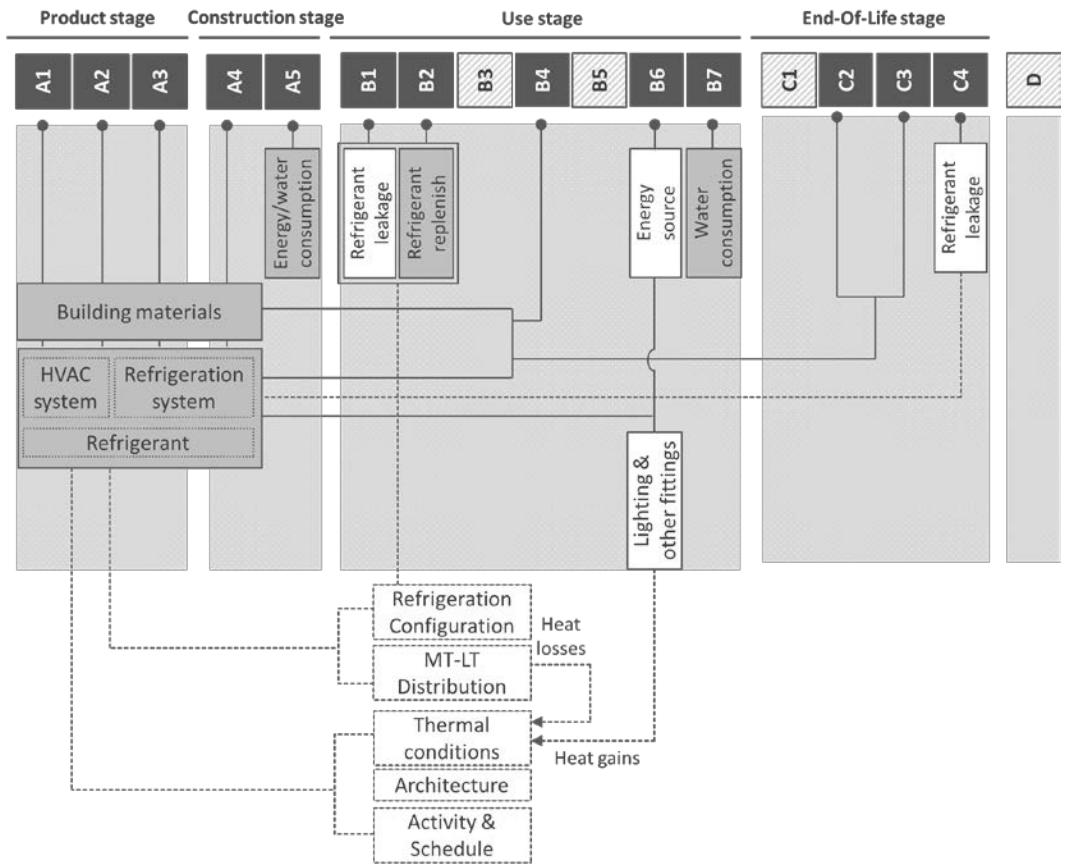


Figure 2. Externalities and variables affecting building's performance

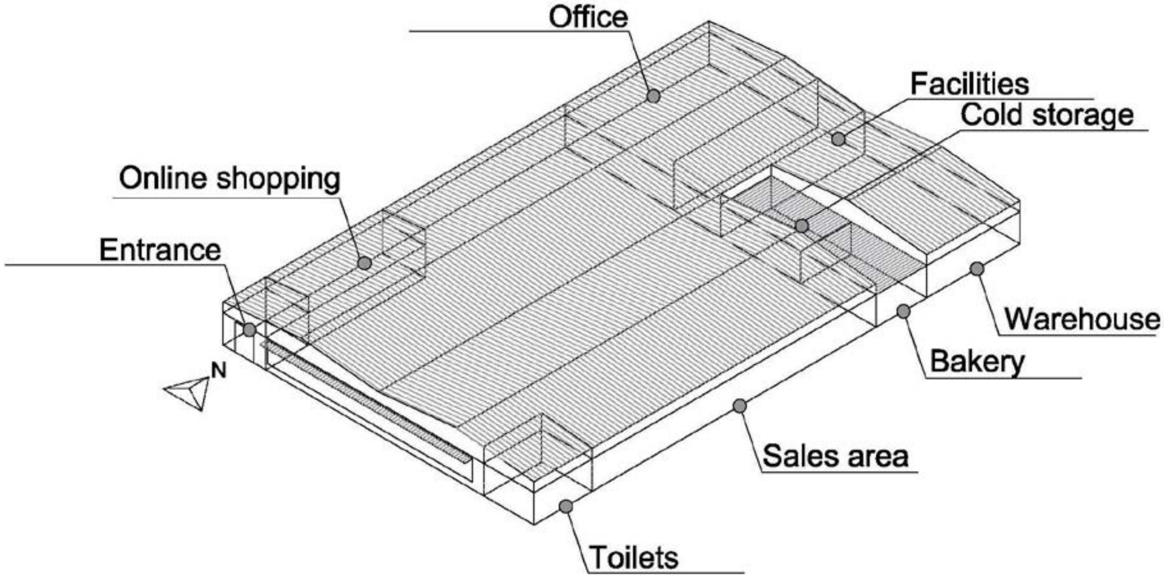


Figure 3. Reference building layout

