To rehabilitate the habitability. Scenario simulation for consolidated urban areas in warm regions

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Abstract: - Present research seeks to analyse the extent to which CO_2 emissions can be diminished by means of different measures of energy efficiency simulated in a consolidated urban area on the Mediterranean coast. The study focuses its scope in analysing the incidence of summer climatic conditions over a Nineteenth Century urban fabric. Assessment is through the establishment of three scales of intervention: the neighbourhood, the plot and the building. These scales are assessed by three different scenarios, the original and two retrofit proposals. The study demonstrates that a potential reduction of CO_2 emissions takes place if a retrofit programme is jointly undertaken at the three different scales. It also reveals how specific actions can reduce indirect emissions depending on the location, orientation and wind regimes, and how diverse typologies of buildings behave differently according to their location in the neighbourhood, in the plot and according their envelope.

Key-Words: - Urban resilience, Urban regeneration, Simulation, Roofs, Ventilation.

1 Introduction

This research analyses the reduction of CO_2 emissions that can be achieved in urban areas of warm regions. To do this, the analysis of the neighbourhood of El Cabanyal located in the city of Valencia is investigated. Present research examines the resilience to the impact of climate warming of a specific Mediterranean residential building stock during the warmest season of the year. Strategies and measures involving three scales of urban fabric simulations are considered for the adaptation of existing buildings. The case study exposed here is based on a consolidated urban area, whose existing buildings and urban planning date back to the mid Nineteenth Century. This model analyses, by means of a summer bioclimatic diagnosis, the neighbourhood, the plot and the most representative building typologies.

The model under scrutiny, quite extensive in the Mediterranean region, can be found more in populated cities like Barcelona or Valencia -the quick growth since the 1950s absorbed several towns in their metropolitan area-, than in the rest of the counties and regions. The Mediterranean Basin Area is already experiencing an increase of temperatures. Because of an increasing tendency over the next few decades [1] this study simulates a case study to evaluate whether contemporary policies of urban fabric retrofit in warm regions are effectively contributing to the reduction of CO_2 emissions for cooling or not. Solar radiation, roofs and façade disposition, wind regimes and energy demand are analysed according to current regulations and according to the available materials in the market.

In the Spanish context, the energy crisis of 1973 forced the Royal Decree 1490/1975 about energy consumption forced the Royal Decree about energy consumption, which previously had been totally dissociated from the characteristics of the envelope of buildings. The first construction -Norm CT79 [2]- established the characteristics of the envelope of buildings. It was projected to improve conditions of comfort for multi-family houses and apartment blocks built from the 1950s onwards. The absence of a norm about efficient refurbishments on consolidated neighbourhoods is still absent; instead there exists the Spanish Technical Building Code (STBC) [3]. Any contemporary retrofit of single-family houses, terraced houses and multi-family houses [4] built before 1979, are subjected to the same regulations as those established for new developments by STBC (Section HE-1 on Energy Demand Limitation).

Because of the late transposition of European Directive 2002/91/EC [5], a debate and specific regulation is still pending for the refurbishment of those “deregulated” buildings mentioned before. In terms of thermal inertia, ventilation and orientation should be understood as a notion of re-engineering the existing urban environment [6, 7] focusing attention on climate change mitigation. Some authors have talked about retrofit programmes [8, 9] because of their potential to promote socio-technical and technical-innovative changes [10, 11]. Nonetheless, in order to do that, it is of first importance to characterise and understand the high span timeframe of the fabrics, forms and systems of built environments, [12, 13] as well as comprehension of the societal behaviour; whether or not each regional development is ready for such a “compromise”.

The database containing the environmental characteristics of the different construction materials that can be found in the Spanish market was used to establish the different scenarios to be simulated with “Heliodon 2TM” and “radiac2” software. Materials were selected considering the embedded energy (MJ), CO2 emissions (kg CO2 eq) and weight (Kg).

Indicators of energy consumption were basically focused on heating, cooling and hot water. CO2 emissions were obtained jointly by means of the database and “Cerma.R” software. This software also provided the thermal comfort based on the average temperature and its fluctuation for the summer season.

Methodology proposed for the Energetic Rehabilitation of Consolidated Urban Areas			
Selection of the area of study			
Data Collection			
Urban form	**Environmental statistics**	**Environmental charts**	
Urban planning	Temperature & humidity	Olgyay: external comfort	
Residential unit	Wind	Givoni: internal comfort	
Constructive typology	Topography		
Scales of analysis			
Neighbourhood	**Plot**	**Building**	
Scenario			
Original		**Retrofit**	
Urban materials	Building’s envelope	Urban materials	Building’s envelope
Indicators			
	Energy consumption CO$_2$ emissions Thermal comfort		

Table 1: Methodology of study

2 Methodology

The methodology involves four different stages.

Data collection was begun by analysing the urban form; collecting maps and plans of the place alongside its history. An extensive graphic portrait helped in analysing the residential unit and the constructive typology. National and regional boards provided the environmental statistics of the place. Environmental charts also helped to set up a pre-diagnosis of the summer-time clime.

Scales were established once the urban fabric had been analysed. One of the most unfavourable plots was selected for its analysis. The plot had one of the lengthiest east and west façades of the urban fabric. Different types of buildings were chosen to gain a representative spectrum of the different residential units; each one affected in a different manner by other surrounding buildings.

