Sunshine and line of shadows in an East – West oriented street of a Historic Centre (TH) in Castellón.

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Potential reduction in energy consumption in consolidated built environments. An analysis based on climate, urban planning and users.

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ABSTRACT

In order to minimise the environmental problems of energy consumption this study aims to assess the potential energy demand reduction of the three main building types within three urban configurations of a Mediterranean city in the Comunitat Valenciana Region, Spain. To do so this project aims to identify the urban configuration which makes the best use of sun and natural ventilation, and whether this potentially affects the energy consumption of users in three vulnerable neighbourhoods as an analysis methodology prior to any intervention on the building stock.

Factor analysis was carried out in summer taking into account the greater influence of the climate factors in the warm region under study. Therefore, winter conditions were excluded from this analysis as the installations, and the state of conservation of the envelope were the main factors affecting the energy consumption at this time of year. The results obtained show that there is true potential for reducing consumption in the buildings analysed. Due to the viability and easy implementation of these actions, and given the embodied energy, the measures for optimising the envelope of buildings are inadvisable or to be considered only as a last resort.

KEYWORDS

obsolete buildings, warm regions, user behaviour, energy consumption; building refurbishment

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1. INTRODUCTION

In order to minimise energy dependence and CO2 emissions this study is proposed as an analysis methodology to assess the potential reduction of energy demand. In Spain, residential buildings are responsible for up to 25% of the national electricity demand (IDEA, 2011). The optimization of buildings from an energy-efficient perspective has been widely studied at project level to estimate energy demands based on their geometric variables (Ordoñez, 2011) (Pacheco-Torres , 2015). Some authors have spoken of the potential of retrofit programmes (Karvonen, 2013) in promoting socio-technical and technical-innovative change (Seyfang, 2012) (Vergragt, 2012). However, before proceeding it is essential to characterize and understand the long-term timeframe of the fabrics, forms, and systems of built environments (Eames, 2013), taking into account societal behaviour, ascertaining whether or not each regional development is ready for such a 'commitment'. This should be understood as a way of re-engineering the existing urban environment (Cole, 2012) (García-Esparza, 2016). So, the novelty of this research is in the analysis of user behaviour by using real data and relating them to the urban environment in order to look for "behaviours of almost zero consumption".

Studies on solar urban planning suggest that for the main façade to make the most of solar gains it must be within 30° south orientation. More easterly or westerly orientations will receive less solar gains, especially in winter, when these are most useful (Littlefair, 2001). The study by Kanters & Horvat (Kanters, 2012) shows the importance of the impact of geometric shape in potential solar energy; which can be doubled. Therefore, compactness reduces thermal envelope surface area, and accordingly energy consumption, although solar energy gains can also be reduced significantly (Kosir, 2014).

Climate factors such as sun and wind (Manzano-Agugliaro, 2015) are analysed as external environment factors which could directly affect the natural or mechanical climatisation of the housing units, helping to reduce CO2 emissions (Littlefair, 1998). Hence, the climate analysis includes the incidence of sunlight and passive cooling (Santamouris, 1996). Within this context this research was carried out on a pre-existing urban layout that has little to do with what is known as solar urbanism (Amado, 2014). This made it possible to analyse how the potential use of climate factors is greatly conditioned by the shape of buildings and the pre-existing urban layout (Vermeulen, 2015).

As observed in the French research project VALERIE (Chesné, 2012), energy consumption in buildings can be greatly reduced if good use is made of the resources of the environment (Antone Faggianelli, 2014). However, building environments are not the sole factor affecting energy consumption. As stated by Pérez-Lombard et al. (Pérez-Lombard , 2008), size and location are key factors in energy consumption in residential sectors. Ratti et al. (Ratti, 2005) consider that the energy performance of a building depends on four factors: 1. Urban geometry; 2. Building design; 3. Efficient systems; and 4. Occupant behaviour. In agreement with this, Butera (Butera, 2013) notes this as the challenges in obtaining zero-energy buildings.

Previous research highlighted how occupant behaviour affects approximately 4.2% of energy consumption in homes (Kurtz, 2015) while building characteristics determine 42% of energy use. Subsequent analyses showed that occupant behaviour is often conditioned by the type of housing unit or building and accordingly the effect of occupant behaviour and profile on consumption may be greater than expected (Santin, 2009). In a recent study on the Comunitat Valenciana building stock, Serrano-Lanzarote et al. (Serrano-Lanzarote , 2016) concluded that only a profound

Figure 1.
Distribution of the main urban layouts in Castellón.

1.1- Orientation of cardinal points.
1.2- NW-SE – NE-SW 50° deviation of streets - Ensanche.
1.3- NW-SE – NE-SW 25° deviation of streets Ensanche.
1.4- Orientation of streets in the Ensanche.
1.5- Orientation of streets in historic centre.
1.6– Ensanche. Closed blocks (Building typology MH).
1.7 - Ensanche. Open blocks (MH & AB).
1.8 – Historic Centre (TH).
Source: Author's own.

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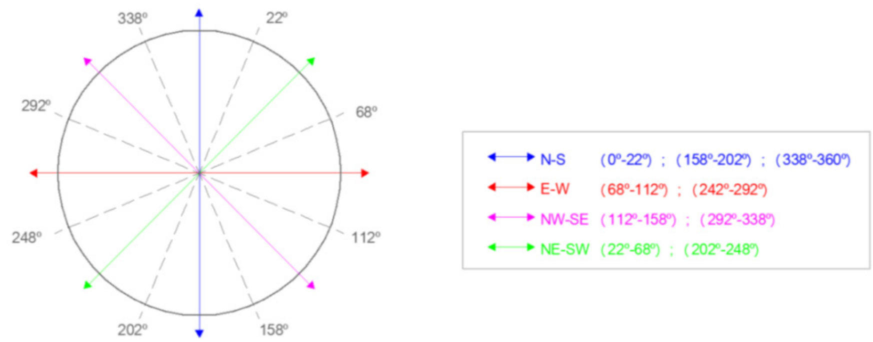
1.1



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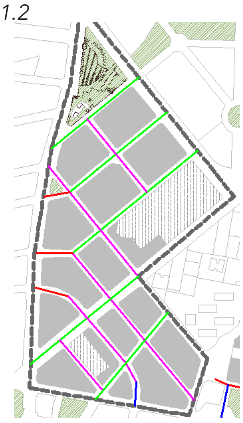

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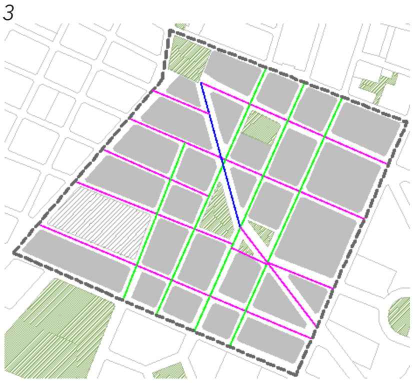

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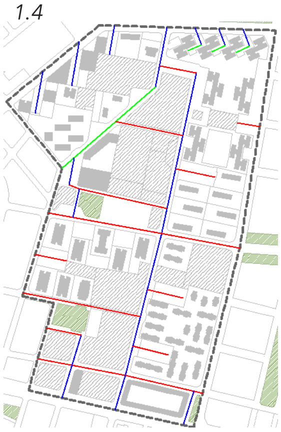

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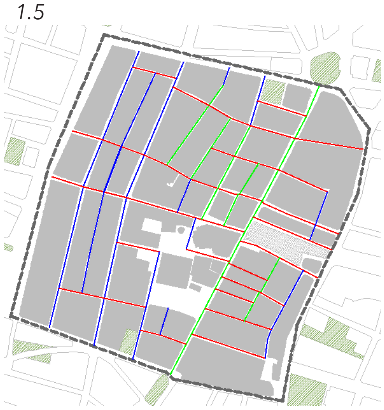

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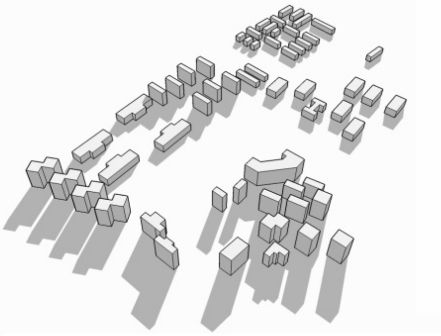

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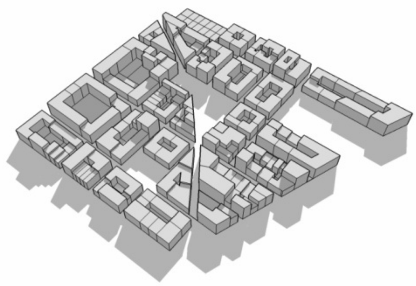

transformation of the building fabric (80%) could help in achieving a 20% reduction in consumption. Nonetheless, an analysis based on climate, urban planning and user behaviour conducted prior to any programme for building renovation of the building fabric could minimise the percentage of buildings to be retrofitted as well as the embodied energy of the retrofit, the spending costs and the final energy consumption (García-Esparza, 2017).
This is exactly what this research aims to establish by using real consumption and behaviour data. In any case it should be noted that the amount of energy consumed in homes also depends on the vulnerability of occupants (Pérez-Lombard, 2008). According to the Spanish Institute for Diversification and Energy Saving (IDAE, 2014), the mean of energy consumption in multifamily buildings in the Mediterranean region is 6,128 kWh/yr per housing unit, as regards electricity 3,487 kWh or 40.15 kWh/m2/yr and according to the data obtained in this project electricity consumption is 2,767.33 kWh or 32.94 kWh/m2/yr. To analyse behaviours comparatively the study was undertaken in neighbourhoods classed as vulnerable or at risk of vulneravility by the National Classification in Spain [28]. This study considers vulnerable neighbourhoods to be those which have experienced an increase in

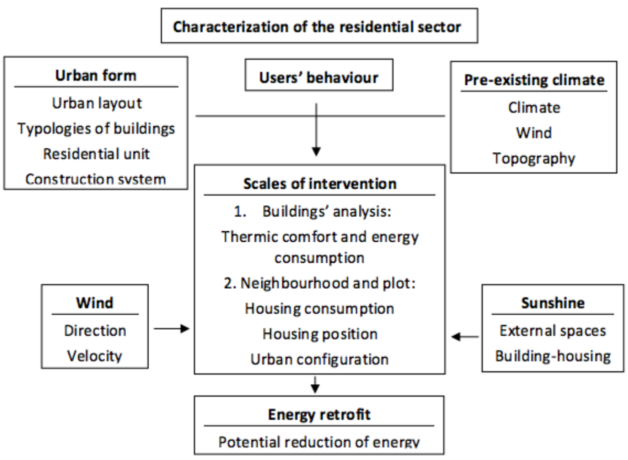

Table 1.
Scheme of the methodology

foreign population -10.08% from 2001 to 2006- and the remaining, elderlies and lower income families are suffering from social exclusion, abandon and lack of attendance.