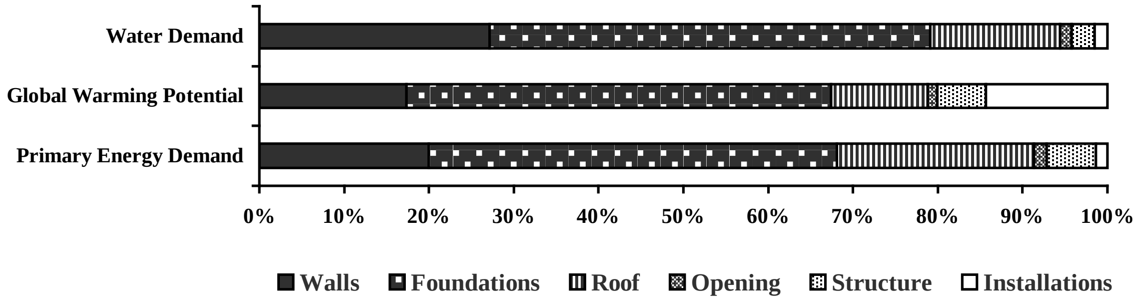


Figure 4. Reference building's production phase breakdown

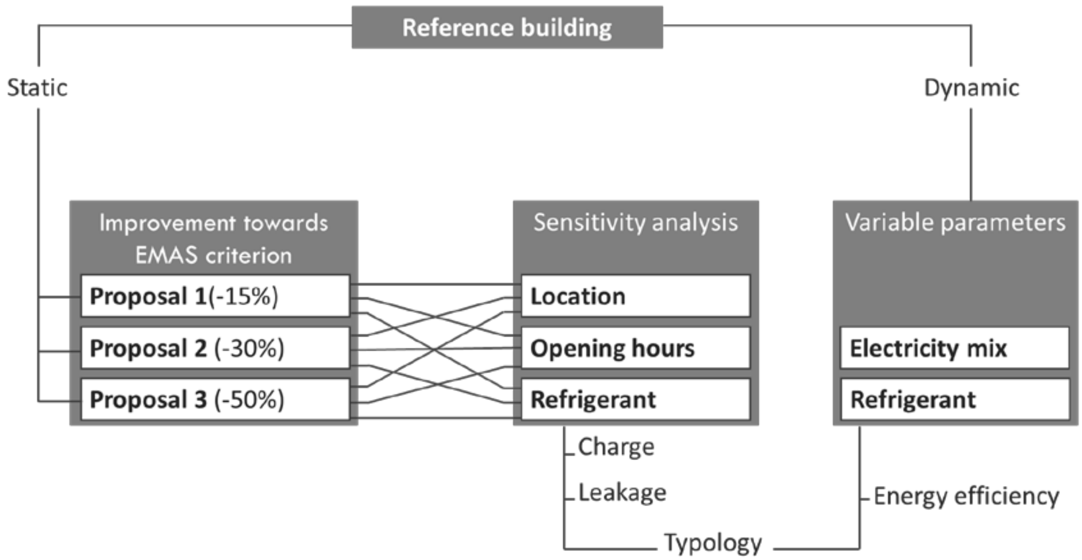


Figure 5. Scenarios evaluated

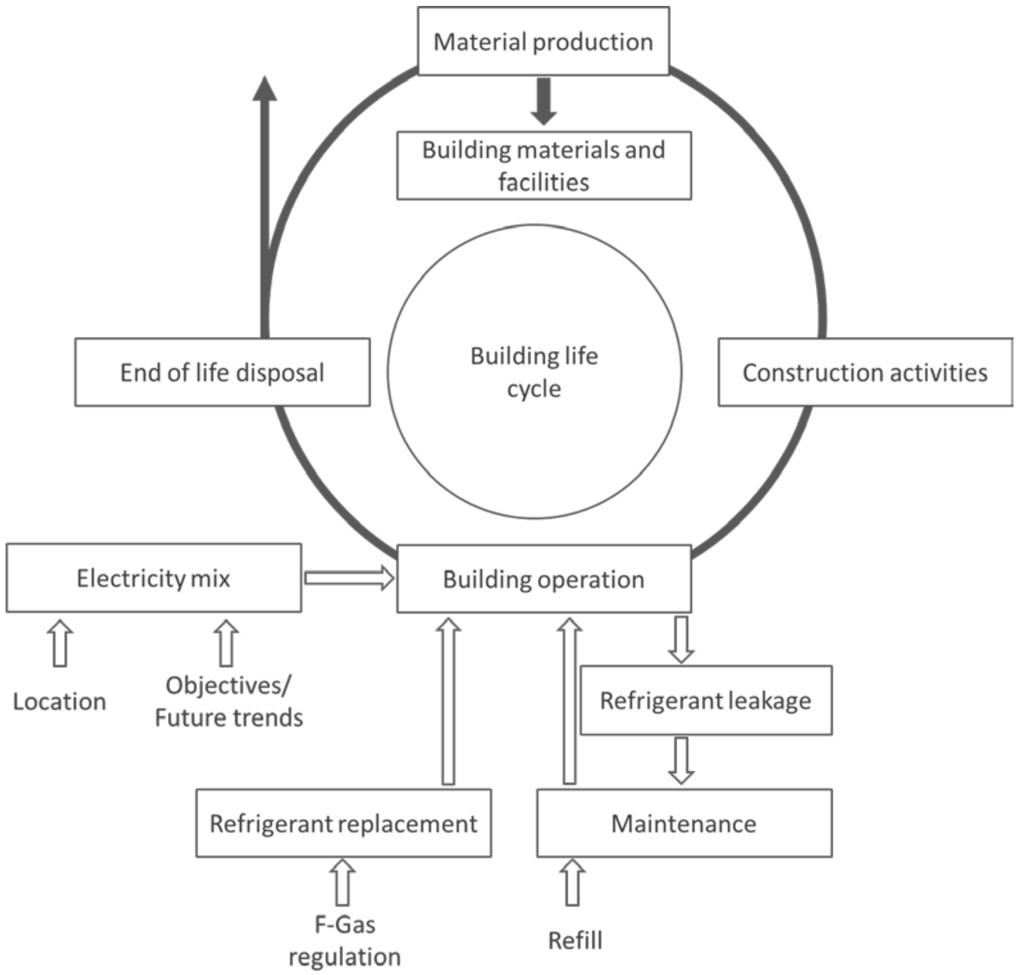