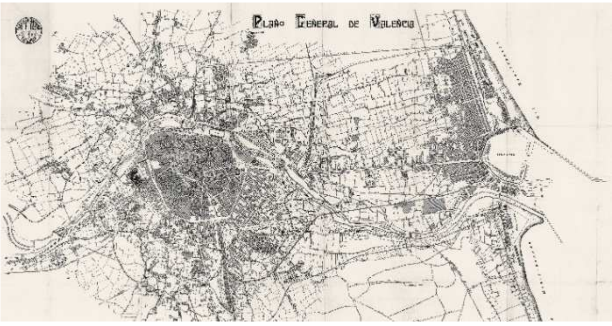
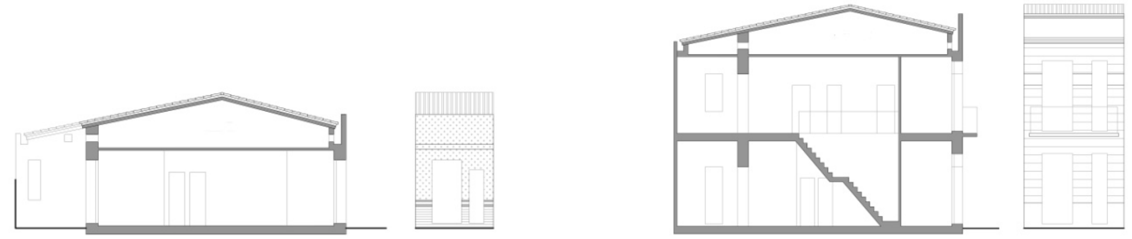


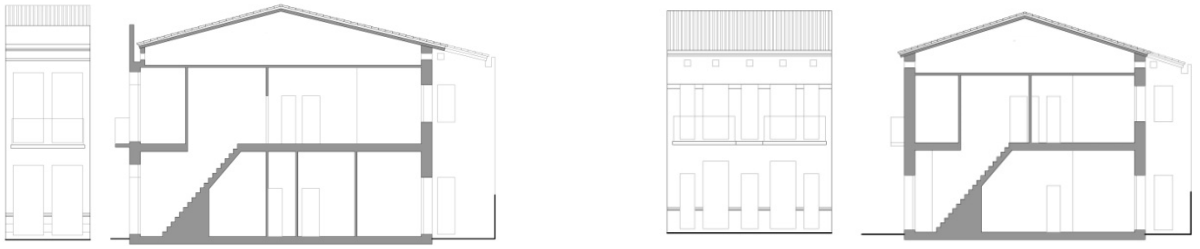
Figure 1: Valencia in 1925

2.1. Research setting

The typological analysis shows a common pattern in the plots: the width of the façades varies from 6,40 to 7,10 m and the depth of the plots between 9,00



Housing type A1 Housing type A2



Housing type B Housing type C

Figure 2: Housing typologies

and 11,00 m. The typologies of buildings chosen for the analysis are:

Type A1: one storey, single-family housing (Street Progreso nº 279, built up between 1901-1936). - Type A2: two storeys, single-family housing (Street Barraca nº 223, built up between 1901-1936). - Type B: two storeys, one household per storey (Street Reina nº 200, built up between 1840-1900). - Type C: two storeys, two households per storey (Street Reina nº 192, built up between 1840-1900). The average age of the buildings of the neighbourhood are: 1. Before 1840 (2.00%), 2. Between 1841 and 1900 (14.03%), 3. Between 1901 and 1936 (37.22%), 4. Between 1937 and 1950 (16.52%), 5. Between 1951 and 1960 (6.70%), 6.

Between 1961 and 1988 (12.19%), 7. Between 1989 and 1997 (1.08%). Most of the buildings have two floors (ground floor + 1) and mostly correspond to the earlier periods. Taller buildings date from the 40s and 50s and some 60s and 70s. Renewals and replacements from the 40s are rare, occur sporadically and are scattered throughout the area.

Regarding the road, streets and plots are narrow and disposed parallel to the Mediterranean sea with cross pathways reserved at times only for pedestrian use.

2.2. Construction typology

Façades of 50cm thickness are made with solid bricks. Frameworks are composed of 2 bays of wooden joists and jack vaults of solid brick that close the structure. Above them a layer of lime mortar provides the surface for paving. Roofs are built up with wooden joists supporting a layer of solid bricks, then another of mortar and tiles. Traditionally the sloped roof was covered from the inside by a horizontal gypsum panel, acting as ceiling for the inhabited space. The resulting chamber dispelled the solar radiation by providing ventilation through small holes in the main and rear façades. Nowadays this chamber has disappeared in the name of aesthetics and space. Façades are made with a layer of solid bricks, -24 to 30 cm width-. The ground is composed of a sub-base of sand and pebbles and a final layer of concrete over which the pavement is placed.

2.3. Environmental pre-existences

- Temperature, solar radiation and exposition

The climate of Valencia is the so-called Mediterranean; mild and damp. The average temperature exceeding the limits of comfort inside the house are given, subject to seasonal peaks, during the months of June, July, August and September, when temperatures inside the house can approach 30ºC. The monthly mean values of solar radiation on Valencia City have been calculated from the data of daily global radiation measured by the Spanish Meteorological Agency (Aemet). Data show more than 6.0 Kwh/m^2 of solar radiation from May to August, both included. The city is prone to suffer heat waves, from June to August, due to the arrival of warm fronts from the Sahara. Regarding the sun exposure, Valencia has 2.660 hours of sunshine each year, which equates to 300 days a year.

- Winds

The incidence of wind on houses causes calorific exchange in those surfaces in contact; this is reflected in increased superficial transmission coefficients of heat, both in the façades and roofs. The direction of the favourable wind for the warmer months (June, July, August and September) comes from the East to the West.

- Bioclimatic pre-diagnosis

Olgyay climograph for Valencia, aiming to achieve comfort in external spaces, suggests certain premises for the warmest months of the year:

Shade should be provided in the central hours of May and October, and during the whole day in June, July, August and September. The necessity of being fixed or mobile, perennial or deciduous, completely depends on their location.

The highest external temperatures should be restrained with ventilation in June, July, August and September during the central hours of the day.

Givoni climograph for Valencia, aiming to achieve comfort in internal spaces, suggests the following premises for the warmest months of the year:

It would be necessary to improve the current constructive systems of the building. More insulation and/or thermal inertia to maintain cooled environments, mechanically or manually by means of nocturne ventilation, for the months of June, July, August and September.