2. CLIMATE CHARACTERISATION AND URBAN LAYOUT

The urban layout, built between 1960 and 1980, consists of: 1. The historic centre (HC), 2. The Ensanche district - or outskirts of the original city - built in open blocks (OB) and 3. The Ensanche district, built in closed blocks (CB). These layouts contain multi-family buildings representative of compact Mediterranean residential building stock. In the city of Castellon de la Plana these buildings are representative of the constructive typology of each neighbourhood, a total of 1,146 buildings with 7,652 housing units. By analysing the three different urban layouts, it should be noted that the three different types of urban planning are characterised by density and orientation (fig. 1).

2.1 CLIMATE, RADIATION AND URBAN CHARACTERISTICS

The climate in Castellón de la Plana is characteristically mild and damp, typically Mediterranean. The mean temperature in Castellón de la Plana in summer is close to 25°C in July and August As regards sun exposure, Castellón has 2660 hours of sunshine a year, the equivalent of 300 days a year. The Köppen climate classification places Castellón in a CSA geographical area. The predominant wind in summer is easterly and south-easterly, while in winter it is north-westerly (table 2). One of the determining factors in bioclimate design is solar accessibility, which guarantees direct radiation on buildings. It is therefore necessary, in order to relate radiation, the urban layout –orientation and shades- and consumption (Martins, 2014) (Barcelona, 2009) to analyse the hours of direct solar radiation together with the height of buildings and

street width. The TABULA (Typology Approach for Building Stock Energy Assessment) project classifies typology of buildings as TH (Terrace House), while the predominant constructions in the Ensanche areas are individual multifamily blocks of over 4-storey MH (Multifamily House), and 12-storey AB (Apartment Block) with two or more housing units per storey (Episcope, 2009).
The solar radiation values for each orientation of the urban layouts were calculated using the Radiac2 program. According to the results, the ideal orientation in the historic centre and the Ensanche district, built in open blocks, is that which maximises solar radiation in underheating months and minimises it in overheating months. For both the winter and summer solstice this is the south orientation. In the Ensanche district built in closed blocks, and NW-SE – NE-SW orientation with a 25° angle in relation to the horizontal plane, at winter solstice SW orientation receives most solar radiation. Equally, at summer solstice the same orientation receives lowest solar radiation. For NW-SE – NE-SW orientation with a 50° angle at winter solstice SE orientation receives most solar radiation. In contrast, at summer solstice NW orientation receives the lowest solar radiation. Another determining factor is the ratio between building height and street width (h/w). In the historic centre the h/w ratio results in very limited solar exposure, with little influence from the cold northern winds or easterly summer winds. In the Ensanche district built in open blocks, the h/w ratio in most plots guarantees solar exposure on all south-facing façades throughout the year. In the Ensanche district built in closed blocks the h/w ratio is below 2 and therefore solar exposure only occurs on the lower storeys in the most underheated months.

2.2 SOLAR OBSTRUCTION ANGLE

The ratio between the perpendicular distance measured on the ground between two façade planes on a street and the height of the cornice that is to project shade on the building opposite determine the solar obstruction angle, Ho, also known as the urban canyon. In the case of Castellón, at latitude 40° north, the maximum solar height at winter solstice (21 December) is 27°. In contrast with this, if we consider the distance between buildings h=w, the solar obstruction angle is 45° and the lower storeys do not receive radiation. From the spring equinox (21 March) solar height at 12:00 am exceeds 45°.
According to the solar chart (see table 3, figure 2 and 3), in the historic centre and Ensanche district built in open blocks, for a 15° azimuth angle in relation to the south orientation, solar height in the most underheated months goes from 25° at winter solstice

Climate Data	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN ANNUAL
Mean Temperature ºC	*10.6*	*11.3*	*13.4*	*15.4*	*18.5*	*22.5*	*25.3*	*25.6*	*22.9*	*19.0*	*14.3*	*11.4*	*17.5*
Mean MAX Temperature ºC	*13.0*	*14.2*	*17.4*	*17.5*	*20.5*	*26.5*	*27.4*	*28.1*	*24.3*	*21.2*	*16.5*	*13.5*	*18.6*
Mean MIN Temperature ºC	*7.4*	*9.2*	*10.9*	*13.3*	*15.6*	*19.4*	*22.4*	*23.6*	*21.1*	*16.9*	*12.2*	*9.6*	*16.1*
Mean Precipitation mm	*35.7*	*31.0*	*30.8*	*41.6*	*43.9*	*19.4*	*8.6*	*24.1*	*71.2*	*69.9*	*48.8*	*42.2*	*38.9*
Mean Relative Humidity (%)	*68*	*66*	*65*	*63*	*65*	*65*	*66*	*68*	*69*	*70*	*70*	*70*	*67*
Mean Sunsine Hous	*179.8*	*179.0*	*209.1*	*234.7*	*271.9*	*296.4*	*328.6*	*290.0*	*229.3*	*203.2*	*173.0*	*164.2*	*229.9*

Table 2
Climate data for Castellón de la Plana.

HC (3-4 Storeyes)	Sunshine Hours (Street Width: 9m - Height: 16m			
	N	*S*	*E*	*W*
Level 1 (GF)	*2.50*	*9.00*	*2.50*	*2.50*
Level 2 (F2)	*3.75*	*9.17*	*4.75*	*3.75*
Level 3 (F4)	*7.00*	*9.25*	*8.50*	*8.17*
OB (4 Storeyes)	Sunshine Hours (Distance between buildings: 14m - height of Buildings:12 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*7.00*	*8.83*	*8.00*	*7.42*
Level 2 (F2)	*7.33*	*8.92*	*8.08*	*7.50*
Level 3 (F3)	*8.00*	*9.00*	*8.17*	*7.58*
OB (8 Storeyes)	Sunshine Hours (Distance between buildings: 28m - height of Buildings:30 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*7.00*	*8.83*	*8.00*	*7.42*
Level 2 (F3)	*7.33*	*8.92*	*8.08*	*7.50*
Level 3(F7)	*8.00*	*10.00*	*8.17*	*7.58*
CB Deviation 25ª (8 Storeys)	Sunshine Hours (Distance between buildings: 12m - height of Buildings: 24 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*3.00*	*8.50*	*3.00*	*2.50*
Level 2 (F3)	*3.75*	*8.50*	*4.50*	*7.50*
Level 3(F7)	*8.50*	*9.83*	*8.50*	*9.50*
CB Deviation 25ª (5 Storeys)	Sunshine Hours (Distance between buildings: 12m - height of Buildings: 15 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*3.75*	*8.75*	*4.00*	*3.25*
Level 2 (F2)	*4.50*	*8.75*	*5.75*	*4.25*
Level 3(F4)	*8.50*	*9.83*	*8.50*	*9.50*
CB Deviation 50ª (8 Storeys)	Sunshine Hours (Distance between buildings: 12m - height of Buildings: 24 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*2.00*	*2.50*	*3.50*	*3.00*
Level 2 (F3)	*3.17*	*3.25*	*6.50*	*5.00*
Level 3(F7)	*7.25*	*8.00*	*10.00*	*9.00*
CB Deviation 50ª (5 Storeys)	Sunshine Hours (Distance between buildings: 12m - height of Buildings: 15 m)			
	N	*S*	*E*	*W*
Level 1 (GF)	*3.00*	*3.17*	*6.00*	*4.75*
Level 2 (F2)	*4.17*	*4.00*	*7.75*	*6.50*
Level 3(F4)	*7.25*	*8.00*	*10.00*	*9.00*

Table 3
Sunshine hours depending on the height of buildings and street orientation at summer solstice.

