

1 ***A decision-making LCA for energy refurbishment of buildings: Conditions***  
2 ***of comfort***

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13 **Abstract**

14 This paper is focused on providing information to help in decision-making between five different  
15 scenarios for energy refurbishment, evaluating the lifecycle of each and also taking into  
16 consideration the level of comfort in dwellings.

17 This work centres on one block built in 1983 in which temperatures have been monitored which  
18 show that the optimum temperature conditions are not reached for long periods during the  
19 year. The current state of the building is referred to as scenario one.

20 Energy consumption is evaluated considering the lifecycle of the components necessary for the  
21 refurbishment, their subsequent operation and disposal.

22 All scenarios address the suitability of passive measures or the implementation of active systems  
23 in temperate climates under the assumption that comfort in dwellings is achieved.

24 Scenarios two and three are assessed applying insulation and changing the windows. The fourth  
25 and fifth implement an alternative solution, a controlled mechanical ventilation based on a  
26 typical mild climate cross ventilation.

27 Evaluation uses two environmental indicators, gross energy requirement (GER) and global  
28 warming potential (GWP).

29 It is concluded that scenarios four and five reduce the GER in 4.4 and 9%, respectively, and the  
30 GWP in 2.6 and 4.3% compared to the current state.

31

32 **Keywords**

33 Life cycle assessment (LCA), Energy refurbishment, Thermal confort, Functional unit,  
34 Communication of results

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## 39 **1. Introduction**

40 The energy consumption in the residential sector represents 17% of the total consumption of  
41 energy and 25% of electrical energy consumption [1]. For homes in residential blocks in the  
42 Mediterranean region, in which the IDAE includes all Andalusia, consumption is about 6500 kWh  
43 or 0.53 tep.

44 In the investigation prior to this paper, values of electricity consumption in 140 dwellings for  
45 rent, which are owned by the Municipal Institute of Housing of Malaga, have been obtained.  
46 The analysis of consumption shows that users consume 34.6% of the average value calculated  
47 for Andalusia by the IDAE. No doubt this reduction in consumption is achieved through a loss of  
48 comfort, as put in evidence by measurements of in situ temperatures in living spaces.

49 This example is intended to show that when the problem of the energy analysis of buildings is  
50 addressed, energy consumption (which is generally reduced in public housing), is just as  
51 important as the comfort of occupants when there is no air conditioning. The prospect of dealing  
52 with the refurbishment of existing buildings should definitely bear this in mind.

53 On the other hand, a complete evaluation of the use of energy and the environmental impacts  
54 of buildings requires a life-cycle perspective to quantify these impacts and identify the most  
55 sustainable solutions thus reducing energy demand and, among others, emissions of  
56 greenhouse gases throughout their life cycle. The methodology of life cycle assessment (LCA)  
57 deals with the environmental impacts and can be applied to decision making to improve the  
58 environmental performance of buildings [2].

59 One of the main strong points of LCA is its multi-criteria analysis point of view, addressing a  
60 "complete" set of environmental categories. However, when decision making including different  
61 stakeholders is addressed, one needs to move from the field of LCA to the one of life cycle  
62 management (LCM) [3], [4], needing to take into account others factor such as: time to perform  
63 the study, subjective perspective of important stakeholders, difficulty to find (confidential) data,  
64 etc. In these situations the so called LCM principle [5] need to be addressed and, specifically, the  
65 "when good enough is best" LCM principle [6]. In the construction sector, LCA has been  
66 increasingly motivated through the climate change debate. For these reason, this study is  
67 focused on these two indicators, although we recognize that they are strongly linked.

68 In the last three decades different researchers have used the LCA methodology to evaluate the  
69 use of energy and the environmental impacts of buildings [7], [8].

70 Since the energy consumed in the operation of the building in their lifespan has the highest  
71 percentage of the whole, reducing it through better design becomes the main goal. However,  
72 reducing the demand in the use phase entails an increase in the embodied energy of the building  
73 due to the increase in materials, technology and other installations. Sartori and Hestnes [9]  
74 documented that the percentage of energy embodied in buildings of low energy consumption  
75 in the use phase is three times higher than in a conventional building.

76 Insulation has become the main alternative to reduce energy demand by reducing the need for  
77 heating in cold weather [10], [11]. However, much less research has been carried out on the  
78 evaluation of the life cycle of buildings (in its use stage) whose dwellings require an adaptation  
79 to the conditions of comfort due to excessive heat during summer, and which main alternative  
80 is to reduce cooling demand.

81 The characteristics of cold climates simplify decision making in housing refurbishment methods.  
82 However, in a temperate climate the decision is more complex.

83 This article presents an accurate LCA for decision-making in energy refurbishment of a  
84 residential building in Málaga considering the characteristics of the place, the climate, the  
85 geometry, the constructive characteristics of the envelope and the applicable regulations.

86 A comparison is made between five scenarios to identify the most favourable solutions taking  
87 into account the entire life cycle, based on the design of passive measures and active systems.  
88 The building is taking part in a European research project called ELIH-MED (Energy Efficiency of  
89 Low Income Housing in the Mediterranean) [12].

## 90 2. Description of the building

91 The building, object of this research, was built in 1983 in Málaga, in the South of Spain (36°37' N,  
92 4°25' W). Málaga has a Mediterranean climate, with mild temperatures in winter, hot and humid  
93 in summer with an average annual temperature of 17.9 °C and a horizontal average irradiation  
94 of 337.4 W/m<sup>2</sup>. The main orientation of the building is northeast–southwest.

95 The building is divided into two main volumes where the housing rises from ground to sixth floor  
96 and a third volume (courtyard and stairwells) covered by glass to which both areas are linked  
97 (see Fig. 1).