Inner protection and/or strategies to avoid the direct solar radiation in the inside of the house.

2.4. Bioclimatic analysis

The bioclimatic analysis was built up in three scales: Scale 1, Neighbourhood; Scale 2, Plot; Scale 3, Building. Each scale is assessed by: A. Solar exposition; B. Data processing; C. Data explanation. The study analyses the timely exposition to the sun, the sun radiation and the cumulated energy in the warmer months of the year: June, July, August and September. The software to be used is "Heliodon 2TM, v. 2006", and "radiac2".

The 1st Scale is limited by: Mediterraneo Avenue, Dr. Lluch St., Pintor Ferrandis St., and Marino Blas Lezo St. In this Scale, the solar exposition, the influence of the street width and the high of the buildings are to be studied.

The 2nd Scale is limited by: Espadan St., Barraca St., Carlos Ros St., Padre Luís Navarro St. In this Scale the scope is to study the façades with higher potential of solar capture in each of the façades composing the plot.

The 3rd Scale analyses the different type of buildings; A1, A2, B and C. In this Scale, the potential of solar capture and energy accumulation from the different constructive systems, façades and roof, is to be evaluated.

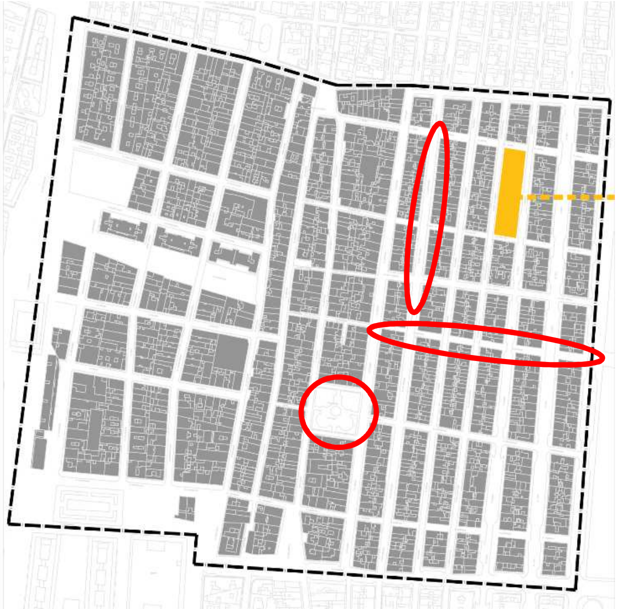


Figure 3: Masks to analyse the solar exposition

2.4.1. Scale 1. Neighbourhood

It was decided to evaluate the neighbourhood space by studying the solar exposition of three different positions in three different locations (Masks) at different urban spaces delimited by the pre-configuration of plots and characterised by its orientation. Thus, we seek the optimal orientation of road and public spaces for the warmer months in order to understand the best areas in which to implement shadings to counteract solar radiation during the day [14].

- Solar exposition analysis

Before inputting details, by having a quick look at the shadings projected on each Mask, we can pre-estimate how the different orientations and form of spaces are conditioning the bioclimatic conditions of the neighbourhood. It is appreciated that Masks 1 and 2 have several hours of solar exposition. Meanwhile, Mask 3 has quite a few hours of solar exposition compared with the others.

- Data processing

The exposition was analysed using "radiac2" software to indicate how exposed the different positions and Masks are.

Before entering details, Mask 1 (public space: square-park) shows that the three positions to be analysed are quite exposed to solar radiation during the whole day. In Mask 2 (road space: E-W orientation) position number 2 is the one that receives the most solar radiation. In Mask 3 (road space: N-S orientation) it could be appreciated that position 1 is the one receiving the most solar exposition.

- Data analysis

Data analysed expose the potential benefits of shading streets and favouring their ventilation in summer. It is clear that the East-West orientation of streets provides greater shade and promotes more wind circulation. But a strategic performance for the cooling of the neighbourhood suggests a more specific approach. This specific case of urban retrofitting would suggest developing some strategies to favour E-W ventilation by aerial or subterranean corridors, maybe taking advantage of derelict or abandoned buildings. The point here would be the improvement of the central positions in Masks type 3. Other improvements can be achieved by shading Masks type 3, but they require undertaking selective shadings along the street. Due to the narrowness of the streets, trees can compromise and stop the effect of the wind in façades and roofs, thus, fixed or mobile devices are required along the pavements and roads if possible. When talking about Mask 1, shadings can be mixed by using trees and fixed or mobile devices as the space is wide. Whichever solution is chosen, it is of great importance not to compromise the effect of the wind on the nearby houses.

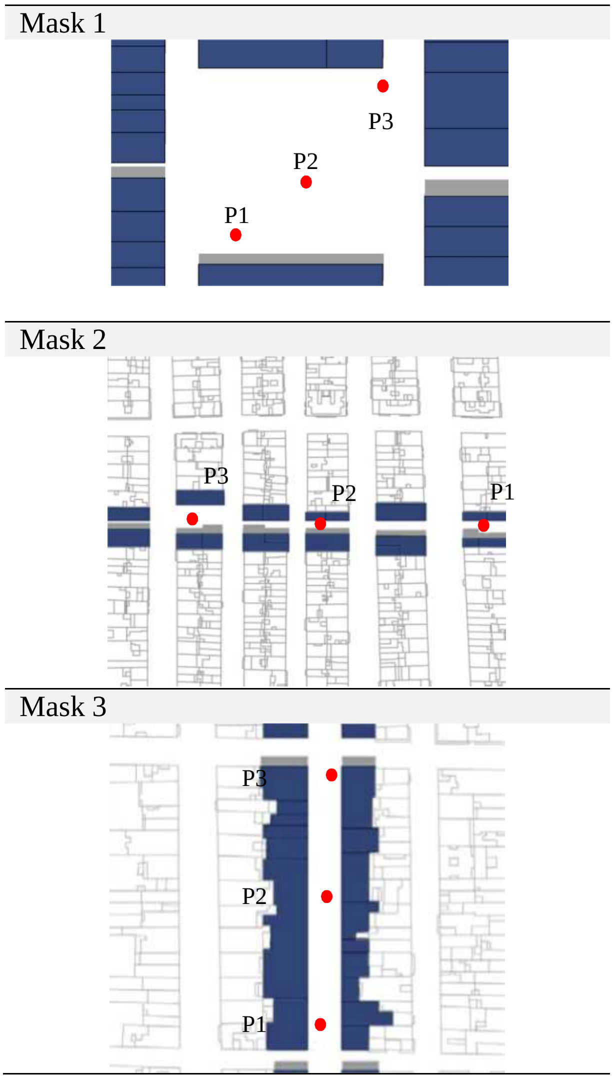


Figure 4. Positions of analysis in the different Masks.