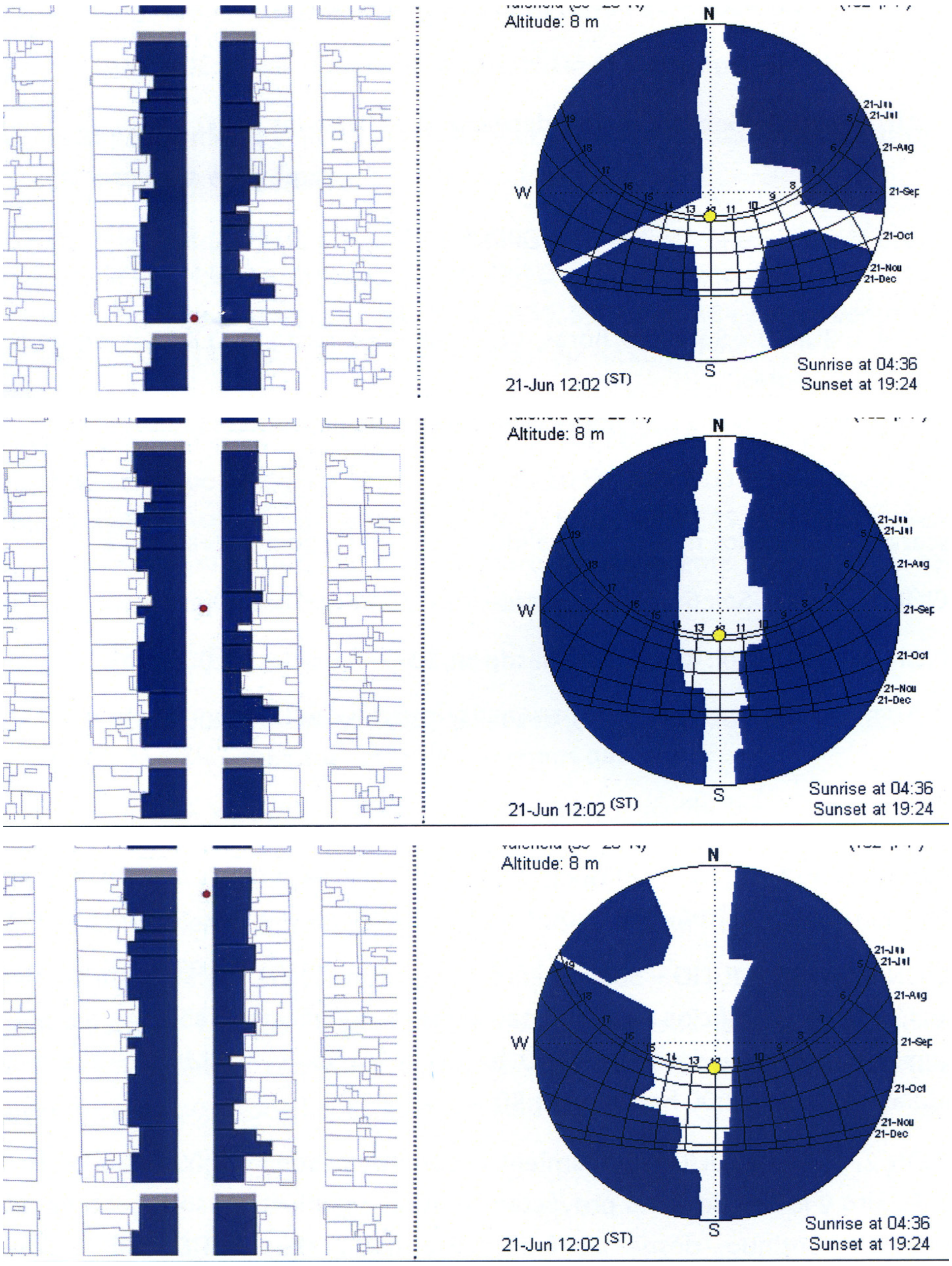

Figure 2
Stereographic diagrams representing solar exposure and shadows in the Historic Centre depending on the position of the housing -1, 2 and 3- in the urban layout. Screen shots from Heliodon software.

Urban Layout	Building type	Housings/storey	Height/width	Street deviation	Courtyard
HC (3-4 storeyes)	*TH*	*1*	*h/w ≥ 2* *1≤ h/2 < 2*	*30ª S-W*	*Interior yard /-*
OB (≥ 4 storeyes)	*MH - AB*	*2-4*	*0.5 ≤ h7w < 1* *1 ≤ h/w <2* *0.25 ≤ h/w < 0.25*	*N-S*	*Gardens*
OB (≥ 5 storeyes)	*MH - AB*	*≥ 4*	*h/w ≥ 2* *1≤ h/2 < 2*	*25ª NW - SE, NE-SW* *50ª NW - SE, NE-SW*	*BLock courtyard*

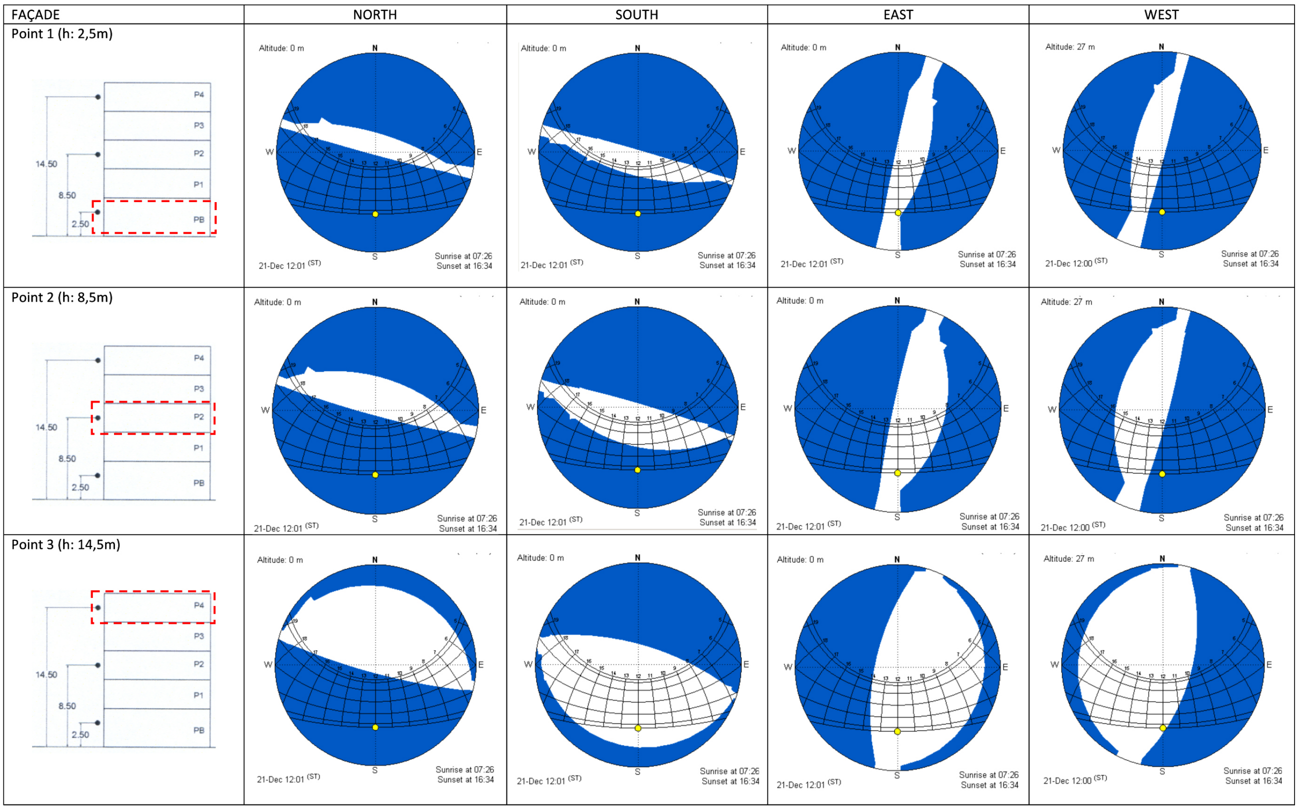

Table 4
Urban characteristics. Ratio between building height and street width (h/w).

Figure 3
Stereographic diagrams representing solar exposure and shadows in the Historic Centre depending on the position of the housing in different storeys of a building. Screen shots from Heliodon software.

to 38° in February. In the case of the Ensanche district built in closed blocks there are two possible angles. For the 25° azimuth angle in relation to the south orientation, solar height in the most underheated months ranges from 23° at winter solstice to 72° in June. For the azimuth angle of 50° in relation to the south orientation, solar height during the most underheated months ranges from 7° at winter solstice to 67° in June.

2.3 CONDITIONING FACTORS FOR WIND

In this study, natural ventilation functions focused on analysing how air flow can potentially reduce energy consumption (Yarke, 2005). The characteristics of the urban layout determines in which extent, direct or indirect winds favour the quality for interior air and thermal comfort in housings (Ai, 2014). Direct ventilation balances the pressure between outdoors and indoors by exchanging masses of air. The wind façade is subjected to excessive pressure and the rest to decompression. The existence of courtyards, their size and positioning are critical in ensuring sufficient ventilation (Jiang, 2003). Thus, cross ventilation is believed to be beneficial in warm climates when it is controlled throughout the day. In the case where narrow courtyards exist, they are in the shade most of the day preventing the entry of warm air in them. Due to differences in pressure, wind needs to be correctly managed in order to generate an air flow that allows wind to cool housings in lower storeys (Shetabivash, 2015). In the other cases in which cross ventilation depends on direct wind, it needs to be properly

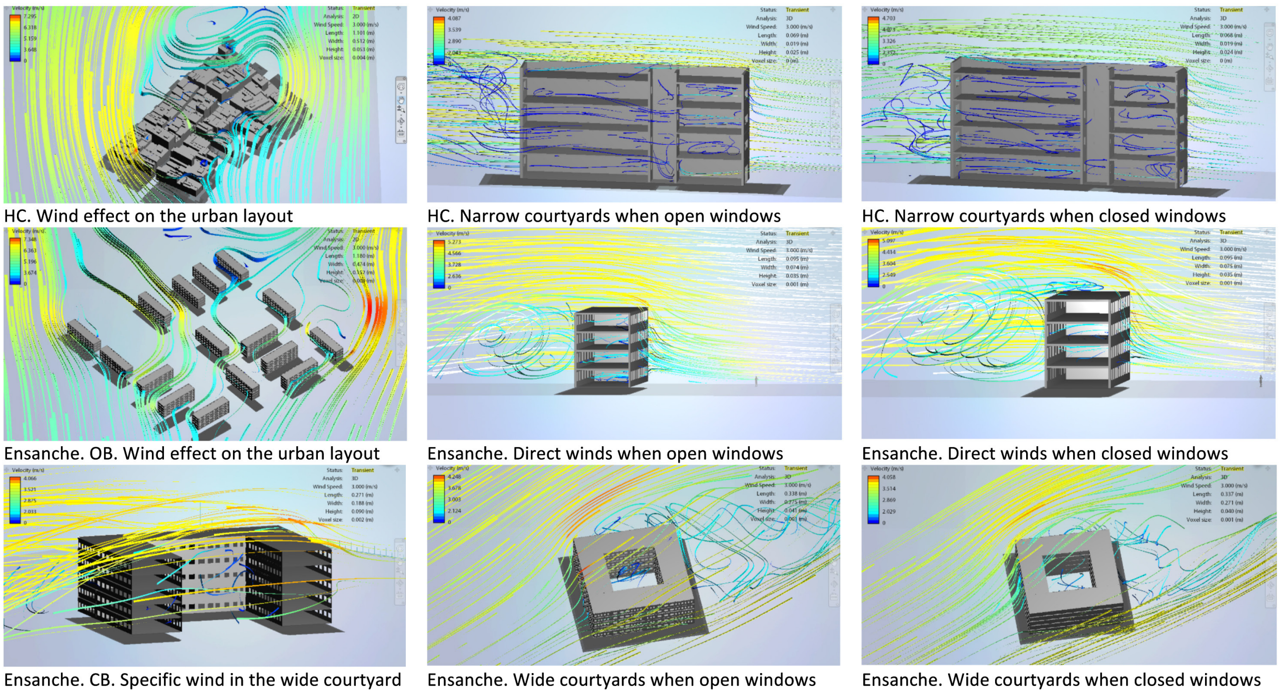

Figure 4
Wind effect on the different urban layouts and type of buildings. Autodesk Flow Design software screenshots.