Fig 1. Exterior view of the building.

105 In the Northeast-oriented volume there are nine homes per floor and eleven duplex on the fifth  
106 floor and in the section with a south-west orientation there are eleven homes per floor and  
107 twenty-two duplex. The space available for each floor is set at 2.50 m with a separation of 30 cm  
108 between floors corresponding to the slab and coating materials.

109 The building in its current state has a usable area of 10,934.68 m<sup>2</sup>.

110 This current state forms the basis for the first of the scenarios to evaluate (Sc1) (see Fig. 2).

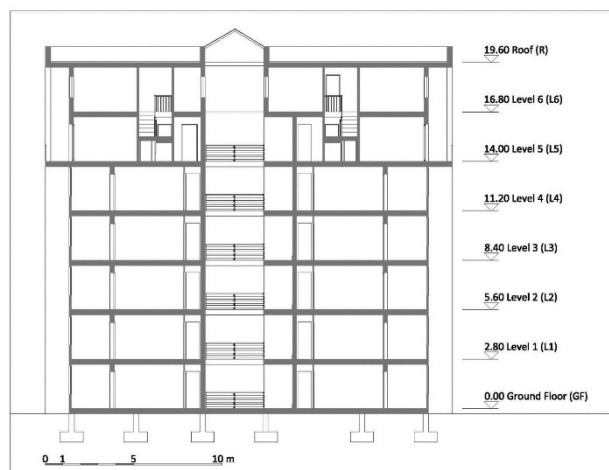
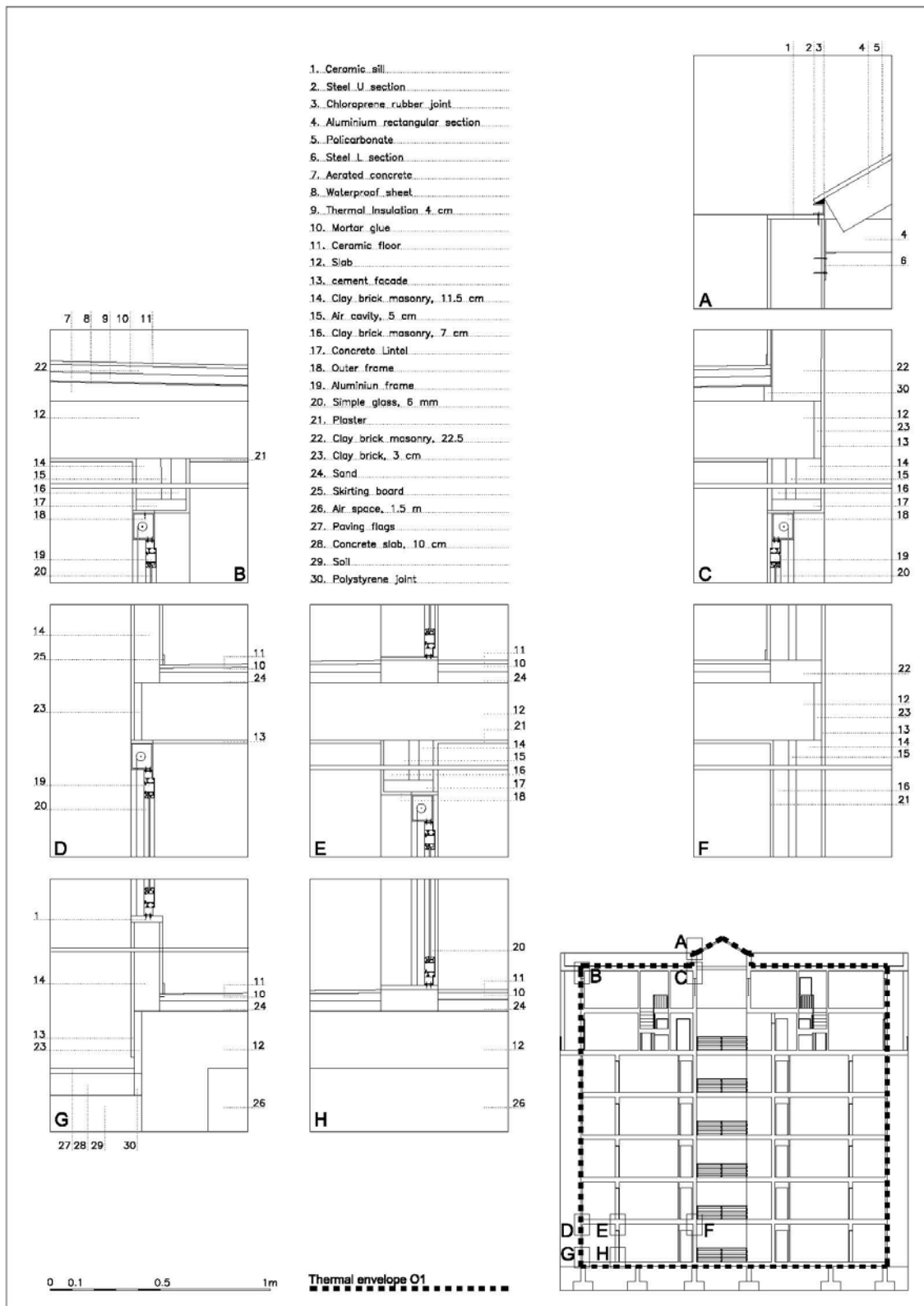


Fig 2. Cross section. Current State (Sc1).

121 The envelope in Sc1 is composed of layers without insulation, a lower slab equally without  
 122 insulation and a roof that does include insulation. The frames of the windows are in aluminium  
 123 with single glass (see Fig. 3).



