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OPTIMIZATION OF ENERGY RENOVATION OF RESIDENTIAL SECTOR IN CATALONIA BASED ON COMFORT, ENERGY AND COSTS

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ABSTRACT

The paper describes OptiHab study, done in the framework of the MARIE project. The objective of OptiHab is to provide technical and economic information to optimize the energy renovation of residential sector in Catalonia, ensuring the comfort of the users. The information of the study gives the criteria to develop regional strategies and policies to improve the energy efficiency of the residential sector. The method used and the results of one building typologies are presented. In addition, the results have been used to propose a subsidy plan for the energy renovation of buildings based on cost-effective measures.

INTRODUCTION

Within the European regulatory framework and the agreement signed by Member States, the nations and regions have an essential role in decision-making to reach the 20/20/20 targets, applying the Energy Performance of Building Directive (European Commission, 2010) and the Energy Efficiency Directive (European Commission, 2012). As the existing residential sector is one with greater potential for energy savings, it is one, which faces more barriers too. In Catalonia, the energy renovation rate is around 0.2% dwellings per year (Cubí et al., 2013), which represents a low fraction of the building stock. The promotion of the energy renovation of buildings is needed, ensuring that available measures are cost-effective in a long term as well as, they improve the comfort of the users.

However, given the current economic situation, is more difficult to achieve the goals of the European Union. In that sense, the definition of ambitious but at the same time, realistic strategies are needed in order to start the way for the change. For that reason, the policy makers have to consider at least two aspects. On the one hand, the technical vision of the renovation (energy efficiency measures, their costs, their energy savings…). On the other hand, the social impact of the intervention (the social acceptance, the economic efforts per household, the improvement of living conditions…).

In this context, the present paper describes the OptiHab study, done in the framework of the MARIE project (Mediterranean building rethinking for energy efficiency improvement, www.marie-medstrategic.eu). The objective of OptiHab is to provide technical and economic information to optimize the energy renovation of residential sector in Catalonia. The study gives the criteria for developing regional strategies and policies to improve the energy efficiency of the residential sector in Catalonia. OptiHab uses as starting point the building stock characterization done also during the MARIE project, where the Catalan residential sector was analysed in detail (building regulations, state of the art, statistical data and survey campaign). The stock characterization defines the constructive features, the equipment and the users of all building typologies.

The paper describes briefly the method used in OptiHab and the results of one of the building typologies evaluated. In addition, the results have been used to propose a subsidy plan for the energy renovation of this building typology.

METHOD

The main objective of the method is providing the cost-optimal measures for the energy renovation of residential buildings, considering three main criteria: thermal comfort, primary energy use and global economic costs. The method was introduced previously in (Salom et al., 2014). The study is done using dynamic building simulations, where the building and its interaction with the user is characterized in detail with TRNSYS (SEL, 2012). The simulation evaluates the three main criteria for the base case, i.e. the existing building, and for the building with different packages of energy efficiency measures (passive and active measures).

All the simulations are done in two-step optimization: passive and active optimization. In the first one, the objective is to obtain optimal passive measures that provide a better thermal comfort without the use of mechanical systems and considering the investment cost. In the second step, the active measures are applied and the primary energy consumption and the global costs have been compared to obtain the cost-optimal solution. In order to reduce the number of possibilities, five packages of passive measures are selected in the first step. These selected measures are combined with the active measures to be tested in the second step.

The co-simulation process is done with SDLPS (Fonseca i Casas, 2012). SDLPS is a general purpose simulation software infrastructure that makes possible to formally define the behaviour of a building and find optimal values for several building parameters and their associated impacts. SDLPS manages the main simulation process and TRNSYS is used as a calculus engine for the energy simulation. Since the objective is to obtain a complete characterization of the problem, the Brute-Force approach is used. This approach consists on run the simulation with all the possible combinations. The factors are insulation of façade, insulation of roof, window, solar protection, heating and cooling system, lighting and renewable systems, implying around 10,000 simulations per building typology.