channelled through the housing creating zones of high and low pressures, speed and suction (Kopp, 2005).
The streets in the historic centre are long and narrow compared to the height of the buildings. This promotes the channelling of wind. In the case of the Ensanche district built in open blocks, the building position, as alternating or diagonal layout in relation to the predominant wind direction, offers greater exposure to the predominant wind. In the Ensanche district built in closed blocks with 25° angle NW-SW orientation streets channel summer winds. This is not the case for the 50° angle layout in which the influence of the wind is in the form of turbulences. Closed blocks have at least two orientations, one façade giving onto the streets and the other onto an interior courtyard. In these wide courtyards differences in pressure are more difficult to be kept than in narrow ones so wind speed is lower and heated faster.

3. BUILDINGS CHARACTERISTICS AND CONSUMPTION

As continuation of a previous study based on the characterization of the building' envelopes and their simulation towards an eventual retrofit (García-Esparza, 2016), the list of buildings was drawn up by using the online dataset from the Ministry of Finance and Public Administration. Conservation Reports of Building and Energy Certification from the Valencian Regional Government and Valencian Institute of Building were produced for some buildings according to the Retrofit Building Solutions Catalogue. The study showed the similarity of pathologies and lack of effective constructive solutions in the envelopes of the different building typologies, TH, MH and AB.
According to the data obtained in the previous study on the very same residential stock, the embodied energy of a typical intervention on the envelope of a TH building in the HC can give rise to a total energy consumption of 511,397.64 KWh/building -20 years of energy consumption-. The same intervention on

Figure 5
Types of buildings, from left to right: 3.1. Calle Enmedio 47 (TH), 3.2. Calle Tenerías 44 (MH), 3.3. Calle Morella 22-30 (AB). Source: Author's own.

a MH building in the OB results in a consumption of 383,061.12 KWh/building -7.8 years of energy consumption-, and on a larger AB building the retrofit can generate a consumption of 1,059,733.24 KWh/building -8.7 years of energy consumption-. These data showed that the consumption of the intervention on the envelope is never recouped. Therefore, among the factors highlighted by Ratti et al. (Ratti, 2005) affecting energy consumption, present study focuses on occupant behaviour and how it can be affected by the urban environment (fig. 4).

4. CONSUMPTION AND BEHAVIOUR

Given the impossibility of monitoring user behaviour, our initial assumption was that everyone seeks similar comfort conditions for their homes. For this reason, and in order to avoid excessive scattering of results, the neighbourhoods chosen were those described as vulnerable or at risk of vulnerability. However, it is understood that there may be occasional consumption peaks in some homes as a result of higher spending power or the degree of knowledge of bioclimate potential of the housing.
As can be observed in tables 4, 6, 8 and 10, in all

ENERGY CONSUPTION (KWH)								
N	ADDRESS	STREET ORIENT	WINTER 2012	SUMMER 2012	WINTER 2013	SUMMER 2013	WINTER 2014	SUMMER 2014
1	*C/ BOVALAR SAN VICENTE 20, 1ª*	*N-S*	*333*	*193*	*379*	*221*	*298*	*196*
2	*C/ALCALDE TERREGA 49, 1ª*	*N-S*	*2546*	*857*	*5296*	*947*	*4983*	*955*
3	*C/ ENMEDIO 110, 1ª*	*N-S*	*2596*	*920*	*1626*	*913*	*1459*	*892*
4	*C/ ENMEDIO 110, 3ª*	*N-S*	*4229*	*324*	*5156*	*429*	*4245*	*238*
5	*C/ PICO ALMAYUD 20*	*N-S*	*1367*	*665*	*1189*	*555*		
6	*C/ MEALLA 31 1ª*	*N-S*	*930*	*878*	*923*	*646*	*1047*	*837*
7	*ALCALDE TERREGA 67, 1ª B*	*N-S*	*1206*	*626*	*1141*	*793*	*1133*	*1164*
8	*PLZA CARDONA VIVES 7, 31ª*	*E-W*	*968*	*647*	*947*	*589*	*620*	*464*
9	*C/ CORDOBA 45, 1ª*	*E-W*	*1363*	*1383*	*1506*	*1575*	*1456*	*1511*
10	*C/ ISABEL FERRER 40, 1ª*	*NE-SW*	*838*	*683*	*1190*	*966*	*1174*	*678*
11	*C/ COBERNADOR 35, 1ª, 1ª*	*NE-SW*	*1442*	*475*	*1683*	*398*	*1132*	*417*
12	*DC FERRAN 18, 3ªA*	*NE-SE*	*1096*	*774*	*1330*	*603*	*931*	*514*
13	*C/ MALAGA 59, 1ª*	*NE-SE*	*1261*	*638*	*1340*	*110*	*1300*	*944*
	TOTAL CONSUPTION		20193	9063	23706	9735	19778	8810
	MEAN CONSUPTION		1553.31	697.15	1823.54	748.85	1648.17	734.17

Table 5
Energy consumption of the housing units located in the historic centre (TH).

cases energy consumption in winter is higher than in summer. In this regard it should be noted that lower consumption in winter may be a direct result of obsolescent envelopes, infiltrations and humidity, joinery and obsolescence and/or lack of communal heating installations. Indirectly, this could be related to user behaviour and urban layout, which is particularly important in the Ensanche district built in open blocks. Although of course, as argued at the start of this section, the envelope does play a part in the summer season, this study will cover the other two factors also affecting consumption at this time of year. The analysis was carried out by compiling the real energy consumption in 2012, 2013 and 2014 in 61 housing units. Despite the usual confidentiality applied by companies when facilitating consumption data, the data were provided by the supply companies with the prior consent of users. The aim of this was to identify which housing units from every urban configuration presented the highest energy consumption, and to establish a relationship between these housing units and their urban configuration (façade orientation and position within the building). This helped to establish whether the efficient use of outdoor climate conditions influences energy consumption.

4.1 HISTORIC CENTRE (HC)

For this urban fabric consumption data were obtained for 13 housing units in different points of the urban configuration. Table 5 shows peaks in the energy consumption of housing units 2, 3, 6, 9, 10 and 13 in the 3 consecutive years in summer.
Based on the previous table three hypotheses can be established to explain above-average consumption. The first hypothesis includes housing units 2 and 3, which are east- and west-facing and receive 2.5 hours of direct solar radiation only when the sun is very high. The second includes housing unit 6, which is south-facing but has no cross ventilation, so that the approximately nine hours of radiation it receives

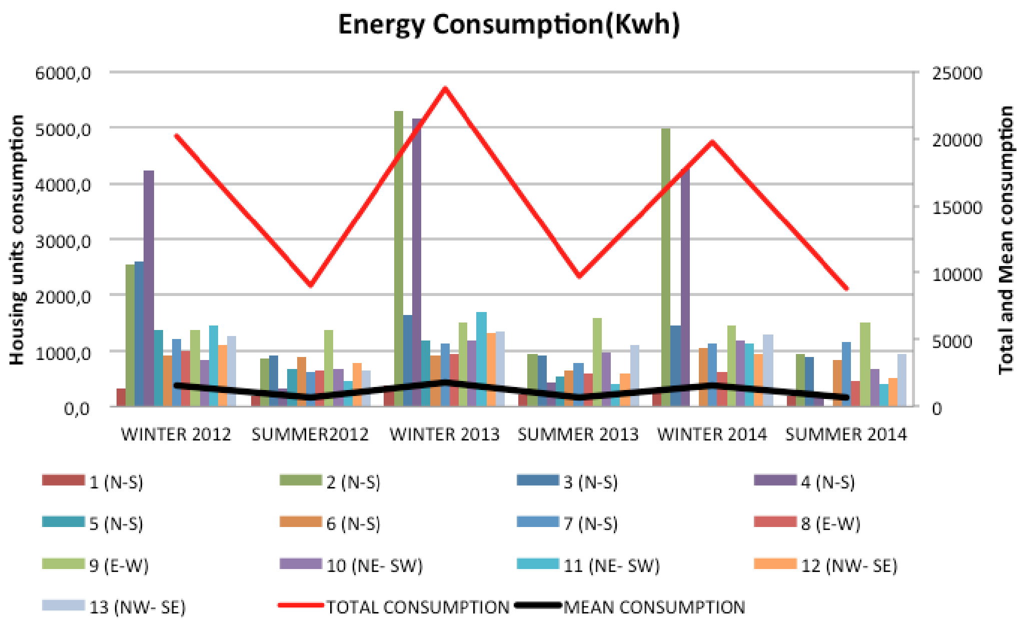

Table 5
In a graph

produce overheating of the envelope although its exposure to wind means that consumption is relatively low. The third includes housing units 9, 10 and 13, with unfavourable orientations and too many hours of radiation, which have no chance of ventilation as they are in an area of wind shade in the layout (table 6).
According to the data analysed, south-facing housing unit 6 displays the lowest energy consumption as it receives the most hours of radiation. In contrast, housing units with a more unfavourable orientation to predominant winds and with possibilities of cross ventilation display the highest consumption. Consequently, neither cross ventilation nor user behaviour are considered determining factors, as the use of this resource greatly depends on the knowledge of the owner (see figure 4).