124 Fig 3. Thermal envelope components. Current State (Sc1)

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### 126 **3. Life cycle assessment (LCA)**

127 LCA is a methodology by which the flows of materials and energy of a system are quantified and  
128 evaluated. These flows are classified into different stages, upstream use (extraction, production,  
129 transportation and construction), and downstream (demolition and relocation to landfill or  
130 recycling plant).

131 Once quantified the flows, the environmental impacts are evaluated (global warming potential  
132 and gross energy consumption); calculations are based on consumption of energy, production  
133 of waste, etc. In conclusion, an LCA study allows an assessment of the impact on the  
134 environment at all stages of the life cycle of a product [13], [14].

135 LCA methodology [15], [16] consists of four phases: definition of the goal and the scope of the  
136 study, inventory analysis, impact assessment and interpretation of results.

137 The reasons for, the public to whom it is addressed, and the limits of the system are defined in  
138 the definition of the objective and the scope of the study. At the inventory phase, data is  
139 evaluated and calculations are performed to quantify the inputs and outputs of the system of  
140 study; the environmental impact assessment evaluates the impact based on the results of the  
141 inventory analysis.

142 Recent developments in LCA methodology distinguish two types of approach [17], attributional,  
143 where the study of LCA of a product does not affect the system and consequential, where the  
144 LCA study of the system influences the product.

145 In studies of LCA of buildings, the attributional approach is the most widely used; only a few  
146 consequential studies have been published. Lesage [18], [19] used both approaches to evaluate  
147 the development of a former industrial area noting that the consequential approach avoided  
148 the marginalization of the site.

149 This research has adopted an approach to the attributional life cycle because the  
150 environmentally relevant flows of the elements and components for energy refurbishment have  
151 been studied.

#### 152 *3.1. Goal and scope definition of the study*

153 This paper is focused on providing information for decision-making by evaluating five separate  
154 scenarios, consisting of passive measures and active systems, throughout their lifecycle, all of  
155 which ensure comfort in dwellings (i.e. 21 °C heating/cooling 25 °C).

156 These measures include the following series of materials and equipment that are common to all  
157 scenarios:

158 - Comfort in dwellings is achieved through an active system multi-split heat pump, with a rated  
159 EER and COP of 3.75 and 4.5, respectively.

160 - The building will have a new coat of mortar on the exterior and a new ceramic tiling on the  
161 roof.

162 Scenario 2 (Sc2) consist in the application of the Directive 2010/31/EU [20] in Spain, which is  
163 called Código Técnico de la Edificación (CTE). For this an exterior and roof insulation facade of 1  
164 cm is applied to the building with 2 cm being applied under the slab over the sanitary space.

165 The aluminium frames are replaced, incorporating in the framework an air vent and fixing double  
166 glazing with an air gap (6 + 4 + 6) (see Fig. 4).

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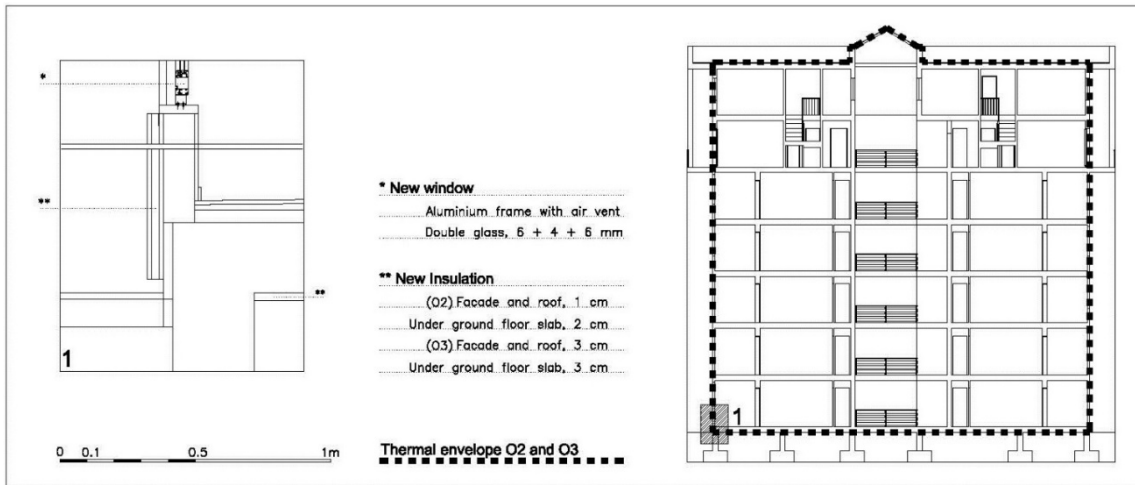


Fig 4. Sc2 and Sc3, detail of the new measures from Sc1.

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170 Scenario 3 (Sc3) is a variant of Sc2 which comes in response to the question; “Does an increase  
 171 in insulation thickness result in less power consumption?” The thickness of insulation considered  
 172 in this case is 3 cm in facade, roof and under the ground floor.

173 Scenario 4 (Sc4) is an alternative solution to the regulatory one, a possibility outlined in the CTE,  
 174 article 5.1, based on the climate and customs of the place, allowing a controlled cross ventilation  
 175 (5 ren/h) in the flats on the ground to fourth floor achieved by new windows on the patio (see  
 176 Fig. 5).