2.4.2. Scale 2. Plot

The solar exposition of the four façades of the chosen type of plot was analysed to determine the solar capture, and the intensity level of solar radiation received by each one in the warmer months.

The plot grid is constantly repeated in the urban fabric of the neighbourhood. The analysis of solar radiation was undertaken by means of the "Radiac2" software.

- Solar exposition analysis

The disposition of the plots in the neighbourhood according to N-S alignment suggests that the façades with higher rates of solar radiation are the East, the West and the South. But the interest of the study lies in knowing what quantity of radiation, and for how many hours a day, is received by each façade. The roof has not been included in this analysis because it is studied in depth at the building level.

Mask 1	June - July	August	September
Position 1	5.30 am - 3.00 pm	7.00 am – 1.55 pm	12.00 pm – 1.50 pm
Position 2	6.00 am – 4.30 pm	6.30 am – 5.05 pm	8.30 am – 4.50 pm
Position 3	8.00 am – 5.00 pm	8.30 am – 5.30 pm	9.00 am – 4.10 pm
Mask 2	June - July	August	September
Position 1	5.30 am - 1.00 pm 2.30 pm – 5.00 pm	5.00 am – 8.55 am 3.30 pm – 5.35 pm	5.00 am – 7.55 am
Position 2	7.30 am - 4.50 am 1.10 pm – 5.00 pm	6.30 am – 7.30 am 2.30 pm – 5.25 pm	3.05 pm – 3.50 pm
Position 3	5.00 am – 5.00 pm	8.30 am – 5.30 pm	9.00 am – 4.10 pm
Mask 3	June - July	August	September
Position 1	7.55 am - 2.00 pm	7.50 am – 2.55 pm	6.30 am – 8.05 am 9.55 am – 12.55 pm
Position 2	10.00 am - 2.00 pm	11.00 am – 1.50 pm	11.05 pm – 1.20 pm
Position 3	11.05 am – 3.00 pm	11.10 am – 2.30 pm	11.15 am – 3.00 pm

Table 2: Solar exposition timetable

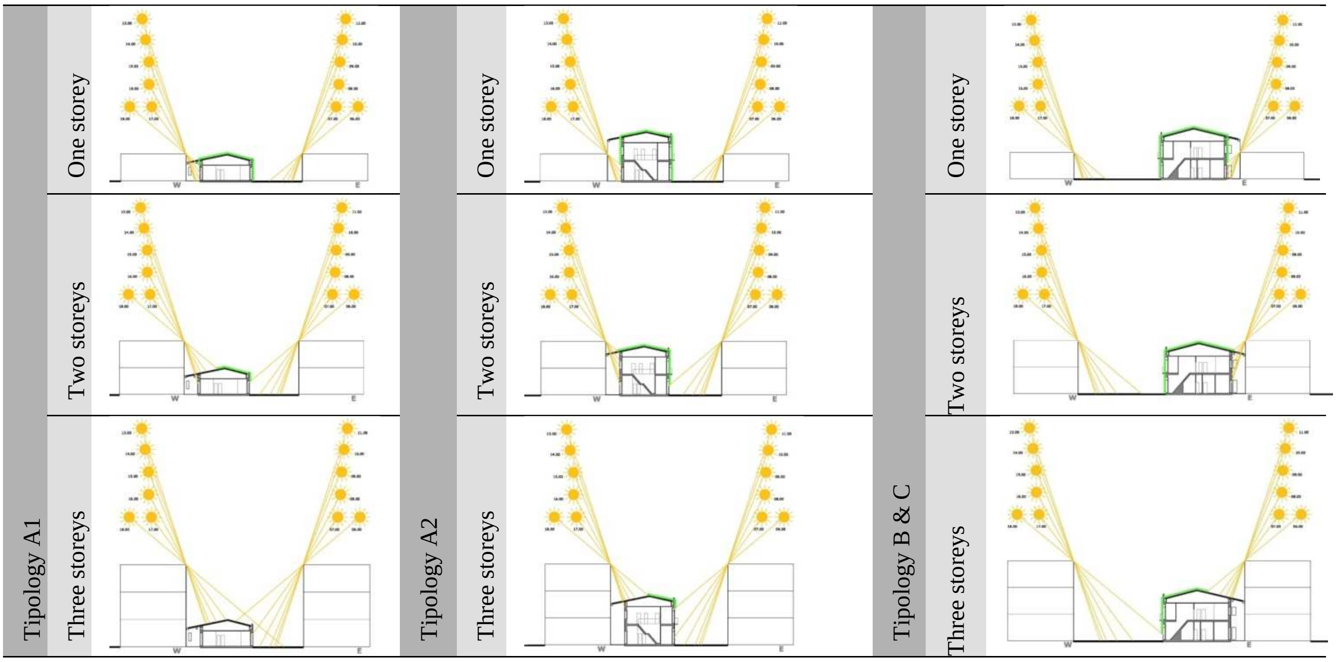


Figure 5: Solar exposition and to nearby obstacles

- Data processing

The façades most in need of protection to solar radiation in summer are the east and west. They present average solar radiation of 2.98 kWh/m^2. Although the radiation on the south façade, on average, is not much lower at 2.67 kWh/m^2, its small size and its lower exposure to radiation, about an hour less than the others, makes the east and west façades the important element of analysis.