Building simulation

The paper is focused in the most representative typology of residential buildings of Catalonia, which represents the 45% of the dwellings (Garrido et al., 2012). This typology was built before the first building regulation (1950-1980) and is characterized for having a low thermal performance. The building typology is a block of apartments with a commercial ground floor and four residential floors. There are two dwellings per floor with a 78.8m^2 of surface each one. The typology is simulated in four climates of Catalonia; however, in the present paper the results of only the Barcelona climate are presented.

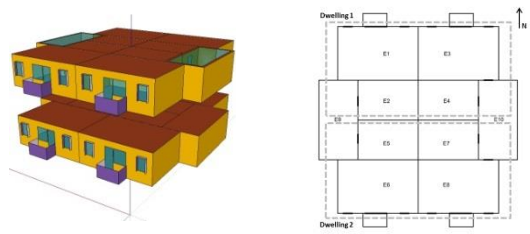

Figure 1 Building typology: block of apartments 1951-1980

The building geometry (Figure 1) is introduced in the simulation by a multizone 3D model, using the plugin Trnsys3D for Google SketchUp. Only two floors are included, in order to simulate the building with more detail: the standard floor and the under roof floor. Then, each dwelling is divided following two zonification criteria: night and day use, and orientation. The building model includes the external environment and their corresponding shadings.

In the simulation, the occupancy has been defined as the main driver of the use of the building (heating, cooling, natural ventilation, solar protection and lighting use). For that reason, one of the main objectives is to use realistic profiles of the occupants. This profile has to reproduce the variability of the real occupants and, at the same time, their behaviour has to be representative of the average occupant. The stochastic profiles are created from the Time Use Data survey of Spain (INE, 2010). This survey allows knowing what the people are doing at each moment of the day. Then, an annual profile can be created applying a statistical analysis of the raw data, assigning a state of each occupant: outside of home, passive at home, and active at home.

Vernacular strategies from the Mediterranean climates have been included in the simulation as the main strategy to cool the household during the warm season. The control strategies of the natural ventilation and the use of solar protections have been defined with the objective to reproduce the actual behaviour of the users. The details of the approach used in the simulations are explained in (Salom et al., 2014).

Finally, the energy systems have been defined with a simplified method based on the efficiency of the different parts of the system: generation, emission and control. The efficiency of generation is calculated using (IDAE, 2009) and the efficiency of the emitters and control following (EN 15316, 2008).

Energy efficiency measures

The energy efficiency measures evaluated in the study includes passive and active measures, including renewable energy systems. Table 1 describes briefly the different measures.

Table 1
Description of the energy efficiency measures

MEASURE	DESCRIPTION	ADD. BENEFIT
Façade insulation	- External - Air chamber - Internal	Reduce the thermal bridge
Roof insulation	- Inverted - Internal	-
Window change	- 4/16/4 Aluminium - 4/16/4 PVC	Reduce air infiltration
Solar protection	Awning	-
Condensing boiler	η 1.09	-
Improve efficiency installation	- Programmable thermostat - Thermostatic valve - Tap aerators - Water volume saving	-
Solar thermal system	16 m^2/building 1500 litres storage tank	-
Efficient split	EER 4	-
PV system	12 m^2/building 240 Wp	-
LED	1.5 W/m^2	Luminous efficiency 80%
Awareness campaign	Reduction of 13% of lighting and appliances	Reduction internal gains

Comfort and economic optimization

The objective of comfort and economic optimization is to obtain the optimal passive measures that provide the best thermal comfort with the lowest initial investment cost. For the evaluation, the building has been simulated without the use of the heating and cooling system (free running mode) and the comfort model used is the ASHRAE adaptive model (ASHRAE 55, 2004). The purpose is to explore to what extend the passive measures are able to improve the comfort conditions without the use of the mechanical systems. The comfort parameters used for the evaluation are the Long-term Percentage of Dissatisfied (LDP) developed by Carlucci (Carlucci, 2013) and the hours of overheating (OH).