Housing units with highest energy consuption in summer						
N	Orientat. main fachade	FLoor	Mean consuption (kWh)	Sunshine hours	Possibility of cross ventilation	Type of countryard
2	E	1	920	2.5	Yes	Interior yard
3	W	1	908	2.5	Yes	Interior yard
6	S	1	787	9	No	-
9	N	1	1490	7	No	-
10	N - W	1	776	5.75	No	-
13	N - E	1	894	7.5	No	-

Table 6
Housing units with the highest levels of energy consumption in summer located in the historic centre.

ENERGY CONSUPTION (KWH)								
N	ADDRESS	STREET ORIENT	WINTER 2012	SUMMER 2012	WINTER 2013	SUMMER 2013	WINTER 2014	SUMMER 2014
1	C/ RAFALAFENA 40B, 2ª7	N-S	2235	746	1187	793	1557	749
2	C/ RAFALAFENA 40B, 2ª8	N-S	1236	714	1630	806	1301	630
3	C/ RAFALAFENA 40 E.B, 4ª16	N-S	1172	728	1386	1096	1346	1350
4	VILLAVIEJA 4 5	N-S	-	1220	4757	1354	5566	1533
5	C/ COLUMBRETES 33 46	N-S	1306	840	3778	877	4597	1118
6	Pique LIDON 1-18ª A	E-W	5252	2095	6679	1709	6587	1978
7	Pique LIDON 1-1ª B	E-W	4832	1840	5867	1637	5632	1895
8	Pique LIDON 1-6ª A	E-W	6350	1648	7596	1576	7264	1567
9	Pique LIDON 1-5ª B	E-W	3899	1130	4122	1270	3988	1420
10	C/ moncofa 14 1ª 3	E-W	621	440	562	458	681	442
11	C/ COLUMBRETES 7 11	E-W	419	378	343	376	390	339
	TOTAL CONSUPTION		27322	11779	37807	11952	38909	13021
	MEAN CONSUPTION		2732.20	1070.82	3437.00	1086.55	3537.18	1183.73

Table 7
Energy consumption of the housing units located in isolated open blocks (MH –units 1 to 3- & AB).

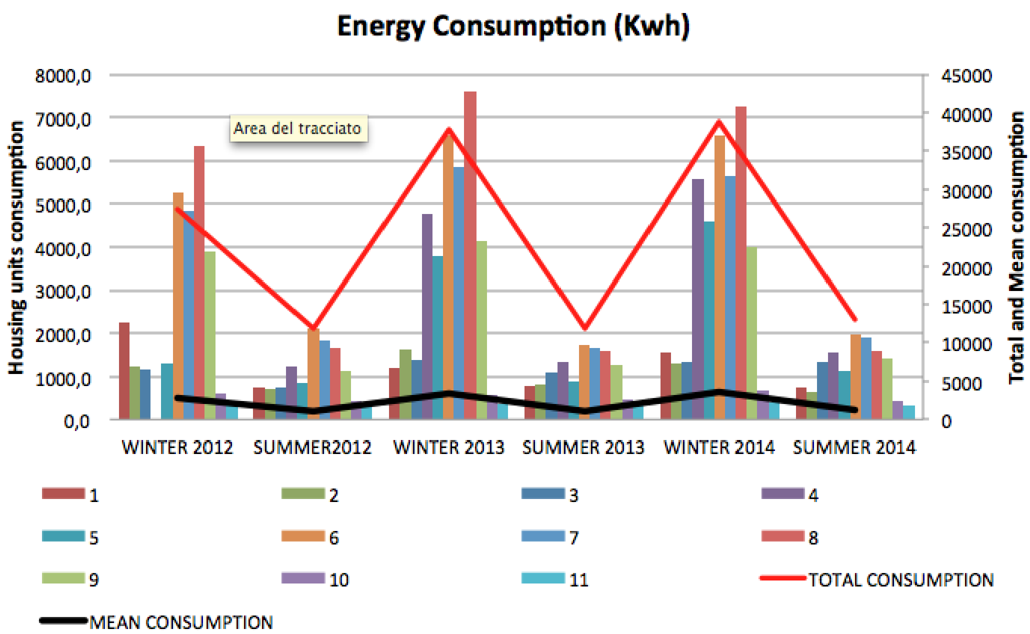

Table 7
In a graph

Housing units with highest energy consuption in summer						
N	Orientat. main fachade	FLoor	Mean consuption (kWh)	Sunshine hours	Possibility of cross ventilation	Type of countryard
4	*W*	*5*	*1369*	*7.5*	*Yes*	-
5	*S-E*	*1*	*945*	*8.8*	*Yes*	-
6	*S*	*8*	*1927*	*10*	*Yes*	-
7	*S*	*1*	*1791*	*8.8*	*Yes*	-
8	*S*	*6*	*1597*	*9*	*Yes*	-
9	*S*	*6*	*1273*	*9*	*Yes*	-

Table 8
Housing units with the highest levels of energy consumption in summer located in isolated open blocks.

4.2 ENSANCHE DISTRICT, OB.

In this type of district consumption data were obtained for 11 housing units situated in different parts of the urban layout. From table 7 it can be concluded that over the summer periods of the three consecutive years the energy consumption peaks occur in housing units 4, 5, 6, 7, 8 and 9.

Based on the previous table two hypotheses are established to explain the above-average consumption. The first hypothesis includes housing units 5 and 7 which due to their south- and southeast-facing façades and their location on the first story received no direct incidence of the predominant wind in summer, only secondary ventilation in the form of turbulence which generated calm or underventilated areas in the lower storeys. The second hypothesis includes housing units 4, 6, 8 and 9, mostly oriented to the south and on the upper storeys, which receive excessive radiation, between 7.5 and 10 hours/day, with subsequent overheating in the façades. As opposed to the first hypothesis, the effect of direct ventilation could be considered an element which might lessen consumption, although once again the facing and southeast-facing orientations presenting the highest consumptions. This suggests that the position of the housing unit within the urban layout is not a determining factor in reducing consumption, despite the fact that in the housing units of intermediate and upper storeys consumption could be reduced through user behaviour.

4.3 ENSANCHE DISTRICT, CB.

For this type of district consumption data were obtained for the two areas of the Ensanche district studied with different mesh orientations. From the mesh with NW-SE orientation and that with NE-SW orientation and a 25° angle in relation to the horizontal plane, consumption data were obtained for 24 housing units, while for the mesh with a 50° angle in relation to the horizontal plane the consumption data were obtained for 13 residential buildings.

Mesh with NW-SE and NE-SW orientation and a 25° angle in relation to the horizontal plane

From table 9 it is concluded that the peaks in energy consumption occurred for 3 consecutive years in the summer period in housing units 1, 3, 12, 17, 21, 23 and 24.

From the above table three hypotheses can be established to explain above-average consumption. The first hypothesis includes housing unit 1, which has many hours of radiation, is on the first storey, and is in part of an area in the urban layout which is under-ventilated. The second includes housing units 3, 12 and 17 which, although they are on intermediate and upper storeys and exposed to between 8.5 and 9.5 hours of radiation a day, have a SW and SE orientation which is more favourable to ventilation. The third hypothesis includes housing units 21, 22, 23 and 24. Despite the similar orientation, similar height and similar radiation, housing unit 23, the only one where cross ventilation is possible, stands out for its high consumption (table 10).

In any case, the different consumptions for hypothesis 2 are higher than those for hypothesis 1 except in the case of housing unit 12, where higher exposure to wind is a determining factor in stabilising consumption. In the case of housing units located on lower storeys the importance of the aforementioned cooling effect in the narrow courtyards should also be noted, although this cannot be said of the housing units in upper storeys, such as 17 or 23. In the case of housing unit 23 user behaviour is seen to be a determining factor in consumption.

Mesh with NW to SE – NE to SW orientation at a 50° angle in relation to the horizontal plane

From table 11 it is concluded that the housing units experiencing peaks in energy consumption in the 3 consecutive years in the summer period are 4, 5, 8, 10, 11 and 13.

From the above table two hypotheses were established to understand above average consumption. The

N	ADDRESS	STREET ORIENT	WINTER 2012	SUMMER 2012	WINTER 2013	SUMMER 2013	WINTER 2014	SUMMER 2014
					ENERGY CONSUPTION (KWH)			
1	C/ ARTANA, 1, pl:1 pt:2	NE-SW	1056	775	1062	910	859	642
2	C/ ARTANA, 5, pl:3 pt:5	NE-SW	647	435	900	694	758	258
3	C/ ARTANA, 12, pl:5 pt:9	NE-SW	988	1200	712	1063	791	1116
4	C/ BENICARLO, 2, pl:6 pt:16	NE-SW	1079	394	970	363	1150	291
5	C/ BENICARLO, 2, pl:7 pt:21	NE-SW				282	399	336
6	C/ OROPESA, 12, pl: 2 pt:5	NE-SW	1336	171	787	128	955	43
7	C/ BENARABE, 6, pl:5 pt:10	NE-SW					1100	547
8	C/ SANTA CRUZ TEIJEIRO, 9, pl:5 pt: 10	NW-SE	406	400	308	349	286	352
9	C/ SANTA CRUZ TEIJEIRO, 11, pl:5 pt:15	NW-SE	440	507	394	376	375	363
10	C/ SANTA CRUZ TEIJEIRO, 11, pl:5 pt:14	NW-SE	375	602	539	444	323	560
11	C/ SANTA CRUZ TEIJEIRO, 3, pl:6 pt:12	NW-SE					1134	874
12	C/ SANTA CRUZ TEIJEIRO, 5, pl:7 pt:13	NW-SE	1324	933	1697	794	1097	657
13	C/ MADRE VEDRUNA, 16, pl:6 pt:A	NW-SE	963	509	959	534	1048	504
14	C/ LA LLOSA, 2, pl:3	NW-SE			925	389	844	386
15	C/ MONTORNES, 1, pl:8 pt:20	NW-SE	1047	539	1040	624	940	511
16	C/ RIO PALANCIA, 6, pl:7 pt:13	NW-SE	951	481	779	274	587	357
17	C/ SEGARRA RIBES, 9, pl:5 pt:23	NW-SE	1045	1174	1086	734	912	1017
18	C/ TENERIAS, 51, pl:1 pt:1	NW-SE			331	460	450	654
19	C/ PINTOR SOROLLA, 6-BIS A, pl:1° pt:1	NW-SE				690	1325	761
20	Avda. DOCTOR CLARA, 38, pl:8 pt:C	NW-SE	837	313	588	314	467	284
21	C/ CRONISTA MUNTANER, 3, pl:5	NW-SE	1507	925	1374	997	1361	959
22	C/ CRONISTA MUNTANER, 3 esc. 1, pl:5 pt:10	NW-SE	1415	836	1568	764	1334	629
23	Avda. ALCORA, 13, pl:4 pt:10	NW-SE	1696	1282	1815	1153	1228	1007
24	C/ FELIPE II, 5, pl:6 pt:17	NW-SE	1708	746	1015	957	844	621
	TOTAL CONSUPTION		18820	12222	18849	13293	20567	13729
	MEAN CONSUPTION		1045.6	679.00	942.45	604.23	856.96	572.04

Table 9
Energy consumption of the housing units located in detached closed blocks with deviation of 25° (MH).