- Data analysis

It could be said, considering the arrangement of the plots in the urban fabric, and depending on the values obtained for the warmer months, that the south façade is the one with the greatest potential for solar irradiancy; it has peaks of 305 W/m^2 from 12:00 to 1:00 pm, which is higher than the peaks of the west and east façades. The west and east façades are those with the highest potential for solar protection. Therefore, the thermal behaviour of housing facing east and west appears to be less appropriate when related to solar radiation, but not with reference to ventilation. It should be borne in mind that in summer the maximum incidence of radiation is received by the roof, which receives 4.5 times more radiation than the rest of the façades.

2.4.3. Scale 3. Building

The reduction of hours of solar radiation was made by studying the different typologies of buildings in between the obstacles of solar insulation represented by the other buildings. To do this, data was obtained from the calculation of the radiation with "Radiac2" software. A cylindrical chart was also used to latitude 40° as well as specific schemes specifically elaborated to represent the simulation.

- Solar exposition analysis

The schemes presented here reflect how obstacles significantly diminish the radiation depending on the dimensions of both the housing and the obstacle, the distance in between and the position of the sun at each stage of the day.

- Data processing

The analysis made by the schemes show that, in the three cases exposed, houses receive the irradiation determined in the previous section (Table 3) if the height of the obstacle is equal to or smaller than the housing. If the obstacle is taller than the house, solar radiation only affects the housing in the central hours of the day. Having said that, in all the cases examined it appears that the surface that constantly receives the effects of the sun, irrespective of the obstacle, is the roof.

- Data analysis

The schemes shown above explain that all types of housing are exposed to the sun's irradiancy at practically all hours. Tall buildings act as obstacles that significantly reduce the exposition, and they could be considered as shadings for others. Nonetheless, they greatly compromise the ventilation of nearby houses. Therefore, rather than a possible advantage, they are a major problem related to the historical evolution of the neighbourhood. They bring on poor ventilation and excess of heat (UHI) for the closest houses.

3 Energetic Retrofit

The energy rehabilitation measures contemplated in this work relate to the incorporation of passive systems of environmental control and materials of low environmental impact as elements to add to or replace the urban fabric and buildings (see table 4).

3.1. Urban materials, the surface

To develop a future and hypothetical scenario of energy rehabilitation a number of materials are proposed with a lower value of CO_2 emissions than those we already have in the original scenario.

Study of CO_2 emission_ Roads			
Scenario	**Materials**	**CO_2 emissions**	
		(Kg CO_2 eq)	(Kg CO_2 eq/m^2)
Original	O1 Asphalt (continuous, hot, in-situ)	18558351,35	299,16
	O2 Continuous concrete pavement + layer of mortar	22234,97	51,40
Retrofitted (62.034,90 m2)	R3 Asphalt (hot batch) 3cm thick	1474568,83	23,77
	R4 Porous asphalt 4 cm thick	1420598,50	22,90
	R5 Concrete cobble on 3cm sand layer	1763651,32	28,43
Retrofitted (432,60 m2)	R6 Asphalt (hot batch) 3cm thick	10282,59	23,77
	R7 Porous asphalt 4 cm thick	9906,24	22,90
	R8 Concrete cobble on 3cm sand layer	12298,45	28,43
		(%)	(Kg CO_2 eq/m^2)
	Difference R3-O1	-92,05	-275,39
	Difference R4-O1	-92,35	-276,26
	Difference R5-O1	-90,50	-270,73
	Difference R6-O1	-53,75	-27,63
	Difference R7-O1	-55,45	-28,50
	Difference R8-O1	-44,69	-22,97

Study of CO_2 emission_ Pavements			
Scenario	**Materials**	**CO_2 emissions**	
		(Kg CO_2 eq)	(Kg CO_2 eq/m^2)
Original	O1 Cement mortar tiles	1423963,55	30,92
Retrofitted	R2 Natural stone slabs	305792,95	6,64
	R3 Concrete cobble on 3cm sand layer	1309291,20	28,43
	R4 Natural stone paving 10 cm thick on a 5cm layer of sand	249608,10	5,42
	R5 Ceramic cobblestone 5 cm thick on a 3cm layer of sand	904483,96	19,64
	R6 Natural stone paving 8 cm thick on a 5 cm layer of sand	320990,49	6,97
	R7 Concrete pavement 10 cm thick	1278435,58	27,76
		(%)	(Kg CO_2 eq/m^2)
	Difference R2-O1	-78,53	-24,28
	Difference R3-O1	-8,05	-2,49
	Difference R4-O1	-82,47	-25,50
	Difference R5-O1	-36,48	-11,28
	Difference R6-O1	-77,46	-23,95
	Difference R7-O1	-10,22	-3,16

Study of CO_2 emission_ Squares			
Scenario	**Materials**	**CO_2 emissions**	
		(Kg CO_2 eq)	(Kg CO_2 eq/m^2)
Original	O1 Cement mortar tiles	11770,64	6,64
Retrofitted	R2 Natural stone paving 10 cm thick on a 5cm layer of sand	9607,96	5,42
		(%)	(Kg CO_2 eq/m^2)
	Difference R2-O1	-18,37	-1,22