The LDP is a long-term index that evaluates the comfort along a period. The index has been calculated for three periods (annual, cold season and warm season), in order to have information about the behaviour of the building under different weather conditions. The comfort requirement for a residential building is LDP < 20% (ASHRAE 55, 2004). It means that the occupants have comfortable condition at least during the 80% of the time.

$$LDP = \frac{\sum_{t=1}^{T}\sum_{z=1}^{Z}(p_{z,t} \cdot LD_{z,t} \cdot h_t)}{\sum_{t=1}^{T}\sum_{z=1}^{Z}(p_{z,t} \cdot h_t)} \quad (1)$$

Where t is the counter of the time step of the calculation period, T is the calculation period, z is the counter for the zones of the household, Z is the total of zones of the household, $p_{z,t}$ is the zone occupation rate at certain time step, h_t is the duration of a calculation time step and $LD_{z,t}$ is the Likelihood of Dissatisfied inside a certain zone (z) at a certain time step (t). The LD depends on the comfort model and is a function of the short-term index. As the ASHRAE adaptive model is used, the LD is the ASHRAE Likelihood of Dissatisfied (ALD) and the short-term index is the operative temperature (T_{op}). The calculation details are explained in (Carlucci, 2013).

The hours of overheating are included in order to complement the LDP of the warm period. One of the main problems of the Mediterranean regions is the increase of the overheating hours due to a not appropriate design of the building. Then, analysing the OH could help to detect the overheating problems and then, try to avoid them. The criterion used is that the percentage of OH has to be lower than the 1% of the period calculation in order to have a comfortable building. If the hours of OH are lower than 1% it means that the building achieve comfortable conditions without the use of mechanical cooling system, and then it could be removed. The criterion was proposed by CIBSE (CIBSE, 2006), however, an adaptation in the calculation of the index has been done: the upper threshold is not a constant value and it depends on the ASHRAE adaptive comfort model.

$$P_{OH} = \frac{\sum_{t=1}^{T} p_t \cdot OH_t}{\sum_{t=1}^{T} p_t \cdot h_t} \quad \begin{cases} OH_t = 1 \Rightarrow T_{op,t} > T_{upperASH,t} \\ OH_t = 0 \Rightarrow T_{op,t} \leq T_{upperASH,t} \end{cases} \quad (2)$$

Where P_{OH} is the Percentage of hour of overheating, $T_{op,t}$ is the operative temperature and $T_{upperASH,t}$ is the upper comfort temperature of the ASHRAE adaptive comfort model at time t. For the climate analysed the 1% of the warm season hours corresponds to 41 hours.

Analysing both comfort parameters and the initial investment cost, a set of passive measures can be selected, as in the Results and Discussion section is detailed.

Cost-energy optimization

The second step of the method is the cost-energy optimization. The objective of the analysis is to minimize the primary energy consumption with the minimum global cost. In that case, the simulation of the building has been done with the heating and cooling systems. The primary energy consumption includes heating, cooling, domestic hot water (DHW), lighting and appliances consumption.

The global costs calculation follows the European Directive 2010/31/EU (European Comission, 2010) and 2012/27/EU (European Comission, 2012), and the method is described in EN 15459 (UNE-EN 15459, 2008). The global costs represent all the costs needed over a long period (30 years), which includes: energy costs, initial investment costs, replacement costs and maintenance costs. All the calculations take in consideration the evolution of the money (2.5% of inflation rate and 4.5% of market interest rate) and the evolution of the energy costs. This method allows to compare passive and active measures maintaining the technological neutrality between them (e.g. the investment cost of passive measures are usually higher than the active ones, however, the lifespan of the active ones are shorter and needs to be replaced earlier).