Figure 6. Spatial and time dependent variables considered in building operation

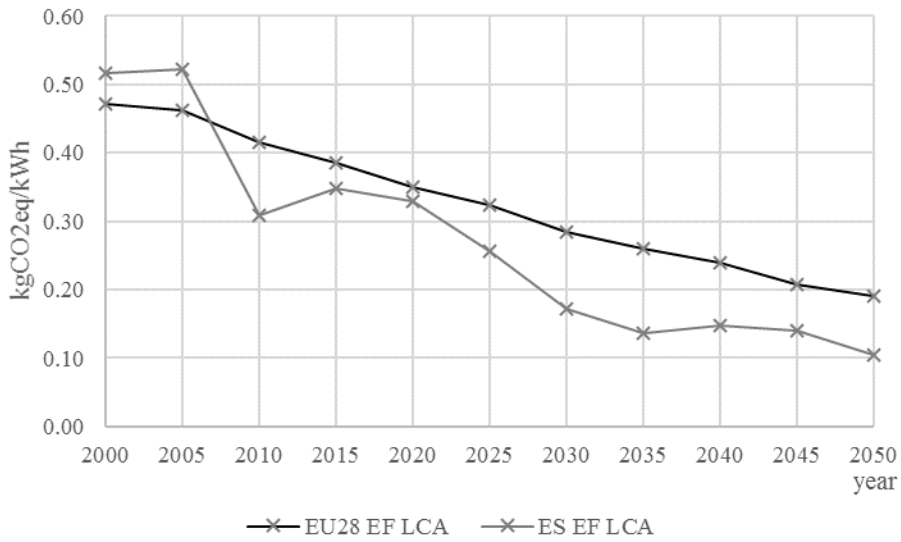


Figure 7. Electricity generationLCA emission factors expected evolution. (EU28 EF LCA: EU-28 Life Cycle