Comparative summary of the urban materials				
Scenario	**Element**	**Materials**	**CO_2 emissions**	**Total CO_2 emissions**
			(Kg CO_2 eq/m^2)	(Kg CO_2 eq/m^2)
Original	Road	R-O1 Asphalt (continuous, hot, in-situ)	299,16	396,18
		R-O2 Continuous concrete pavement + layer of mortar	51,40	
	Pavement	P- O1 Cement mortar tiles	30,92	
	Square	PL-O1 Cement mortar tiles	6,64	
		PL-O2 Compacted soil surface	8,06	
Retrofitted	Road	R4-R7 Porous asphalt 4 cm	22,90	41,80
	Pavement	R4 Natural stone paving 10 cm thick on a 5cm layer of sand	5,42	
	Square	R2 Natural stone paving 10 cm thick on a 5cm layer of sand	5,42	
		R3 Compacted soil surface	8,05	
		Difference [R4/R7] - [R-O1/R-O2]	-327,66 (92,8%)	-354,38 (91,50%)
		Difference [R4] - [P-O1]	-25,50 (82,47%)	
		Difference [R2] - [PL-O1]	-18,37 (1,22%)	
		Difference [R3] - [PL-O2]	0,00 (0%)	

Table 3: Study of CO2 emission and Comparative of materials: Roads, Pavements and Squares

The objective is to establish to what extent we can reduce the environmental impact of current materials towards the improvement of the energy efficiency of the different scales (section 2.4).

In the following tables the emissions of the different scenarios, based on the environmental characteristics of the selected materials, are studied.

The use of materials with high thermal conductivity is favourable to transmit energy to lower layers of the ground, reducing the temperature of the surface (UHI).

Constructive materials of the original envelope		Physical characterization				Thermic characterization
Element	Material	Density (kg/m^3)	Thickness (cm)	Thickness total (cm)	λ (W/mK)	*U* (W/m^2 ºC)
Façade 1	Plaster of lime & cement mortar	1900	1,5		1,3	
	Solid brick	2300	47		0,85	
	Gypsum plastering	900	1,5	50	0,4	1,30
Façade 2	Ceramic tile	2300	2		1,3	
	Solid brick	2300	47		0,85	
	Gypsum plastering	900	1,5	50,5	0,4	1,29
Façade 3	Plaster of lime & cement mortar	1900	1,5		1,3	
	Solid brick	2300	11,5		0,85	
	Gypsum plastering	1000	1,5	14,5	0,4	2,82
Party wall	Gypsum plastering	1000	1,5		0,4	
	Solid brick	2300	11,5		0,85	
	Gypsum plastering	1000	1,5	14,5	0,4	2,13
Wall contact uninhabited space	Gypsum plastering	1000	1,5		0,4	
	Solid brick	2300	7		0,85	
	Gypsum plastering	1000	1,5	10	0,4	2,40
Roof contact uninhabited space	Reed surface	900	7		0,24	
	Gypsum ceiling	1000	1,5	10	0,4	4,17
	Cement tile	1900	2		1,3	
	Sand layer	1800	2		2	
	Mixed mortar layer	1800	5		1,3	
	Bricked jack vaults	770	3,5	12,5	0,32	2,68
Floor contact the ground	Cement tile	1900	2		1,3	
	Concrete slab	2300	10		1,65	
	Layer of pebbles and sand	1770	15	27	1,1	2,69
Floor contact uninhabited space	Cement tile	1900	2		1,3	
	Sand layer	1800	2		2	
	Mixed mortar layer	1800	5		1,3	
	Bricked jack vaults	770	3,5	12,5	0,32	2,68
Doors	Wooden door	600	5	5	0,18	2,00
	Wooden door	600	5		0,18	
	Simple glazing 6mm (30%)	2500	0,6	5	1	4,50
	Simple glass 6mm (80%)	2500	0,6		1	
	Wooden frame	500	5	5	0,15	4,59
Windows	Simple glass 6mm (80%)	2500	0,6		1	
	Wooden frame	500	5	5	0,15	4,59

Table 4: Characterization of the building materials that compose the envelope

- Data analysis

In consolidating neighbourhoods the absence of intervention could be seen as the most efficient action towards reducing any new emission of CO_2, both those embedded in the materials to be used and those generated by the action of deconstructing the existing. Nonetheless, depending on the case, some action could be necessary to reduce indirect emissions generated by the urban-heat-island effect (UHI). The analysis of materials to be used in roads shows a radical reduction of CO_2 emission when comparing O1 with R4. But probably the more realistic reduction is shown by comparing O1 with R6, R7 or R8 (intervening in half of the existing surface) in a prospective of 50 years time. As regards the pavement, the study shows important reductions when acting on the whole surface. Nonetheless, acting strategically in only those areas where the insulation is higher in summer would be the most desirable. As shown in the case of squares, no important reductions are found to justify a specific intervention if other additional causes do not apply.

3.2. Building materials, the envelope

The characteristics of the thermal envelope of the selected type of housing are defined below in order to subsequently classify them by adding new materials, which can help to optimise thermal behaviour, and reduce the energy demand of the house.

Since most of the existing homes to be retrofitted in the neighborhood are declared Heritage of Cultural Interest -*Bien de Interés Cultural* (BIC)-, the external appearance of the façades cannot be modified; then, the most appropriate solution to improve the envelope is to intervene from the inside.

Based on the available solutions of the database [4], the most appropriate intervention, environmental, technical and economically seems to be the collocation of insulation finished with plasterboard or brick wall with plaster as a finish.

Before analysing the various solutions proposed by the database, it should be noted that the systems proposed by the software don't take into account the action of the thermal inertia of massive walls. The table below shows the comparative analysis of several constructive materials to be considered as best to improve the thermal envelope. Indicators considered in the election of the materials are: the embedded energy (MJ), CO_2 emissions (kg CO_2 eq) and weight (Kg) (see table 6).

The criteria followed for Scenario R1 is the fulfillment of the values defined by the STBC. In the case of Scenario R2 more restrictive values than the limit established in DB-HE1_Energy Demand Limitation for a climate zone B3 in STBC are proposed.

- Housing energy consumption.

Below, table 7 set out the comparative results of annual emissions of CO_2 for heating, cooling, and hot water for the two retrofitted scenarios defined. The data and percentages were obtained using the software "Cerma.R" (see table 7).