To analyse the results, the energy labelling has been included in the evaluation. However, the energy label includes heating, cooling and DHW, and the results of the study considers the lighting and the appliances. For that reason, an adaptation of the labels is needed in order to be comparable. First, the energy labels are calculated following the EU regulation. Thereafter, the average lighting and appliances consumption have been included to obtain the *Energy Label of Total Consumption of Dwelling*.

RESULTS AND DISCUSSION

Thermal comfort, energy and economic analysis

The first step of the method is the passive evaluation and the results are shown in Figure 1 and Figure 2. In both figures, each dot represents the result of one simulation and the base case and the selected measured are highlighted in both figures. The description of these simulations and the comfort results are detailed in Table 2 and Table 3.

How the thermal comfort is improved as the passive measures become more expensive can be observed analysing the Figure 1. The base case (BC) starts around 30% of discomfort achieving a 22% of discomfort with the best combination of passive measures. Analysing the shape of the point cloud, two tendencies can be differentiated: the BC, 1081, 1118 and 338 group and the 1121 and 341 group. The main difference between both point clouds is the window type. The first group has the window base case, and the second one has improved the window performance. Increase the window performance has an important repercussion on the thermal comfort improvement however, the investment cost is increased considerably (8,000€/dw). In addition, each point cloud can be divided in 2 groups, depending on the type of façade insulation: air chamber insulation (1081, 1118, 1121) and external insulation (338 and 341). In this sense, the air chamber insulation is cheaper than the external insulation; however, the thermal behaviour is better for the external insulation.

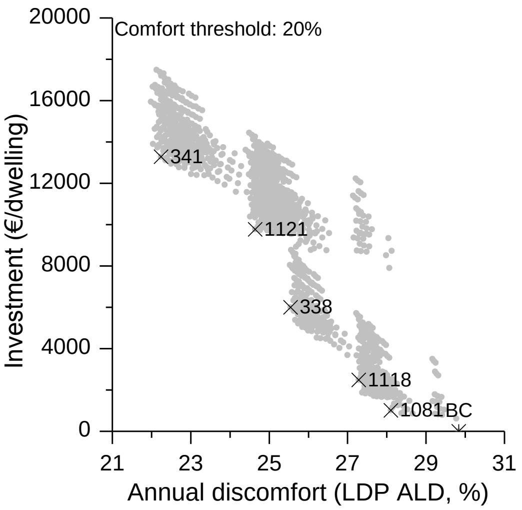

Figure 1 Comfort and economic optimization: Annual discomfort and initial investment cost.

Figure 2 shows the difference between the cold and warm season discomfort index, complemented with the hours of overheating. The starting point of both seasons is quite different: 47.6% and 9.9% for cold and warm season respectively. The effect of the passive measures improves the discomfort in the cold season reducing up to 33.5%. Analysing the warm season parameters, the effect of the passive measures are not very significant in the percentage of discomfort due to the good starting point. However, focusing on the hours of overheating, all the simulation provides problems of overheating giving more than 41 hours of inadequate temperatures. Even there are some combinations of measures where the hours of overheating are higher than 150. The results show that the measures have a high impact over the cold season index and the high level of overheating does not allow avoiding the mechanical cooling system to guarantee comfortable conditions during the warm season. Therefore, the cold season discomfort will be the main criteria for choosing the optimal measures.