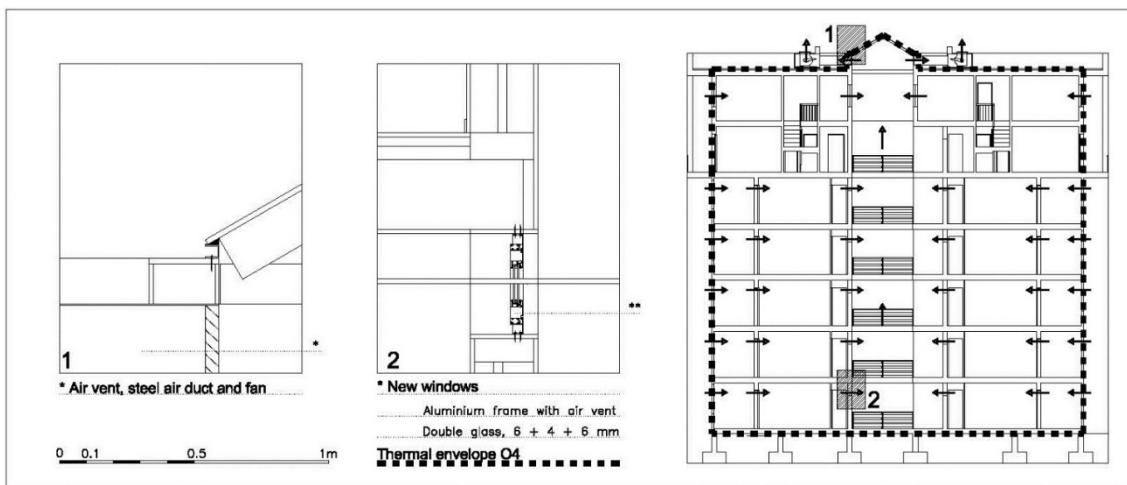


Fig 5. Sc4, details of the new measures from Sc1.

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179 Scenario 5 (Sc5) differs from the Sc4 on the envelope of the building, since Sc5 retrieves the  
 180 open covered terrace which homes had in their original state and which tenants have closed  
 181 during the life of the building, eliminating an obstacle to ventilation.

182 In this way the surface area of the dwelling is diminished and therefore the energy demand. It  
 183 also recuperates the idea of using a building refurbishment to return it to its original appearance  
 184 (see Fig. 6).

185 Sc4 and Sc5 require a gap opening/closing control system based on temperature and pressure  
 186 differences.

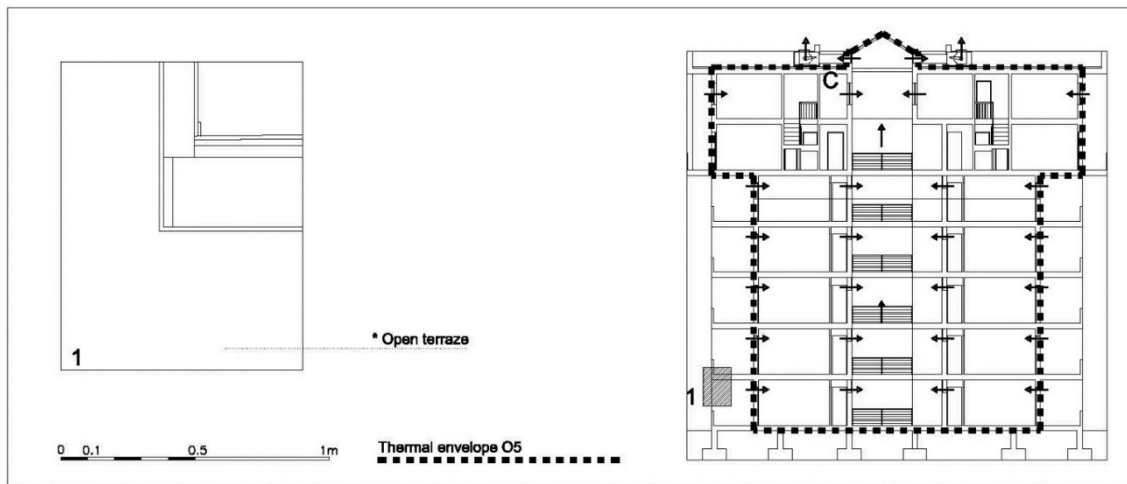


Fig 6. Sc5, detail of the measures from Sc4.

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### 189 3.1.1. Definition of the functional unit and of the boundaries systems

190 One of the primary purposes of a functional unit is to provide a reference to which the input and  
191 output data are normalized. Some examples of FU dealing with housing can be found in the  
192 literature. For instance, when the objective of the study was to reduce energy consumption in  
193 the use phase, the FU was the use of 1 m<sup>2</sup> of the building's wall surface area over a lifetime of  
194 50 years [21] or 1 m<sup>2</sup> of opaque building component with similar heat transfer rate over 80 years  
195 [22].

196 When the environmental impact of HVAC systems is assessed, the FU is one air handling unit,  
197 which distributes a constant air flow volume of 4.8 m<sup>3</sup>/s 24 h a day for 15 years [23] or the  
198 amount of kWh of cooling and heating energy produced by unit during its lifespan [24].

199 In this study, the FU is expressed as the energy needed (in MJ) to ensure the conditions of  
200 comfort with in the dwellings during one year.

201 Another parameter which must be collated in a study of LCA is the system boundary to specify  
202 what stages have been considered [25], the technical systems that have been used and the  
203 components that comprise them [26], [27].

204 The evaluated energy for refurbishment is considered as a multi-input process, inputs ranging  
205 from the gate to the grave, therefore including the transportation of components from the  
206 factory to the building, the annual consumption of the building and the end of life of the  
207 components in relation to the remaining useful life of the buildings.

### 208 3.1.2. Data quality and assumptions

209 Issues relating to data representativeness, data availability and quality remain top priorities for  
210 streamlining the LCA process [28]. A good study of LCA should accurately portray data correlated  
211 to the reality of the site. It is not so important to be precise with the data. For example, if the  
212 building to evaluate is in Spain it is more important to approach the consumption data to the  
213 Spanish electric mix rather than to obtain a very precise mean of the European electricity mix.