- Consumption analysis:

a. Energy consumption analysis: As noted in the tables above, firstly it can be seen that the annual CO_2 emissions associated with heating are far higher than those due to the use of cooling.

b. Cooling emissions analysis:

The analysis shows how dependent cooling emissions are from ventilation. It is totally dependent on the configuration and wideness of roads and the size of adjacent buildings.

Element	Material	Criterion	Unit (U)	Weight (kg/U)	Embedded energy (MJ/U)	CO_2 emissions (Kg CO_2 eq/U)
Insulation	Rockwool	Same thermal resistance 0,95 m^2k/W	1m^2 of panel	3,17	70,72	4,48
	Polystyrene EPS			0,5	58,97	8,70
	Black cork			4,62	**18,20**	**1,11**
Vapour barrier	Bituminous type EB	Sealing layer designed to prevent the passage of water vapour	1m^2 of panel	2,20	48,52	7,13
	Self-adhered bitumen			1,65	73,78	10,53
	Polyethylene			0,16	**16,16**	**2,38**
Sub structure	Galvanized steel	Same payload weight of panels	1m^2 of panel	2,51	**65,31**	**5,02**
	Aluminium			0,87	235,65	19,13
	Recycled aluminium			0,87	81,74	5,22
	Wood			1,68	3,53	0,10
Finishing layer	Plasterboard		1m^2 panel	23,69	**148,75**	**8,50**
	Double hollow brick		1m^2 panel	107,54	297,66	22,58
	Painted aluminium	Minimum features: 4 air permeability, water tightness 9A and CS Wind resistance	1U of 150x 120cm	30,24	5902,28	868,10
	Polyvinyl chloride			44,46	3095,01	420,33
	Pine wood			26,86	**69,51**	**3,58**

Table 5: Characteristics of materials to be added to the envelopes

Housing type A1								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	2236,3	71,4	1391,9	44,5	453,5	14,5	387,8	12,4
Retrofit 1	534,3	17,1	372,2	11,9	125,1	4,0	37,5	1,2
Retrofit 2	39,0	1,2	0,0	0,0	0,0	0,0	37,5	1,2
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-76,11	-54,3		-32,6	**-27,58**	-10,5		-11,2
Difference R2 - O	-98,26	-70,2		-44,5	**-100**	-14,5		-11,2
Housing type A2								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	17728,0	203,1	14382,0	164,7	2519,5	28,9	826,7	9,5
Retrofit 1	9122,6	104,5	7567,5	86,7	1108,0	12,7	447,1	5,1
Retrofit 2	8587,6	98,4	7213,3	82,6	927,1	10,6	447,1	5,1
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-48,54	-98,6		-78,0	**-43,98**	-16,2		-4,4
Difference R2 - O	-51,56	-104,7		-82,10	**-36,80**	-18,3		-4,4
Housing type B								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	20822,0	229,3	19397,0	213,6	703,7	7,7	720,6	7,9
Retrofit 1	10690,0	117,7	9998,6	110,1	350,2	3,9	341,0	3,8
Retrofit 2	9803,8	108,0	9049,7	99,7	413,1	4,5	341,0	3,8
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-48,66	-111,6		-103,5	**-49,76**	-3,8		-4,1
Difference R2 - O	-52,92	-121,3		-113,9	**-58,70**	-3,2		-4,1
Housing type C								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	33902,0	432,4	32740,0	417,0	487,0	6,2	674,0	8,6
Retrofit 1	14182,0	180,9	13770,0	175,6	115,1	1,5	294,5	3,8
Retrofit 2	12477,0	159,1	11893,0	151,7	290,4	3,7	294,5	3,8
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-58,17	-251,5		-241,4	**-23,63**	-4,7		-4,8
Difference R2 – O	-63,20	-273,3		-265,3	**-59,63**	-2,5		-4,8

Table 6: Housing annual emissions of CO_2

Thus, ventilation, facing the position of the building in the plot and the effect of the UHI can also explain the differences in the emissions between A and B-C types. The exposition of the building to radiation seems not to be the biggest problem if the roof is properly isolated; the simulation was done considering the original non-habited chamber between the outside of the roof and the inhabited space.

c. Retrofit scenarios analysis: Regarding the total annual CO_2 emissions due to use, it should be said that energy retrofitting can lead to a reduction in emissions to the order of 50% by improving the thermal envelope of the house. Results show that A2 type housing is more affected by the urban fabric than by a hypothetical retrofit scenario of its envelope, explained by the high levels of emissions achieved after the retrofit. Meanwhile, A1, B and C housing types are more conditioned by the type of intervention to occur in their façades. There is a clear improvement if the intervention is more restrictive than the limits set by the STBC (see table 8).

	Original Scenario	Radiation	Ventilation	Plot position	Facing
Housing type A1	14,5 Kwh/m^2 cond	Lower	Obstacle/ Narrow St.	Good / UHI	East
Housing type A2	28,9 Kwh/m^2 cond	Higher	Obstacle / Narrow St.	Bad / UHI	East
Housing type B	7,7 Kwh/m^2 cond	Higher	No obstacle / Wider St.	Good	West
Housing type C	6,2 Kwh/m^2 cond	Higher	No obstacle / Wider St.	Bad	West

Table 7: Physical factors affecting cooling conditions

- Temperatures analysis:

The analysis of the temperatures shows how, after the R2 scenario, none of the housing achieves a temperature under 25ºC. This leads to a consideration about the convenience or otherwise of the intervention and whether or not there is a need to use mechanical ventilation. Several studies have shown that night ventilation can succeed in decreasing the diurnal indoor air from 1.5 to 2°C [15] or 3ºC depending on the case [16].

Other authors have investigated the incorporation of thermal inertia, with the aim of taking advantage of natural night-time ventilation. Studies have shown how high thermal inertia walls can result in a reduction of energy requirements of about 20% [17], maintaining comfortable indoor conditions without the help of AC systems [18].

3.3. The roof

The simulation has shown how transmittance across the roof is very low when a non-habitable chamber intermediates between the external layers and the inhabited space. The real situation of the cases analysed shows how owners have historically removed the intermediate ceiling for aesthetic and spatial reasons.