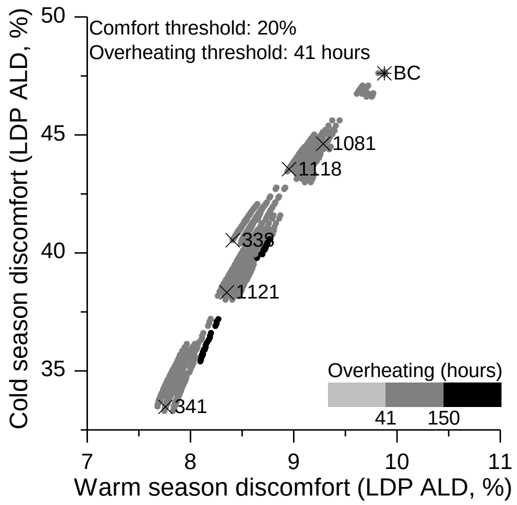

Figure 2 Comfort and economic optimization: warm season discomfort and cold season discomfort (colour map: hours of overheating)

Table 3 shows the comfort parameters of the selected passive measures and their corresponding investment cost. The measures selected include investment costs from 1,000 to 13,500 €/dw providing a wide range of investment options. The measures were defined in the framework of the MARIE project.

Table 2
Selection of passive measures. Description of façade insulation, roof insulation, window performance and optimal solar protection (SP)

(u-value) /(g-value)	**FAÇADE ($W/m^2·K$)**	**ROOF ($W/m^2·K$)**	**WINDOW ($W/m^2·K$) / (%/100)**	**SP**
BC	Base case (1.22)	Base case (1.17)	Base case (5.68) / (0.85)	Internal
1081	AirChamber Cel. 10cm (0.31)	Base case (1.17)	Base case (5.68) / (0.85)	Internal
1118	AirChamber Cel. 10cm (0.31)	Internal RW 8cm (0.32)	Base case (5.68) / (0.85)	Awning
338	External EPS 12cm (0.24)	Internal RW 8cm (0.32)	Base case (5.68) / (0.85)	Awning
1121	AirChamber Cel. 10cm (0.31)	Internal RW 8cm (0.32)	4/16/4 PVC (2.83) / (0.75)	Internal
341	External EPS 12cm (0.24)	Internal RW 8cm (0.32)	4/16/4 PVC (2.83) / (0.75)	Internal

Once the passive measures have been selected, the second step optimization is done. The selected passive measures are combined with all the active measures in order to develop the cost-enegy evaluation.

Table 3
Selection of passive measures. Comfort parameters and initial investment cost

	INVEST-MENT €/dw	LDP_A %	LDP_C %	LDP_W %	OH hours
BC	0	29.5	47.6	9.9	110
1081	1,021	27.7	44.6	9.3	126
1118	2,485	26.9	43.5	8.9	108
338	5,999	25.4	40.5	8.4	110
1121	9,770	23.9	38.3	8.3	94
341	13,284	21.1	33.5	7.7	98

Figure 3 shows the results of all the simulation, each dot represents one simulation. The x-axis represents the primary energy consumption and the y-axis the global costs over 30 years. The background of the figure represents the energy label scale adapted to the results of the study (including lighting and appliances consumption). The three points highlighted in the figure represent the base case (BC), the cost-optimal measure (CO) and the low energy deep renovation (DR). All the simulations that are below the horizontal dash-line of the BC provide energy and economic savings in comparison with the base case. However, most of the cases are outside this area.

Analysing in detail the results, cost-energy measures that achieve a B-class, improving 3-classes, can be found. However, a deep renovation of the building and the use of renewable energies are needed to achieve the A-class.

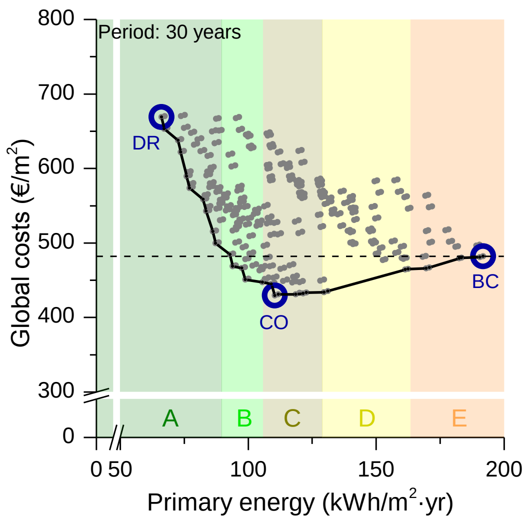

Figure 3 Cost-energy optimization: primary energy consumption and global costs (colour background: energy label scale of Total consumption of dwelling)