214 Components data have been obtained from different sources of information, databases and  
215 environmental product declarations. Proxy data for insulation and windows have used as a  
216 starting point. These data are:

217

218 - Insulation panel XPS, 5 cm wide and 135 cm long with a density of 30 kg/m<sup>3</sup>. It is manufactured  
219 in Navarra, Spain. Data are valid for the period 2010–2015 and its service life is 50 years [29].

220 - 4 m<sup>2</sup> window (3.52 m<sup>2</sup> of glass) weighing 104.11 kg. Aluminium frame with thermal break and  
221 double glazed with air gap. It is manufactured in Toulouse, France. Data are valid for the period  
222 2007–2010 and its service life is 50 years [30].

223 - Mechanical ventilation system consisting of fan, box and steel tube (1 m long and 50 cm in  
224 diameter) connected to the courtyard, for a flow of 12,000 m<sup>3</sup>/h, with power of 2.2 kW and 170  
225 kg in weight. It is manufactured in Barcelona, Spain. Data are valid for the year 2013 and its  
226 service life is 20 years [31].

227 Window data are said to be valid until the year 2010. However, the technology for its production  
228 has not changed and they are therefore considered valid.

229 A 16–32 t truck [32] has been considered for transport. When the production of the component  
230 is in the same city as the building, transportation is not considered. The same happens with  
231 transport at the end of life as it is considered that wastes are taken to local plants at a distance  
232 of less than 10 km.

233 The environmental information relating to the proposed system of heating and cooling  
234 production is not considered because it is the same in all scenarios. The same happens with the  
235 mortar for the envelope of the building and the new roof covering.

236 Having obtained product information, the energy assessment of the various alternatives in the  
237 building is undertaken to calculate the annual consumption during the use phase. This  
238 assessment is conducted under the following hypothesis:

239 - Division of the building into five thermal zones (see Fig. 7):

240 The division is carried out according to the two main sections of the building. Both sections are  
241 divided to define two thermal zones in each one, characterized by the number of floors that it  
242 has and the total useful space per floor.

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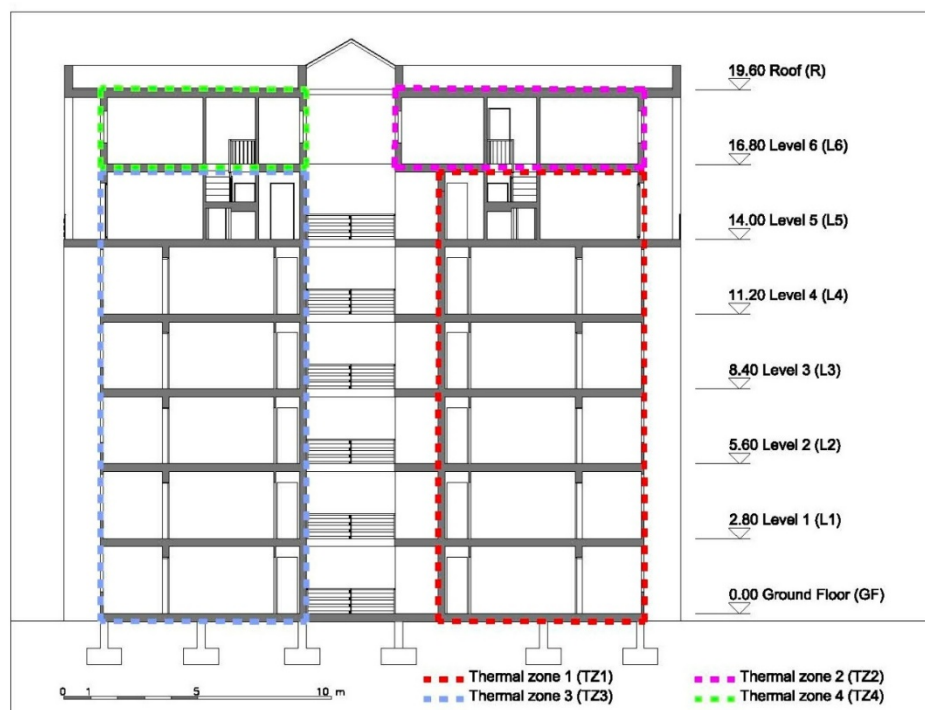


Fig 7. Thermal zones definition.

257 The section with a north-easterly orientation comprises the first thermal zone (TZ1) which  
258 corresponds to the area between the ground floor and the fifth floor with a surface area of 698  
259 m<sup>2</sup> per floor; and the second thermal zone (TZ2) which corresponds to the sixth floor with a  
260 surface area of 704.95 m<sup>2</sup>.

261 The section with a south-westerly orientation comprises the third thermal zone (TZ3) which  
262 corresponds to the area from the ground floor to the fifth one, with a surface area of 820 m<sup>2</sup> per  
263 floor, and the fourth thermal zone (TZ4), which corresponds to the sixth floor with a surface area  
264 of 968.19 m<sup>2</sup>, and the fifth thermal zone (TZ5) corresponds to the courtyard with an area of 636  
265 m<sup>2</sup>.

266 - Selection of ventilation flow rates:

267 In Sc1 the level of ventilation through infiltrations in the windows of 1 ren/h has been  
268 considered. In Sc2 and Sc3 a level of ventilation through air vents in windows for a flow rate of  
269 11 l/s per person as outlined in the CTE is considered.