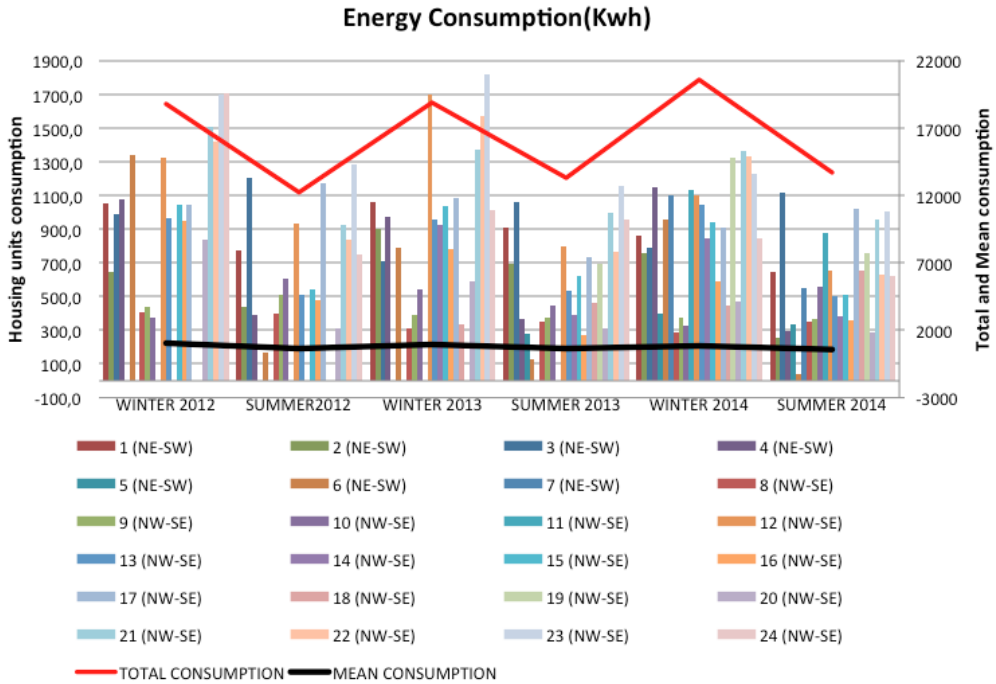

Table 9
In a graph

Housing units with highest energy consuption in summer						
N	Orientat. main fachade	FLoor	Mean consuption (kWh)	Sunshine hours	Possibility of cross ventilation	Type of countryard
1	*N-W*	*1*	*776*	*3.25*	*Yes*	*Courtyard*
3	*S-W*	*5*	*1126*	*8.5*	*Yes*	*Block courtyard*
12	*S-W*	*7*	*795*	*9.83*	*Yes*	*Block courtyard*
17	*N-W*	*5*	*975*	*9.5*	*Yes*	*Courtyard*
21	*N-E*	*5*	*960*	*8.5*	*No*	*-*
22	*N-E*	*5*	*743*	*8.5*	*No*	*-*
23	*N-E*	*4*	*1147*	*8.5*	*Yes*	*Courtyard*
24	*N-E*	*6*	*775*	*8.5*	*No*	*-*

Table 10
Housing units with the highest levels of energy consumption in summer located in detached closed blocks with deviation of 25°.

first hypothesis includes housing units 5 and 8, which are located on the first storey with south-east orientation, and which do not receive excessive hours of solar radiation due to solar obstruction. The second hypothesis includes housing units 4, 10, 11 and 13, which are located on the upper storeys of the buildings with variable orientation, and which receive intense heat transmission through the roof. Nevertheless, as they are on the upper storeys they are subjected to the direct action of wind, regardless of the orientation of the street (table 12) (see figure 4).

In the first hypothesis the differences between inner courtyards and quadrangles do not appear to be determining factors for first-storey housing units, which do appear to be conditioned by the shade they receive, as they are the ones which consume least in summer among the housing units with the highest consumption. In the second hypothesis, one of the four housing units cannot guarantee cross ventilation and presents the highest consumption. Nevertheless, excess of consumption is not significant compared to the rest of housing units with different orientation

ENERGY CONSUPTION (KWH)								
N	ADDRESS	STREET ORIENT	WINTER 2012	SUMMER 2012	WINTER 2013	SUMMER 2013	WINTER 2014	SUMMER 2014
1	*C/ CASTELLDEFELS, 1, pl:1 pt:2*	*NE-SW*			*855*	*467*	*786*	*436*
2	*C/ CASTELLDEFELS, 15,pl:5 pt:11*	*NE-SW*	*813*	*504*	*591*	*495*	*635*	*440*
3	*C/ CASTELLDEFELS, 11, pl:5 pt:10*	*NE-SW*	*1233*	*351*	*816*	*353*	*991*	*228*
4	*C/ CASTELLDEFELS, 17, pl:7 pt:15*	*NE-SW*	*966*	*555*	*888*	*560*	*1090*	*705*
5	*C/ CASTELLDEFELS, 17, pl:1 pt: 3*	*NE-SW*			*769*	*523*	*1177*	*552*
6	*C/ CASTELLDEFELS, 16, pl:3 pt:7*	*NE-SW*	*903*	*559*	*511*	*373*	*589*	*150*
7	*C/ PEROT DE GRANYANA, 19, pl:1 pt:3*	*NE-SW*	*1147*	*127*	*678*	*165*	*1912*	*145*
8	*C/ PEROT DE GRANYANA, 17, pl:1 pt:4*	*NE-SW*	*1019*	*543*	*770*	*517*	*945*	*479*
9	*C/ DEL PUIG, 1, pl:4 pt:9*	*NW-SE*	*422*	*21*	*269*	*3*	*400*	*17*
10	*C/ DEL PUIG, 4, pl:5 pt:10*	*NW-SE*		*911*	*797*	*877*	*972*	*799*
11	*C/ DOCTOR FERRAN, 26, pl:7 pt:13*	*NW-SE*	*1608*	*858*	*1186*	*728*	*921*	*690*
12	*Plza DOLCAINERS DE TALES, 2, pl:5 pt:2*	*NW-SE*	*607*	*382*	*691*	*436*	*672*	*407*
13	*C/ LERIDA, 6, pl:9 pt:17*	*NW-SE*		*703*	*1174*	*1025*	*1136*	*937*
	TOTAL CONSUPTION		8718	5514	9995	6522	12226	5985
	MEAN CONSUPTION		968.67	501.27	768.85	501.7	940.46	460.38

Table 11
Energy consumption of the housing units located in detached closed blocks with deviation of 50° (MH).

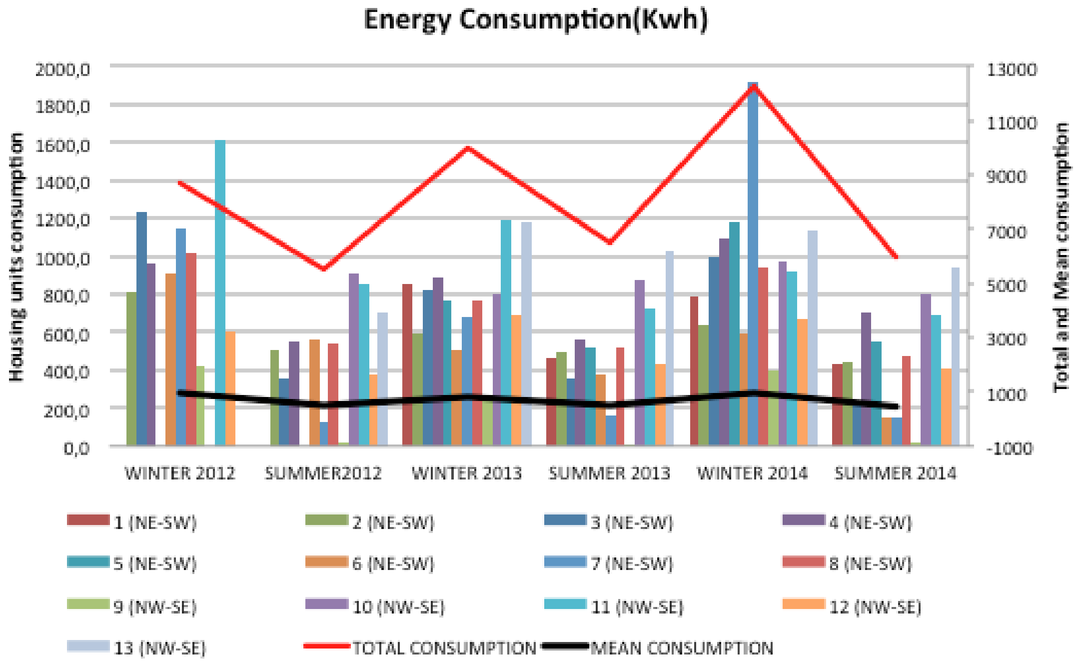

Table 11
In a graph

Housing units with highest energy consuption in summer						
N	Orientat. main fachade	FLoor	Mean consuption (kWh)	Sunshine hours	Possibility of cross ventilation	Type of countryard
4	*S-W*	*7*	*607*	*8*	*Yes*	*Block courtyard*
5	*S-E*	*1*	*538*	*6*	*Yes*	*Block courtyard*
8	*S-E*	*1*	*513*	*10*	*Yes*	*Courtyard*
10	*S-W*	*5*	*862*	*9*	*Yes*	*Courtyard*
11	*N-E*	*7*	*759*	*7*	*Yes*	*Courtyard*
13	*N-W*	*9*	*888*	*8*	*No*	*-*

Table 12
Housing units with the highest levels of energy consumption in summer located in detached closed blocks with deviation of 50°.

except in the case of south-east facing housing units where consumption is reduced drastically, as is the case of housing unit 4. In this regard, it should be noted that consumption for the upper storeys is conditioned by orientation, the possibility of cross ventilation and accordingly, user behaviour.