The description of the BC, CO and DR and their energy and economic results are detailed in the Table 4. The CO simulation includes air chamber insulation in the façade and the performance improvement of the heating system and lighting. The measures give a 42% of energy saving and the initial investment cost is around 5,000€/dw. The DR simulation includes a deep renovation of the building (façade and roof insulation, and window improvement) and the installation of photovoltaic solar system. In that case, the energy saving achieve the 65%, however the initial investment cost is higher (around 23,000€/dw).

Table 4
Cost-energy optimization. Energy and economic results of base case, cost-optimal measure and deep renovation

MEASURE	BASE CASE	COST-OPTIMAL	DEEP RENOV.
PASSIVE	Base case	1081	341
HEATING +DHW	Conventional NG boiler	Condensing NG boiler	Condensing NG boiler + S. Thermal
COOLING	Conventional AC Split	Conventional AC Split	Efficient AC Split
PV SOLAR SYSTEM	NO	NO	YES
LIGHTING	CFL	LED	LED
AWARENESS CAMPAIGN	NO	YES	YES
PRIMARY ENERGY kWh/yr·dw	15,114	8,704	5,208
P. ENERGY SAVING %	-	42	65
CO_2 REDUCTION %	-	47	70
ENERGY LABEL	E	C	A
GLOBAL COST €/dw	38,000	33,850	52,717
INITIAL INVESTMENT €/dw	0	4,594	22,831

Subsidy definition

The study provides complete information to help taking decisions to the users, professionals and policy makers. In this case, the results obtained have been used to define a proposal for a subsidy plan to improve the energy efficiency of the residential buildings evaluated in this study.

Three parameters are needed to define the subsidy plan: the energy requirement to receive the subsidy, the percentage of initial investment to pay by the subsidy, and the maximum amount of the subsidy.

The rationale to define the subsidies wants to distinguish between two levels of actuation: the minimum required without additional costs in a long-term period (30 years) and the measures that go beyond the minimum requirement and imply a high cost. Then, the energy requirement can be divided in: the cost-effective measures and the deep renovation.

In the first case, all the simulations with a global cost lower than the BC (below the dash-line) have been analysed. The best class achieved for this group of measures is a B-class and imply an improvement of 3-classes in comparison with the BC. For that reason, the requirement to receive the first level of subsidy is to improve 3-classes of energy. The second level of subsidy is defined by the simulations that improve more than 3 energy classes. Then, the requirement to receive the second level of renovation is to improve 4 or more energy classes.

To define the amount of subsidy the two groups of measures of the Figure 4 are analysed (black-dot square for the first level of subsidy and black-dash square for the second level of subsidy). In both cases, two scenarios are evaluated: the minimum initial investment cost and the average initial investment cost. The minimum is used to define the maximum amount of subsidy. Complementary, the average helps to define the percentage of initial investment to be paid by the subsidy. Table 5 shows the information of the minimum and average simulations in both levels of intervention.

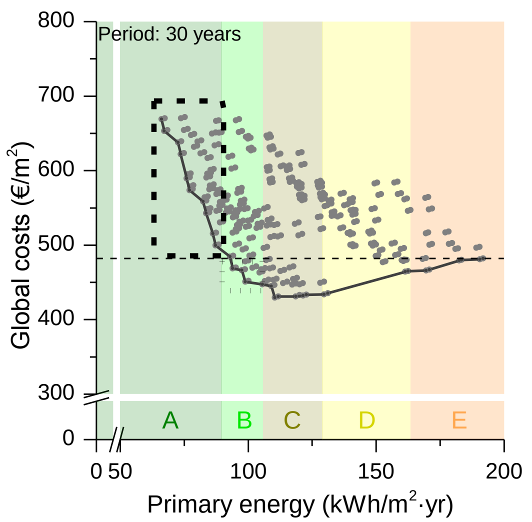

Figure 4 Group of measures analysed to define the two levels of subsidies: cost-energy measures (red square) and deep renovation (purple-dash square).