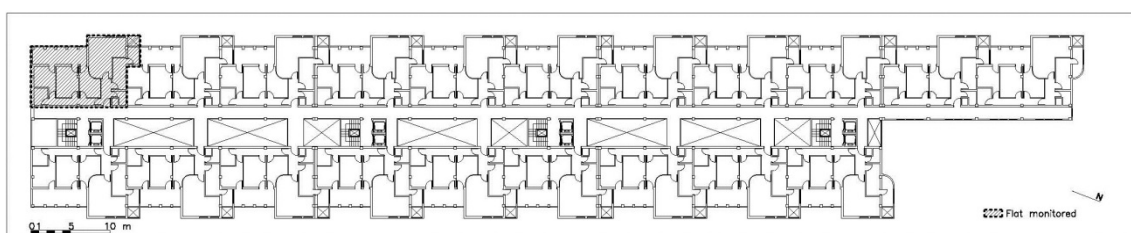
270 Sc4 and Sc5 a 5 ren/h ventilation flow, supported by mechanical extractors that will work when  
271 the outside temperature is lower than 25 °C, has been considered. The indoor temperature will  
272 be higher than the outside and will be between 23 and 25 °C. This flow of ventilation  
273 complements the mandatory minimum flow of 11 l/s per person.

274 - User action:

275 It is assumed that the user will close the blinds on windows when solar radiation is greater than  
276 400 w/m<sup>2</sup> and windows will be opened to allow cross-ventilation, supported by an automation  
277 system.

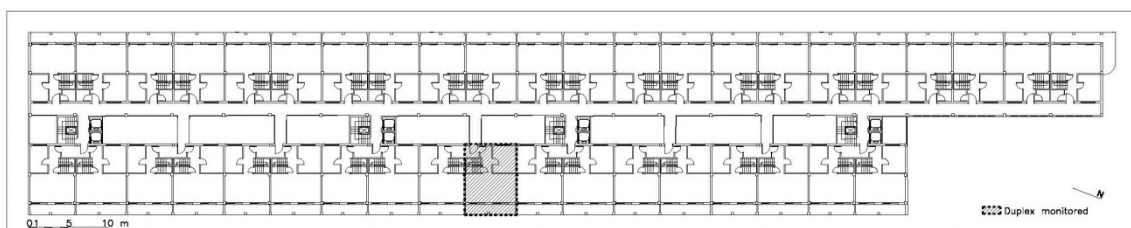
278 Finally and to validate the simulation of the current state, the results of the study have been  
279 compared to a prior monitoring of the building. The monitoring was carried out over two  
280 periods, the first one between the 20th of December of 2011 and the 25th of January of 2012  
281 and the second from 20th of July of 2012 to the 20th of September of 2012.

282 Temperatures in the general area and at the surface have been monitored and heat transference  
283 test have been carried out in a dwelling placed at a corner on level 2 (see Fig. 8), and a central  
284 duplex (see Fig. 9). A weather station was placed in the dwelling on level 2.



285

286 Fig 8. Levels from ground floor to level 4. Level 2, showing monitored housing.



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288 Fig 9. Level 5, showing monitored dúplex.

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290 *3.2. Life cycle inventory*

291 The life cycle inventory analysis phase (LCI) is an inventory of input/output data with regard to  
292 the system being studied. It involves the collection of the data necessary to meet the goals of  
293 the defined study.

294 The inventory is conducted during the three phases of the life cycle, production stage, use stage  
295 and end of life stage.

296 *3.2.1. The manufacturing stage*

297 In this phase data concerning materials and systems for the different options were assessed.

298 In Sc2 and Sc3 the outside insulation facade was measured and a quantification of the embodied  
299 energy and CO<sub>2</sub> emissions by unit of mass, depending on the thickness was made (see Table 1).  
300 The windows were measured and a quantification of impacts by area was made (see Table 2).

301 Table 1. Insulation data in Sc2 and Sc3

Insulation 30 Kg/m <sup>3</sup>	Facade (m <sup>2</sup> )	Roof m <sup>2</sup>	Ground floor m <sup>2</sup>	MJ of primary energy /m <sup>2</sup> of panel	Kg CO <sub>2</sub> eq./ m <sup>2</sup> of panel
Sc2. Width 1 cm	6,244.72	2,321.31		5.35	0.87
Sc2. Width 2 cm			2,321.31	10.71	1.75
Sc3. Width 3 cm	6,244.72	2,321.31	2,321.31	16.06	2.62

302

303 Table 2. Windows data in Sc2 and Sc3

Windows	Units	MJ/ Unit	Kg CO <sub>2</sub> eq./ Unit
Sc2-Sc3. 2 m <sup>2</sup> (GF-L4)/ 4 m <sup>2</sup> (L5)	600 / 80	1,562/ 3123	157/ 313
Sc4-Sc5. 4 m <sup>2</sup> (GF-L4)	100	3,123	313

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305 Moreover, in Sc2 and Sc3 the windows of the thermal envelope were changed. From ground  
306 floor level to the fourth level six windows per dwelling were changed and on the fifth level two  
307 windows per dwelling.

308 In options Sc4 and Sc5 new windows were opened to the courtyard and one per dwelling to  
309 ensure cross ventilation. They are 4 m, 80 cm high and 5 m long, under the top of the corridor  
310 and hall wall (see Fig. 5, detail 2).

311 The mechanical system to ensure the movement of air from the dwellings and patio to outside  
312 of the building consists, in Sc4 and Sc5, of 16 units placed on the roof of the building. The  
313 embodied energy by unit is 7332.45 MJ and greenhouse emissions are 554.92 kg CO<sub>2</sub>eq.

314 All these components are transported from the factory gate to Malaga by truck; A 16-32t truck  
315 is employed, with an associated impact per t-km of 5.10 MJ of embodied energy and 0.16 kg  
316 CO<sub>2</sub>eq. of greenhouse gases emissions. Therefore 3.95 and 9.79 t of insulation are transported  
317 980 km in O2 and O3, respectively, and 2.16 t are transported 1100 km in Sc4 and Sc5.