Temperatures analysis			
Summer			
Scenario External conditions		Average temperature (ºC) - Te	Temperature fluctuation (ºC) - Ψ Te
	Original	29,6	4,5
Scenario Internal conditions			
H. Type A1	Original	27,2	4,4
	Retrofit 1	25,95	0,9
	Retrofit 2	26,15	1,3
	Difference R1 - O	**-1,25**	**-3,5**
	Difference R2 -O	-1,05	-3,1
H. Type A2	Original	26,75	3,5
	Retrofit 1	25,2	1,1
	Retrofit 2	26,2	1,3
	Difference R1 - O	**-1,55**	**-2,4**
	Difference R2 -O	-0,55	-2,2
H. Type B	Original	26,75	2,5
	Retrofit 1	25,85	1,5
	Retrofit 2	25,25	1,9
	Difference R1 - O	-0,9	**-1,0**
	Difference R2 -O	**-1,5**	-0,6
H. Type C	Original	25,5	1,0
	Retrofit 1	25,1	0,4
	Retrofit 2	24,75	0,5
	Difference R1 - O	-0,4	**-0,6**
	Difference R2 -O	**-0,75**	-0,5

Table 8: Temperatures for the different scenarios

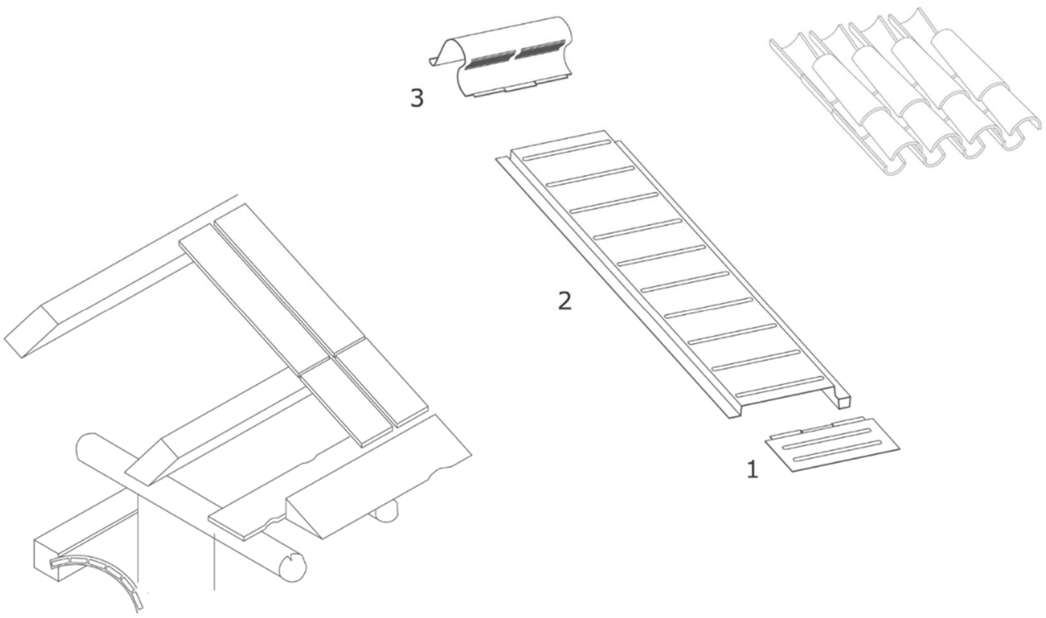


Figure 6: Roof ventilation modules

In the study, it has been analysed how levels of irradiancy can reach 1000 and 1350 W/m^2 on the roof. New techniques developed from the analysis of this case study [19] show how the direct effect of irradiancy can be diminished on these inhabited spaces by providing a 10 cm width ventilation space in between the layers of the roof [20, 21]. The irradiancy can be diminished to values of 250 W/m^2 [22] if combined with a standard layer of 4mm of insulation [23] in standard slopes, from 15 to 60 degrees.

4 Conclusions

The study exposes the simulation of different scenarios at three different levels of intervention: the neighbourhood, the plot and the building. Results obtained reflect that potential reduction of CO_2 emissions is achieved if a retrofit programme is jointly undertaken at the three different scales. Only in this way can the relative importance of one scale over the others be determined. The study has demonstrated how specific actions are needed to reduce indirect emissions generated by the urban-heat-island effect (UHI), as in the case of housings type A1 and A2. The analysis of different materials has demonstrated a potential reduction of a 92,35% in the CO_2 emissions associated with the roads' retrofit. The percentage achieved in the case of pavements, a 82,47%, suggests a more accurate intervention due to their reduced surface. An optimal solution is considered only by intervening with the pavement exposed to most solar radiation.

The analysis of the plot states how buildings are affected by solar irradiancy with peaks of 305 W/m^2 in the southern façades and a constant exposition, in the central hours of the day, to a range of 1000 and 1350 W/m^2 on the roof. It also has been demonstrated how tall buildings can act as obstacles that significantly compromise the ventilation of the nearby houses; as shown in the case of housings type A1 and A2 located in the narrowest streets. Therefore, rather than a possible advantage as shade, they slow down or stop the wind, keeping the area and surrounding buildings warm at night. The effect is not so relevant to types B & C because of their location in the plot and in the neighbourhood.

It could be said that the wide scope of this study has demonstrated the relatively low benefits of the insulation of façades, and how the potential of thermal inertia of walls due to night-time ventilation establishes clear incompatibilities when insulating them if cooling is not going to occur through mechanical means. When referring to the roof, the relatively low CO_2 emissions when simulating traditional characteristics have led to the necessity of implementing a technical-innovative solution [19]. Nonetheless if the study has demonstrated something, it is the tremendous importance of acting properly to reduce CO_2 emissions, depending on the three scale levels exposed: the neighbourhood, the plot and the building.

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