The Table 6 and Table 7 show the relation between the maximum amount of subsidy and the percentage of subsidy for the first and second level of actuation. Different percentages of subsidy are applied to the average intervention and the selected percentage corresponds when the subsidy is equal or close to the minimum initial investment cost scenario. It means that for the first level of subsidy the percentage of initial investment to pay by the subsidy is the 70% with a maximum of 5,000€/dw; and for the second level is 50% of initial investment with a maximum of 9,000€/dw.

Table 5
Simulations used to define the subsidies for the two levels of actuation: cost-energy and deep renovation.

ACTUATION		INITIAL INVEST-MENT €/dw	PRIMARY ENERGY SAVING %
Cost-effective	Minimum	5,123	48
	Average	7,133	51
Deep renovation	Minimum	9,188	54
	Average	16,863	56

Table 6
First level of intervention: subsidy definition

PERCEN-TAGES	INITIAL INVEST.[1]	SUBSIDY	PRIVATE INVESTMENT
%	€	€	€
30		2,140	4,993
40		2,853	4,280
50		3,567	3,567
60	7,133	4,280	2,853
70		**4,993**[2]	**2,140**
80		5,706	1,427
90		6,420	713

[1] Initial investment cost of the average measure
[2] Equivalent to the minimum initial investment cost

As it is introduced in the rationale of the subsidy definition, the first level of subsidy wants to be available to most of the population of the region (excluding the social housing, which needs specific plans of actuation). For that reason, economic data has been collected in order to verify that the subsidy definition and, in particular, the average private investment is coherent with the incomes and expenditures of an average household in Catalonia. Table 8 summarizes the annual incomes (INEa, 2013) and expenditures (INEb, 2013) of the average household in Catalonia in 2013. In global, the 4% of the income can be saved by a household during a year (around 1,000€/yr). In addition, if the expenditures are analysed in detail, there is a group of expenditures that are related with furniture and maintenance costs of the household and represents around 1,000€/yr. Finally, after the intervention the group of expenditure related with the energy costs (housing, water, electricity, gas and other fuels) will be reduced around 450€/yr (electricity and natural gas savings). Then, assuming these figures and in comparison with the average intervention, the private investment of 2,140€ seems a reasonable amount of money to be assumed for an average household in Catalonia.

Table 7
Second level of intervention: subsidy definition

PERCEN-TAGES	INITIAL INVEST.[1]	SUBSIDY	PRIVATE INVESTMENT
%	€	€	€
30		5,059	11,804
40		6,745	10,118
50		**8,432[2]**	**8,432**
60	16,863	10,118	6,745
70		11,804	5,059
80		13,490	3,373
90		15,177	1,686

[1] Initial investment cost of the average measure
[2] Equivalent to the minimum initial investment cost

Table 8
Annual net incomes and expenditures for the average household in Catalonia
(Source: INEa, 2013 and INEb, 2013)

AVERAGE ANNUAL NET INCOME	€/yr·dw
Total	30,423
AVERAGE ANNUAL EXPENDITURE	€/yr·dw
Food	4,394
Clothing and footwear	1,476
Housing, water, electricity, gas and other fuels	9,786
Furniture and maintenance costs of house	1,192
Others	12,461
Total	29,309

After checking the reasonability of the subsidy definition, both subsidy levels are applied to the results of the cost-energy optimization in Figure 5. In comparison with the results without subsidy, there are more combinations of measures (simulations) that are below the global costs of the BC. Regarding to the measures that are related with the second level of subsidy, some of them are also below the BC global costs, becoming the deep renovation more interesting for the users.