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320 *3.2.2. The use stage*

321 The alternatives are assessed during their life cycle and it is assumed that in the use phase the  
322 dwelling will achieve the desired conditions of comfort. To calculate the consumption during the  
323 use phase and due to the fact that active systems are employed, an energy simulation of the  
324 distinctive options is carried out.

325 Cooling and heating demand has been evaluated using the heat balance method with  
326 ENERGYPLUS software [33]. The model used to evaluate the consumption of the systems has  
327 been made in function to the outside temperature and PLR [34]:

$$328 \quad P = PIR \cdot Load$$

$$329 \quad PIR = PIR_{nominal} \cdot f_1(t_a, t_b, \dots) \cdot f_2(PLR)$$

330 where: P is the equipment power, kW; PIR is the energy input ratio; “load” is the power delivered  
331 to load, kW; PIR<sub>nom</sub> is the energy input ratio under nominal full-load conditions;  $f_1$  is the function  
332 relating full-load power at off design conditions ( $t_a, t_b, \dots$ ) to full-load power at design conditions;  
333  $f_2$  is the fraction full-load power function, relating part-load power to full-load power;  $t_a$  and  $t_b$   
334 are the various operating temperatures that affect power; and PLR is the part load ratio.

335 It can be observed how the use of insulation and new windows in Sc2 and Sc3 improve heating  
336 demand but worsen the cooling demand because the insulation and characteristics of the new  
337 windows make heat flow difficult with in the building envelope (see Table 3).

338 The number of hours to calculate the consumption of the fans of the air vent was carried out  
339 using ENERGYPLUS software and were estimated at 1837 h/year. These fans are of variable flow  
340 and are regulated by a pressure sensor placed in the patio. The model used to assess  
341 consumption is [35]:

$$342 \quad W_w = W_{vn} \cdot \left(\frac{Q}{Q_n}\right)^3$$

343 Where  $W_w$  is the real consumption, kWh;  $W_{vn}$  is the nominal consumption, kWh; Q is the real  
344 flow, m<sup>3</sup>/h; and  $Q_n$  is the nominal flow, m<sup>3</sup>/h.

345 Conversion factors for final energy to primary energy and greenhouse gases emissions from the  
346 Spanish electric mix are for 2011, 2.21 MWhp/MWh and 0.27 t CO<sub>2</sub>eq./MWh, respectively [36].

347 Table 3. Annual demand and annual consumption in the Sc1, Sc2, Sc3, Sc4, Sc5

Scenarios	Heating demand MWh/year	Cooling demand MWh/year	Electric Consumption MWh/year	Fans Consumption MWh/year	Electric
Sc1. Current State	463	738	241		
Sc2. Option 2	239	996	246		
Sc3. Option 3	224	995	245		
Sc4. Option 4	425	654	225	1.9	
Sc5. Option 5	405	624	215	1.9	

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### 3.2.3. The end of life stage

The end of life phase is studied by the lifespan of the building and the various systems and components incorporated for energy refurbishment. The useful life considered for the building is 50 years. It was built in 1983 so the end of life will be in 2033. The energy refurbishment is going to be carried out in 2013 so the new elements must comply with a service life of 20 years.

The service life of the insulation and windows is fifty years, and it exceeds the remaining twenty years of the building so that has a corresponding effect on its depreciation which is calculated over twenty years, increasing therefore the contribution to the global amount (see Fig. 10).

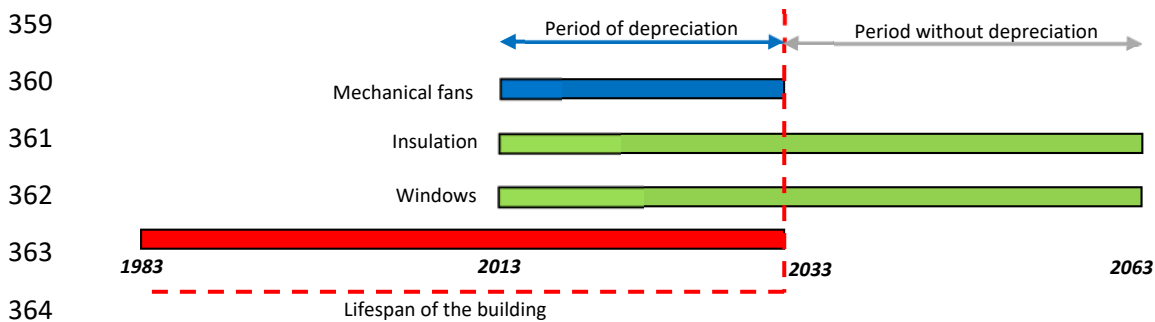


Fig. 10. Period of depreciation of the impacts associated with the measures under study

## 4. Life cycle impact assessment

Life cycle impact assessment (LCIA) allows the description of the potential consequences of the input and outputs flows that are quantified in the inventory analysis in terms of their adverse effects on the environment.

In order to limit the uncertainty and subjectivity of the results, it was decided to rely on mid-point indicators (defined as indicators of impact specific to each impact category and calculated along the impact pathway, such as, e.g. global warming potential and acidification potential), rather than end-point indicators (which entail an additional step to relate the mid-point indicators to the final intended area of protection, such as, e.g. human health of ecosystem quality). For the same reason, it was also decided not to perform any normalization or weighting, in fact, presenting the results in terms of an aggregated single-score indicator would not only have reduced the transparency of the study, but it would also have prevented the comparison of the considered alternatives from being ISO compliant.