electricity emission factor; ES EF LCA: Spanish Life Cycle electricity emission factor)

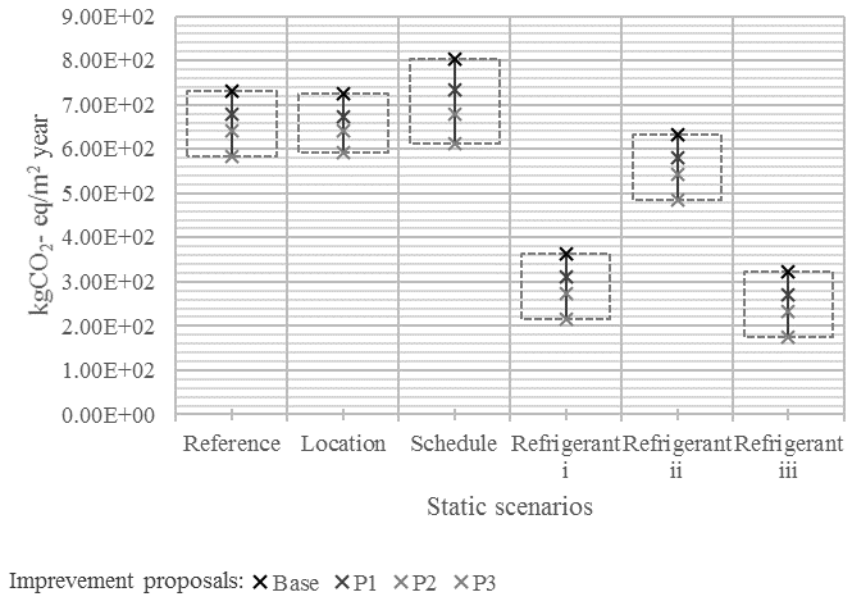
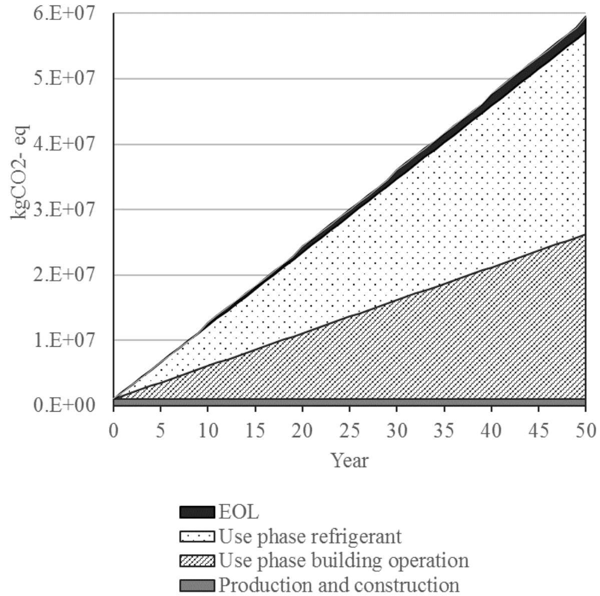
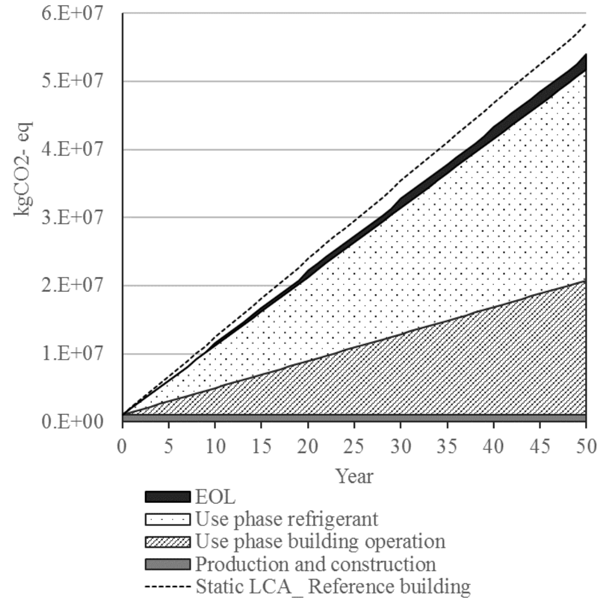