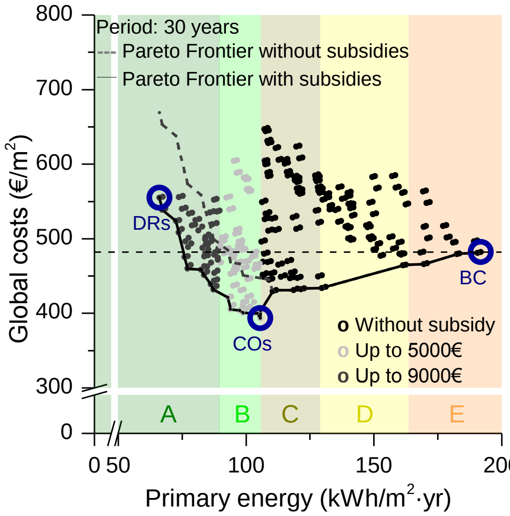

Figure 5 Cost-energy optimization including the two levels of subsidies: primary energy consumption and global costs (colour background: energy label scale of Total consumption of dwelling).

CONCLUSIONS

The paper presents a detailed method to optimize the energy renovation of residential buildings. The method introduces an innovative approach based on two-step optimization, which uses three criteria for choosing the appropriate energy efficiency measures: thermal comfort, primary energy savings and global costs over a long period.

The first optimization step has the objective to reduce as much as possible the discomfort conditions with the minimum cost of passive measures. If the comfort is improved with passive measures then the energy demand will be lower. The results show that, in this case, the main criterion for selecting the appropriate passive measure is the cold season comfort. Its improvement is more noticeable than the warm season comfort, and the hours of overheating cannot be reduced below the comfort threshold (1%).

The passive measures evaluated in this step provide the following conclusions: a) the external insulation has a better thermal performance than the air chamber insulation; however, the costs are higher. b) the roof insulation has a positive effect reducing the hours of overheating and improving the cold season comfort. c) the improvement of the window performance has a high impact in the annual discomfort (around the 5% of reduction), nevertheless its initial investment cost is high (around 8,000 €/dw).

The second optimization step has the objective to evaluate the energy savings in comparison with the global costs over 30 years. In this evaluation is possible to select the measures depending on the objective of the user: increase the energy savings and/or reduce the global costs. The results show that it is possible to improve 3-classes of the energy label with measures with equal or lower energy costs than the base case. Nevertheless, most of the measures evaluated imply an increase of the global costs, especially when the energy improvement is high.

Finally, the subsidy definition shows how the results of Optihab can be used for defining programmes based on robust and cost-optimal criteria.

Concluding, the method and the results provide useful and complete information that can be used as starting point for future studies related with the development of the energy renovation of residential buildings.

NOMENCLATURE

LDP	= Long-term Percentage of Dissatisfied
OH	= hour of overheating
t	= counter for the time step
T	= calculation period
z	= counter for the zones of the household
Z	= total of zones
p	= occupation
h	= time step
LD	= Likelihood of Dissatisfied
ALD	= ASHRAE Likelihood of Dissatisfied
T_{op}	= operative temperature
P_{OH}	= Percentage of hour of overheating
$T_{upper,ASH}$	= upper comfort temperature of the ASHRAE adaptive model
DHW	= domestic hot water
SP	= solar protection
BC	= Base case
Cel	= Cellulose
RW	= Rockwool
LDP_a	= Long-term Percentage of Dissatisfied for the annual period
LDP_c	= Long-term Percentage of Dissatisfied for the cold season
LDP_w	= Long-term Percentage of Dissatisfied for the warm season
NG	= natural gas
AC	= air conditioning system
PV	= photovoltaic solar system
CFL	= compact fluorescent lamp
LED	= light-emitting diode
kWh	= kilowatt per hour
yr	= year
dw	= dwelling
m^2	= square meter

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