Specifically, the two categories of impact under which the evaluated scenarios have been compared are gross energy requirement (GER) and global warming potential (GWP).

The gross energy requirement represents the amount of energy needed in the processes that define the system at different stages of its life cycle. It is expressed in terms of primary energy MJ/FU.

The global warming potential measures how much a given mass of greenhouse gas emission contributes to global warming. It is a relative scale which compares the impact of a given chemical with that of the same mass of carbon dioxide. The indicator is expressed in terms of kg CO<sub>2</sub>eq./FU and refers to a period of 100 years.

These categories are evaluated for the five scenarios under studio and the results show manufactured and transport phases have marginal impacts compared to the use phase (see Fig. 11 and Table 4).

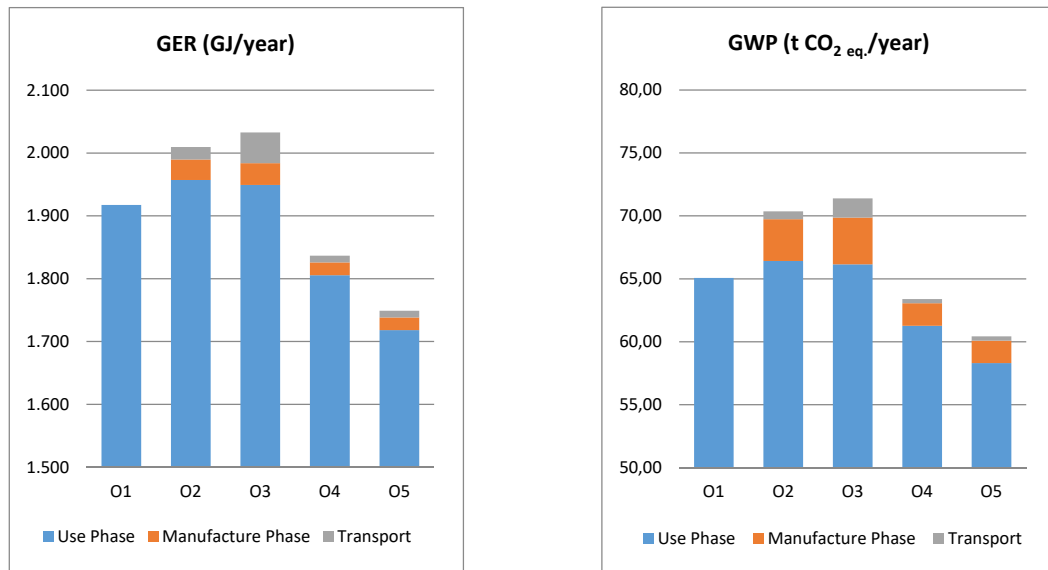


Fig. 11. GER and GWP

402

403

Table 4. GER and GWP in the Sc1, Sc2, Sc3, Sc4 and Sc5

	Sc1	Sc2	Sc3	Sc4	Sc5
GER (GJ/year)	1,917	2,009	2,032	1,836	1,757
GWP (tn CO <sub>2</sub> eq/year)	65.07	70.36	71.40	63.40	60.70

404

405 Sc4 and Sc5 are those that have less impact on the life cycle against the so-called, Sc1, Sc2 and  
406 Sc3.

407 Therefore for Sc4 and Sc5 the gross energy requirement would be reduced by 80.73 GJ/year  
408 (4.4%) and 160 GJ/year (9%), respectively, and the global warming potential in 1.67 t CO<sub>2</sub>eq.  
409 (2.6%) and 4.3 t CO<sub>2</sub>eq. (7%) with respect to Sc1.

410 The last phase of this research is the communications of results, in function of the public to  
411 whom they are targeted. In this case study they are presented to members of the construction  
412 sector, where the information is expressed in terms of reference to the square metre.

413 Consequently the impact avoided per usable m<sup>2</sup> per dwelling and year in scenarios Sc4 and Sc5  
414 are 7.38 and 15.33 MJ and 0.15 and 0.41 kg CO<sub>2</sub>eq. less respectively in regard to Sc1.

## 415 5. Conclusions

416 This paper is focused on providing information for decision-making by evaluating five separate  
417 scenarios, consisting of passive measures and active systems, throughout their lifecycle, all of  
418 which ensure comfort in dwellings (i.e. 21 °C heating/cooling 25 °C). This research clarifies the  
419 question; "In temperate climates, does an increase in insulation thickness result in less power  
420 consumption?" Gross energy requirement (GER) and global warming potential (GWP) impact  
421 indicators have been assessed.

422 The main conclusions are:

423 A LCA for energy refurbishment helps to know the impact associated with each stage and impact  
424 avoided in regard to the current state (Sc1), making an inventory analysis accurate to the reality  
425 of the site and to the functional unit.

426 In buildings located in temperate climates, more impacts are saved by designing ventilation  
427 systems (Sc4 and Sc5), against the implementation of insulation measures (Sc2 and Sc3).

428 Sc5 is more advantageous than Sc4 because the opening of the terrace decreases demand and  
429 therefore consumption. Moreover, there is one less obstacle, therefore the ventilation is better.

430 Therefore for Sc4 and Sc5 the gross energy requirement would be reduced by 4.4% and 9%,  
431 respectively, and the global warming potential in 2.6% and 7% with respect to Sc1.

432 In this case study the results are presented to members of the construction sector, where the  
433 information is expressed in terms of reference to the square metre.

434 Consequently the impact avoided per usable m<sup>2</sup> per dwelling and year in scenarios Sc4 and Sc5  
435 are 7.38 and 15.33 MJ and 0.15 and 0.41 kg CO<sub>2</sub>eq. less respectively in regard to Sc1.

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