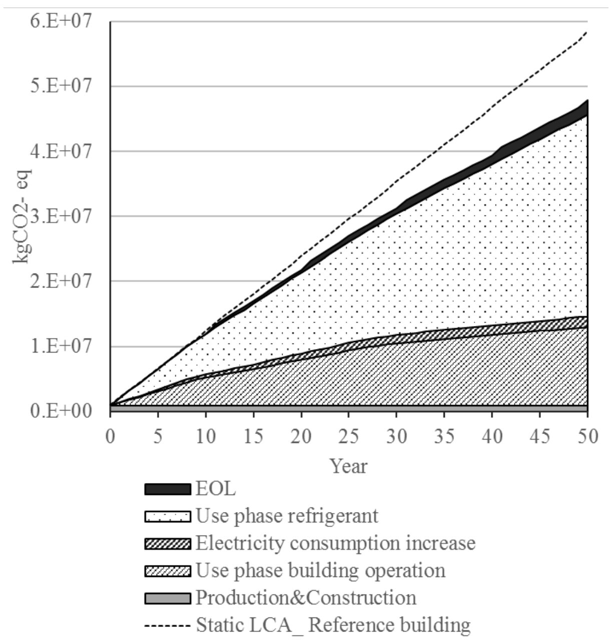
Figure 8. Static sensitivity analysis

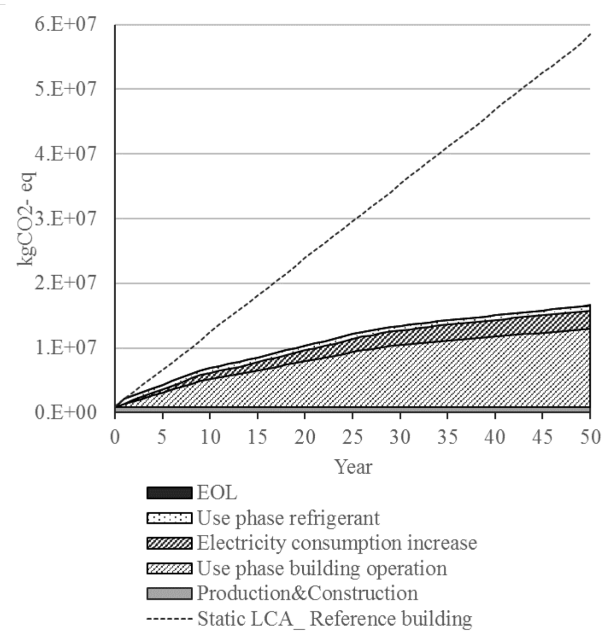




i) Cumulative static LCA Reference
(ES-Ecoinvent v2.2 electricity mix)

ii) Cumulative time-static LCA results
(Spatial variation: EU LCA electricity mix)





iii) Cumulative dynamic LCA results
(ES electricity mix trend, energy efficiency loss due to leakages, R404a)

iv) Cumulative dynamic LCA results
(ES electricity mix trend, energy efficiency loss due to leakages, CO_2)