5. OCCUPANTS

Following the overall analysis of consumption, relatively low consumption was observed in all housing units. It should be noted that this is not a result of optimum building behaviour or a mild climate, but is rather due to low spending power of most of the households.
During the data collection process for energy consumption it was observed that the most deteriorated areas were the historic centre and the Ensanche area in closed blocks. In both, occupants are relatively worse off economically so that in order to keep down energy expenditure they barely make use of heating and cooling systems. In addition, data collected from households demonstrated that occupants barely recognise how to take advantage of the orientation and climate.
In this respect, the study aimed to examine the social situation of the setting under study and obtain information about how housing unit occupants assess the level of importance they attach to the technical, economic and environmental aspects when hypothetically carrying out a retrofit in their building. The study consisted of 300 surveys among of random samples of occupants with an estimated error of 5.5% for a 95% level of trust.
The general results of the survey on economic, environmental and technical criteria that should guide an integrated intervention showed that for 80% of those surveyed Economic Criteria are the most important when deciding to carry out a retrofit on their home, and Environmental Criteria are considered the least important, while 17.7% of those surveyed considered both of these to be of little or no importance.

Occupants were asked about the hypothetical willingness to fund an energy retrofit of their home. Over 69.2% of those surveyed would not carry out any interventions on their housing units as they could not afford a partial or full intervention. However, some users expressed willingness to fund part of the intervention. 25.6% could pay in kind with a rural plot, 5.1% with a second home in the country, and 4.6% with a second home on the coast or in the city. 39.1% stated they had up to 1,000€ to improve the energy efficiency of the home; 15.3% up to 3,000€, 6% up to 5,000€ and 5% up to 10,000€. In this regard, based on these data and the previous research which gave a financial estimate for an intervention on the envelopes of the building types included in this study, it can be stated that the costs would be too high and could probably not be covered by owners or administrations.
Finally, although the surveys are not put directly into relation with a specific urban layout, the analysis of consumption over a 3-year period and its correlation with the spending power of users shows that the same type of housing tends to display higher consumption both in winter and summer. This suggests that exterior climate factors are not used correctly and energy consumption is more dependent on other factors such as economy.
As regards energy consumption, this study shows that socially vulnerable housing consumes least energy and consequently these buildings may be considered to have lower priority for retrofitting. However, in social terms, the energy retrofitting of these buildings with the lowest consumption may well be a priority for the same reasons mentioned initially: inequality and exclusion.

6. RESULTS

Results show the potential reduction in energy consumption just by adapting users' behaviour. Due to the obtained data and the potential reduction being analysed for the three months of summer season, in an equivalent energy use intensity KWh/m2/year, year is considered to be 91.31 days. As regards the size of housings, TH are 83.2 m2; MH are 69.8 m2; AB are 98.8 m2 (García-Esparza, 2016). According to the data analysed in the historic centre (TH) the existence of wind shade is a determining factor so that the orientation and position of the housing unit in such a narrow layout make the energy consumption of the unit a determining factor. Therefore, cross ventilation and subsequently user behaviour are highly dependent on the direct incidence of wind in this urban layout. Mean consumption could be reduced, by eliminating wind shade and occasionally intervening on the urban layout to ensure ventilation, by 1.73 kWh/m2/yr in summer (table 6, units 2 & 10).

According to the data analysed in the OB Ensanche, energy consumption is similar for all storeys, except the top storey, where consumption increases sharply regardless of orientation as these buildings have high sun exposure. For this reason the position of the housing unit is not the key factor in reducing consumption, although it is true that in fact the housing units on intermediate and upper storeys could reduce consumption given their more favourable exposure to direct winds and turbulences (AB). As a result, user behaviour could reduce consumption by 3.28 KWh/m2/yr. Additional interventions on the roof could make it possible to reach 6.62 KWh/m2/yr in each housing unit directly under the roof (table 8, units 8 & 9).

In the CB Ensanche with NW-SE and NE-SW orientation and an angle of 25° (MH), in the comparison of consumption for the housing units located on the same intermediate storey, orientation and the existence of a courtyard are not determining factors in energy consumption. Given their greater exposure to wind the housing units located on the upper storeys also experienced a reduction of consumption of 2.65 KWh/m2/yr. In addition to lower exposure to solar radiation the presence of an indoor courtyard should be noted as important in the case of lower storeys, given the cooling effect noted initially, where consumption was lowered by 2.63 KWh/m2/yr compared with the upper storeys. Finally, it becomes apparent that user behaviour is a determining factor in cases with higher consumption. In cases comparable for their orientation, solar radiation and position in the layout, behaviour could reduce consumption by 3.10 KWh/m2/yr (table 10, units 21 & 22).

In the CB Ensanche with NW-SE and NE-SW orientation and 50° angle (MH), according to the consumption analysis, the effect of the courtyard, either quadrangle or interior courtyard, appears more effective on first-storey housing units than on intermediate storeys where consumption can increase by 5.0 KWh/m2/yr. In the case of housing units on upper storeys, the favourable south-east orientation can reduce consumption by 2.18 KWh/m2/yr. Finally, a comparison of the upper storeys shows that consumption may be reduced by 1.84 KWh/m2/yr given possible cross ventilation and subsequently by the user behaviour (table 12, units 4, 11 & 13).

The analysis of total mean consumption for the 6 housing units with the highest consumption in each urban layout shows that consumption for the historic centre is 11.57 KWh/m2/yr. In this case a potential reduction of 1.73 kWh/m2/yr could occur with a one-off intervention in the urban layout. In the OB Ensanche district, the consumption of 3.96 KWh/m2/yr could potentially be reduced by 3.28 KWh/m2/yr through user behaviour and, to a lesser extent, with a one-off intervention on the building. In the CB Ensanche district with NW-SE and NE-SW orientation with an angle of 25° where the generally excessive height of buildings results in different consumption for different housing units, the average consumption of 13.79 KWh/m2/yr could mostly be reduced by the user by 3.10 KWh/m2/yr. Finally in the CB Ensanche district with NW-SE and NE-SW orientation and an angle of 50°, with an average consumption of 9.95 KWh/m2/yr, building characteristics play a major role although users could be potentially reduce this by up to 1.84 KWh/m2/yr.

ENERGY CONSUMPTION (kWh/m2/yr)						
MEAN CONSUMPTION	SUMMER2012	SUMMER 2013	SUMMER 2014	THREE YEARS	POTENTIAL REDUCTION	% OF REDUCTION
Historic Centre - TH	*9.13*	*10.28*	*9.62*	*9.67*	*1.88*	*19.95*
OB Ensanche – AB & MH	*10.08*	*10.23*	*11.14*	*10.48*	*3.05*	*29.09*
CB Ensanche 25° - MH	*12.65*	*11.25*	*7.53*	*10.48*	*3.44*	*29.91*
CB Ensanche 50° - MH	*9.33*	*9.34*	*8.57*	*9.08*	*2.62*	*28.80*

Table 13
Potential reduction of energy consumption in the three urban plots at summer solstice based on 91.31 days of summer.

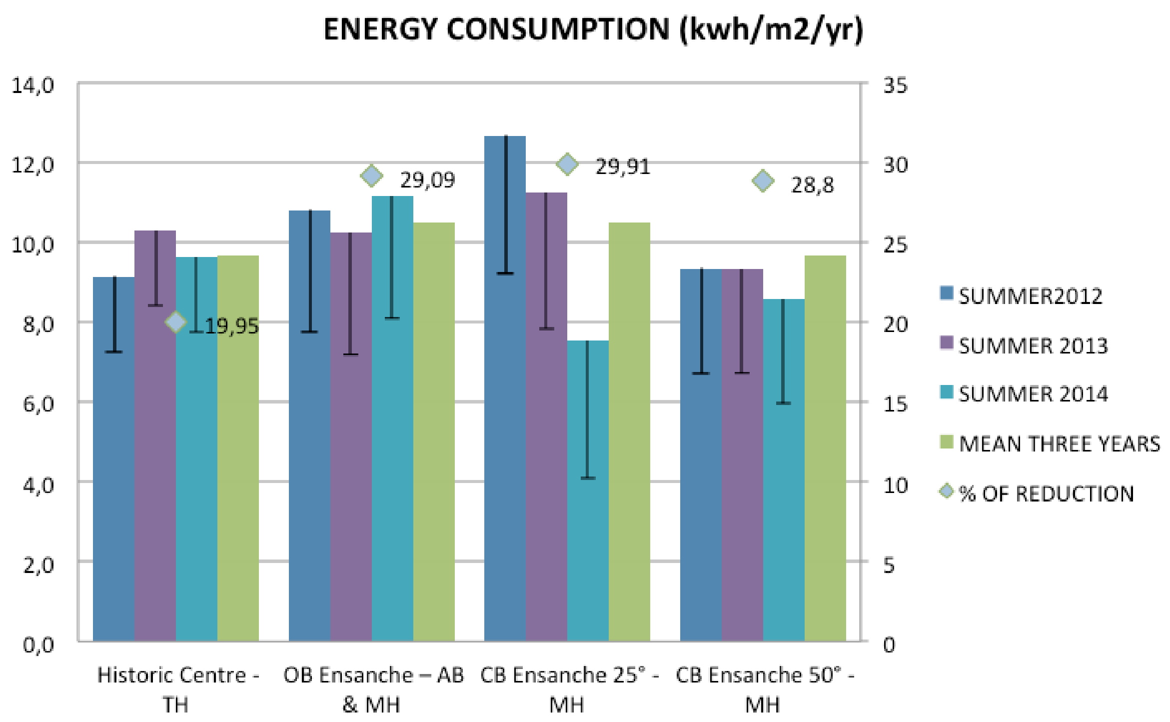

Table 13
In a graph

7. CONCLUSIONS

In view of the analysis in this study, any option of retrofitting the envelopes should therefore be considered as a last resort compared to other strategies aimed at reducing energy consumption through a basic retrofit of the façades to eliminate infiltrations and damp, as well as improving awareness of good practices to achieve "almost zero consumption behaviour" of users, what may mean reducing consumption by up to 29.91 % (table 13), and taking on proposals for solar or bioclimate urban planning whenever possible.