Figure 9. Dynamic sensitivity analysis

Table 1. Reference building data

Characteristic	Value	Units
Façades E-W	875	m^2
Façades N-S	560	m^2
Indoor height	3.50	m
Max. gable height	5.80	m
Glazing	< 10	%
Main roofing typology	Pitched roof	-
External wall average U-value	1.89	W/m^2K
Roof average U-value	0.33	W/m^2K
Glazing U-value	3.10	W/m^2K
Air tightness	0.70	arch
Opening schedule	09:00-22:00	h
Refrigerant charge (R404a)	4.00	kg/kW
HVAC system typology	Centralized DX	-
SCOP- Heating	2.00	-
SEER- Cooling	2.50	-
Illuminance	500	lux
Illumination technology	Metal Halide (MH)	-
Service life	50	Years

Table 2. Production phase main LCI

Component	Materials	Amount	Units
External wall	Concrete block	215,457	kg
	Cement for bricklaying	35,597	kg
	Gypsum plaster board	18,727	kg
	Laminated steel profiles	390	kg
	Metal sheet	6,967	kg
	Cement mortar coat	7,634	kg
	Ceramic tiles	10,992	kg
Adiabatic wall	Hollow brick (double)	13,156	kg
	Gypsum	4,068	kg
	Cement for bricklaying	3,607	kg
Internal wall	Gypsum	2,160	kg
	Concrete block	62,762	kg
	Cement for bricklaying	16,753	kg
	Stainless steel sheet	2,275	kg
	PUR	576	kg
	Mortar coat	14,140	kg
	Ceramic block	35,162	kg
	Stoneware coating	5,966	kg
	Adhesive mortar	4,203	kg
External and internal openings	Glass 4.6.4 (windows)	71.75	m^2
	Glass 6+6 (doors)	7.00	Units
	Aluminium	7.50	m^2
	Roller door	142.00	kg
	Timber	16.80	m^2
Ground foundation	Stoneware	41,250	kg
	Adhesive mortar	29,062	kg
	Reinforced concrete slab	1,150,000	kg
	Poor concrete	275,000	kg
	Stone (gravel and sand)	1,000,000	kg
Pitched roof	Metal sheet	17,775	kg
	Waterproofing layer	24,750	kg
	Rock wool	15,750	kg
	Laminated plaster	27,000	kg
Flat roof	Stoneware	6,250	kg
	Adhesive mortar	4,125	kg
	Lightweight concrete	12,000	kg
	Waterproofing layers	5,500	kg
	Rock wool	1,750	kg
	Concrete slab	62,000	kg
	Gypsum	3,750	kg
Structure and foundations	Vertical structure HEB-240	21,565	kg
	Laminated steel beams	14,490	kg
	Footings	79,200	kg
Installations	DHW electric boiler	50	l
	Heat pump (DX)	200	kW
	Initial refrigerant charge R404a	800.00	kg

Table 3. Construction phase main LCI

Item	Value	Unit[1]
Electricity, low voltage	6.73	kWh/m^2
Diesel, burned in building machine	23.4	MJ/m^2
Tap water	120	kg/m^2
Transport to site	(Depending on material)	tkm

[1] m^2 in construction phase refers to gross surface

Table 4. Use phase main LCI

Item	Value	Unit
Electricity, low voltage	511	kWh/m^2 year
Tap water	2,000	l/m^2 year
Annual Refrigerant Leakage	20	%
HVAC&R EOL refrigerant leakage	15	%

Table 5. LCA results for the reference building

	Primary energy demand MJ eq/m^{2}year	**Global Warming Potential** kgCO_2 -eq/m^{2}year	**Water demand** l/m^{2}year
Production phase	1.48E+02	1.23E+01	1.73E+02
Construction phase	6.31E+00	3.49E-01	7.21E+00
Use phase	6.24E+03	6.91E+02	1.61E+04
EOL phase	1.54E+01	2.89E+01	1.29E+01
Total	6.41E+03	7.32E+02	1.63E+04

Table 6. Variations proposed

	Reference building		Variation
Location of the store	Stand-alone building	>	Premise in a building
Opening hours	13 h/day- 6 days a week (4,056 hours/year)	>	24 h/day- 7 days a week (8,760 hours/year)
Refrigerant	Charge: 4 kg/kW	>	Charge: 0.4 kg/kW
	Annual leakage (20%) and EOL leakage (15%)	>	Annual leakage(15%) and EOL leakage (10%)
	R404a	>	R744

Table 7. Scenarios considered

	Reference Building	**Proposal 1**	**Proposal 2**	**Proposal 3**
Metal deck with bitumen coating	x			
Metal deck without bitumen coating		x	x	x
Metal Halide lighting	x			
Fluorescent lighting		x		
LED technology lighting			x	x
Skylights and dimming control				x
-25 W/m^2 refrigeration thermal losses	x			
-20 W/m^2 refrigeration thermal losses		x	x	x
No wall insulation	x	x		
Wall insulation (MW 0.080 m)			x	x
Air tightness (0.700 ach)	x	x	x	
Air tightness (0.500 ach)				x
Heat recovery			x	x
Free cooling			x	x
Ground Source Heat Pump (GSHP)				x

Table 8. Environmental net benefits of the scenarios proposed

		Primary energy demand MJ eq/m^{2}year	**Global Warming Potential** kgCO_2 eq/m^{2}year	**Water demand** l/m^{2}year
Benefits	**Proposal 1**	1.03E+03	5.19E+01	2.25E+03
	Proposal 2	1.80E+03	8.98E+01	3.96E+03
	Proposal 3	2.98E+03	1.48E+02	6.58E+03

Comentado [BGF1]: Revisar valores

Table 9. LCA results for supermarket located in a premise ($kgCO_2$-eq/m^2year)

	Reference building	**Location (Base)**	**Location (Proposal 1)**	**Location (Proposal 2)**	**Location (Proposal 3)**
Production phase	1.23E+01	1.18E+01	1.17E+01	1.18E+01	1.18E+01
Construction phase	3.49E-01	3.23E-01	3.21E-01	3.67E-01	3.67E-01
Use phase	6.91E+02	6.86E+02	6.34E+02	6.01E+02	5.51E+02
EOL phase	2.89E+01	2.84E+01	2.80E+01	2.80E+01	2.80E+01
Total	**7.32E+02**	**7.27E+02**	**6.74E+02**	**6.42E+02**	**5.91E+02**

Table 10. LCA results for supermarket opened 24h per day- 7days per week ($kgCO_2$-eq/m^2year)

	Reference building	**Schedule (Base)**	**Schedule (Proposal 1)**	**Schedule (Proposal 2)**	**Schedule (Proposal 3)**
Production phase	1.23E+01	1.23E+01	1.21E+01	1.22E+01	1.22E+01
Construction phase	3.49E-01	3.49E-01	3.46E-01	3.31E-01	3.31E-01
Use phase	6.91E+02	7.62E+02	6.93E+02	6.37E+02	5.71E+02
EOL phase	2.89E+01	2.89E+01	2.82E+01	2.82E+01	2.82E+01
Total	**7.32E+02**	**8.04E+02**	**7.34E+02**	**6.78E+02**	**6.12E+02**

Table 11. LCA results for supermarket with refrigerant modifications. ($kgCO_2$-eq/m^2year) i) Indirect system. (R404a charge: 0.4 kg/kW; R744 charge: 4.0 kg/kW); ii) Leakages minimization (ALR= 15%; EOL= 10%); iii) Refrigerant substitution. R744 charge: 4.0 kg/kW