A methodology like that detailed in this study is geared towards providing architects, building surveyors and urban planners with the proper indicators not only to classify and prioritise the building stock to be retrofitted, but also in the planning of new urban residential spaces. The methodology can be replicated and applied to other environments to estimate the optimal urban characterization for pre-existent neighbourhoods. Future research lines should analyse the benefits of having real data of consumption in order to create maps of consumption that allow agents to critically prioritise areas, buildings and interventions. Other lines of future research should monitor daily behaviour of users to correlate it with radiation and temperature analysis within housing units and on façades, using thermography of interior courtyards and quadrangles of the HC and the OB and CB Ensanche districts together with quantitative studies of wind flows.

Acknowledgements

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REFERENCES

A.d. Barcelona, (2009). Plan de Movilidad y Espacio Público de Lugo, Lugo city council, Lugo.

Ai Z., Mak C., (2014). in: Modeling of coupled urban wind flow and indoor air flow on a high-density near-wall mesh: Sensitivity analyses and case study for single-sided ventilation, Environ. Model. Software 60 57-68, http://www.sciencedirect.com/science/article/pii/S1364815214001753.

Antone Faggianelli G., Brun A., Wurtz E., Muselli M., (2014) in: Natural cross ventilation in buildings on mediterranean coastal zones, Energy Build. 77, 206-218, http://www.sciencedirect.com/science/article/pii/S037877881400262X.

Amado M., Poggi F., (2014). in: Solar energy integration in urban planning: GUUD model, Energy Procedia 50, 277-284, http://www.sciencedirect.com/science/article/pii/S187661021400770X.

Butera J.M., (2013). in: Zero-energy buildings: the challenges, Advanc. Build. Energy Research 7 (1), 51-65, http://www.tandfonline.com/doi/full/10.1080/17512549.2012.756430.

Chesné L., Duforestel T., Roux J.-J., Rusaouën G., (2012). in: Energy saving and environmental resources potentials: Toward new methods of building design, Build. Environ. 58, 199-207, http://www.sciencedirect.com/science/article/pii/S0360132312002016.

Cole R.J. (2012) in: Regenerative design and development: Current theory and practice. Building Research & Info, 40(1), 1–6. http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.617516

Eames M., Dixon T., May T., Hunt M. (2013)., in: City futures: Exploring urban retrofit and sustainable transitions. Building Research & Info, 41(5), 504–516. http://www.tandfonline.com/doi/abs/10.1080/09613218.2013.805063

Episcope (2009). Typology approach for building stock energy assessment. Retrieved from http:// episcope.eu/welcome/

García-Esparza J.A., Caballero C., (2016). in: Procedure for evaluating and rehabilitating envelopes of obsolete buildings in warm regions, Advanc. Build. Energy Research 2016, http://tandfonline.com/doi/full/10.1080/17512549.2016.1237376.

García-Esparza J.A., Alcañiz E., (2017). in: To rehabilitate the habitability. Scenario simulation for consolidated urban areas in warm regions, WEAS Trans. Envi. Develop. 13 Printing.

Herrera I.J., (2010). Análisis urbanístico de Barrios Vulnerables en España. Sobre la vulnerabilidad urbana, Gobierno de España, Madrid.

Instituto para la Diversificación y Ahorro de Energía (IDAE) (2011). Analysis of the energy consumption in the residential sector in Spain, (SECH-SPAHOUSEC PROJECT).

Instituto para la Diversificación y Ahorro de Energía (IDAE), Consumos del Sector Residencial en España, Madrid, 2014. Retrieved from: http://www.idae.es/informacion-y-publicaciones/estudios-informes-y-estadisticas

Jiang Y., Alexander D., Jenkins H., Arthur R., Chen Q., (2003). in: Natural Ventilation in Buildings: Measurement in a Wind Tunnel and Numerical Simulation with Large Eddy Simulation, Journal Wind Engin. Indust. Aerodyn. 91(3) (2003), 331-353, http://www.sciencedirect.com/science/article/pii/S016761050200380X.

Kanters J., Horvat M., (2012) in: Solar energy as a design parameter in urban planning, Energy Procedia 30, 1143-1152, http://www.sciencedirect.com/science/article/pii/S1876610212016438.

Karvonen A., (2013). in: Towards systemic domestic retrofit: A social practices approach. Building Research & Info. 41(5), 563–574. http://www.tandfonline.com/doi/abs/10.1080/09613218.2013.805298

Kopp G. A., Surry D., Mans C., (2005) in: Wind effects of parapets on low buildings: Part 1. Basic aerodynamics and local loads, Journal of Wind Engin. Indust. Aerodyn. 93 (11) , 817–841, http://www.sciencedirect.com/science/article/pii/S0167610505000875.

Kosir M., Guedi Capeluto I., Krainer A., Kristl Z., (2014) in: Solar potential in existing urban layouts-Critical overview of the existing building stock in Slovenian context, Energy Policy 69, 443-456, http://www.sciencedirect.com/science/article/pii/S0301421514000846.

Kurtz F., Monzón M., López-Mesa B., (2015). in: Energy and acoustics related obsolescence of social housing of Spain's post-war in less favoured urban areas. The case of Zaragoza, Informes de la Construcción 67 (Extra-1) http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion/article/view/4075/4670.

Littlefair P., (1998) in: Passive solar urban design: ensuring the penetration of solar energy into the city, Renew. Sust. Energy Reviews 2, 303-326, http://www.sciencedirect.com/science/article/pii/S1364032197000099.

Littlefair P. (2001), in: Daylight, sunlight and solar gain in the urban environment, Solar Energy 70 (3), 177-185, http://www.sciencedirect.com/science/article/pii/S0038092X00000992.

Manzano-Agugliaro F., Montoya F.G., Sabio-Ortega A., García-Cruz A. (2015), in: Review of bioclimatic architecture strategies for achieving thermal comfort, Renew. Sustain. Energy Reviews 49, 736-755, http://www.sciencedirect.com/science/article/pii/S1364032115003652.

Martins T.A.L., Adolphe L., Bastos L.E.G., (2014). in: From solar constraints to urban design opportunities: Optimization of built form typologies in a Brazilian tropical city, Energy Build. 76, 43-56, http://www.sciencedirect.com/science/article/pii/S0378778814001704.

Ordoñez J.. Modi V., (2011). in: Optimizing CO2 emissions from heating and cooling and from the materials used in residential buildings, depending on their geometric characteristics, Build. Environ. 46, 2161-2169, http://www.sciencedirect.com/science/article/pii/S0360132311001326

Pacheco-Torres R., López-Alonso M., Martínez G., Ordóñez J., (2015) in: Efficient design of residential buildings geometry to optimize photovoltaic energy generation and energy demand in a warm Mediterranean climate, Energy Efficiency 8, 65-84. https://link.springer.com/article/10.1007/s12053-014-9275-5

Pérez-Lombard L., Ortiz J., Pout C., (2008) in: A review on buildings energy consumption information, Energy Build. 40 , 394-398, http://www.sciencedirect.com/science/article/pii/S0378778807001016.

Ratti C., Baker N., Steemers K., (2005). in: Energy consumption and urban texture, Energy Build. 37 (7), 762-776, http://www.sciencedirect.com/science/article/pii/S0378778804003391.

Santamouris M., Asimakopoulos D., (1996). Passive cooling of buildings. James & James, London.

Santin O.G., Itard L., Visscher H., (2009). in: The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy Build. 41 (11), 1223–1232, http://www.sciencedirect.com/science/article/pii/S0378778809001388.

Serrano-Lanzarote B., Ortega-Madrigal L., García-Prieto-Ruiz A., Soto-Francés L., Soto-Francés V.M., (2016). in: Strategy for the energy renovation of the housing stock in Comunitat Valenciana (Spain), Energy Build. 132, 117–129, http://www.sciencedirect.com/science/article/pii/S037877881630576X.

Seyfang G., Haxeltine A., (2012). in: Growing grassroots innovations: Exploring the role of community based initiatives in governing sustainable energy transitions. Environment and Planning C: Gov. Pol., 30 381–400. http://journals.sagepub.com/doi/pdf/10.1068/c10222

Shetabivash H., (2015). in: Investigation of opening position and shape on the natural cross ventilation, Energy Build. 93, 1-15, ttp://www.sciencedirect.com/science/article/pii/S0378778814011268.

Strategic Management, 24(4) (2012), 407–420. http://www.tandfonline.com/doi/abs/10.1080/09537325.2012.663964

Vergragt P.J., Brown H.S., in: The challenge of energy retrofitting the residential housing stock: Grassroots innovations and socio-technical system change in Worcester, MA. Technology Analysis

Vermeulen T., Knopf-Lenoir C., Villon P., Beckers B., (2015), in: Urban layout optimization framework to maximize direct solar, Comp. Environ. Urban Systems 51, 1-12, http://www.sciencedirect.com/science/article/pii/S0198971515000137.

Yarke E., (2005). Ventilación natural de edificios. Fundamentos y Métodos de Cálculo para aplicación de Ingenieros y Arquitectos, Nobuko, Buenos Aires.