	Reference building	**Refrigerant i (Base)**	**Refrigerant i (Proposal 1)**	**Refrigerant i (Proposal 2)**	**Refrigerant i (Proposal 3)**
Production phase	1.23E+01	1.11E+01	1.09E+01	1.10E+01	1.11E+01
Construction phase	3.49E-01	3.49E-01	3.46E-01	3.31E-01	3.31E-01
Use phase	6.91E+02	3.49E+02	2.98E+02	2.60E+02	2.01E+02
EOL phase	2.89E+01	4.31E+00	3.59E+00	3.59E+00	3.59E+00
Total	**7.32E+02**	**3.64E+02**	**3.12E+02**	**2.74E+02**	**2.16E+02**
	Reference building	**Refrigerant ii (Base)**	**Refrigerant ii (Proposal 1)**	**Refrigerant ii (Proposal 2)**	**Refrigerant ii (Proposal 3)**
Production phase	1.23E+01	1.63E+01	1.61E+01	1.62E+01	1.63E+01
Construction phase	3.49E-01	3.49E-01	3.46E-01	3.31E-01	3.31E-01
Use phase	6.91E+02	5.97E+02	5.46E+02	5.08E+02	4.49E+02
EOL phase	2.89E+01	1.98E+01	1.91E+01	1.91E+01	1.91E+01
Total	**7.32E+02**	**6.33E+02**	**5.81E+02**	**5.43E+02**	**4.85E+02**
	Reference building	**Refrigerant iii (Base)**	**Refrigerant iii (Proposal 1)**	**Refrigerant iii (Proposal 2)**	**Refrigerant iii (Proposal 3)**
Production phase	1.23E+01	1.09E+01	1.08E+01	1.08E+01	1.09E+01
Construction phase	3.49E-01	3.49E-01	3.46E-01	3.31E-01	3.31E-01
Use phase	6.91E+02	3.11E+02	2.59E+02	2.21E+02	1.63E+02
EOL phase	2.89E+01	1.57E+00	8.60E-01	8.60E-01	8.60E-01
Total	**7.32E+02**	**3.23E+02**	**2.71E+02**	**2.34E+02**	**1.75E+02**

Table 12. DLCA selected variables

Level	Category	Variable	Cause
LCI	Building operation	Energy consumption	Annual refrigerant leakages and maintenance operation
LCI	Supply chain dynamics	Electricity generation mix	EU trends and objectives towards 2020, 2030, 2050 Site
LCI	Inventory dynamics	Type of refrigerant	F-Gas regulation
LCIA	Environmental system dynamics	Not evaluated	Not evaluated

Table 13. Review of energy consumption rise due to refrigerant leakages

Source	Refrigerant	Energy efficiency		Undercharge level	Conditions
[60]	R-22	SEER	-5/-10% -10/-20% -15/-20% -30/-40%	-10% -20% -30% -40%	5 systems with and without accumulator (Dry) Outdoor temp=35ºC (Dry) Indoor temp= 27ºC
[61]	R404a	COP	-5% -45%	-25% -50%	Small chiller. Condenser coolant temp= 30-35ºC
[62]	R410 &R134	COP	-10% -20%	-4% -8%	Cascade system. Ambient temp= 7ºC; Compressor speed= 2700 rpm
[63]	R22	COP	-2% -4%	-10% -20%	CO_2 transcritical. Outdoor temp= 35/24ºC Indoor temp= 27/19.5ºC
	R407c		-5% -8%	-10% -20%	
	CO_2		-10% -25%	-10 % -20%	
[25]	General	Energy consumption	-10/-15%	Average annual supermarket leakages	-

Table 14. Refrigerant undercharge assumptions

Annual refrigerant leakage	Refill	Refrigerant typology	Refrigerant undercharge		Energy consumption increase
20%	Every two years	R404a	year 1	20%	+ 10%
			year 2	40%	+ 30%
		CO_2	year 1	20%	+ 20%
			year 2	40%	+ 50%

Table 15. DLCA results ($kgCO_2$-eq/m^2year)

Electricity mix	**Non-time-dependant**	**Time-dependant**	**Time-dependant**	**Time-dependant**	**Time-dependant**
	EU average	**Spain**	**EU average**	**Spain**	**EU average**
Refrigerant	**R404a**	**R404a**	**R404a**	**R744**	**R744**
Production phase	1.23E+01	1.23E+01	1.23E+01	1.10E+01	1.10E+01
Construction phase	3.49E-01	3.49E-01	3.49E-01	3.49E-01	3.49E-01
Use phase	6.24E+02	5.49E+02	5.81E+02	1.84E+02	2.19E+02
EOL phase	2.89E+01	2.89E+01	2.89E+01	1.57E+00	7.38E-03
Total	**6.65E+02**	**5.90E+02**	**6.23E+02**	**1.96E+02**	**2.31E+02**