Analysis of the Influence of Variables Linked to the Building and Its Urban Context on the Passive Energy Performance of Residential Stocks

Marta Braulio-Gonzalo, Mª José Ruá Aguilar and Mª Dolores Bovea Edo

1 Introduction

Several studies have addressed the impact of buildings on energy demand and consumption in recent years. Urban areas are set to become greater energy consumers and the residential building stock has a great deal. Energy efficiency regulations in buildings are recent, and most of the housing stock is far from meeting present standard and is responsible of a high percentage of global energy consumption. Thus intervention in the consolidated city gain importance and the promotion of more sustainable urban development focus on reducing energy demand by adopting passive energy strategies.

This study is based on a previous work where a methodology for modelling the energy performance of existing residential stocks was developed (Braulio-Gonzalo et al. 2016). This model was based on a bottom-up approach (Swan and Ugursal 2009), where a representative sample of buildings was energy modelled to extrapolate conclusions to an urban scale.

In the present work, the influence of a set building and urban parameters on the energy performance of residential stocks is analysed. To this end, an existing neighbourhood in the city of Castellón de la Plana (Spain) (Fig. 1) was selected as a case study and the residential building stock was assessed by dynamic simulation with the DesignBuilder (2015) and EnergyPlus software (U.S. Department of Energy 2013) as a calculation engine. The selection of a set of covariates on both the building scale [shape factor (S/V), year of construction (Y)] and the urban scale [urban block (UB), street H/W ratio, and orientation (O)] allowed its influence on two response variables to be analysed: energy demand for cooling (ED_c) and for heating (ED_h).

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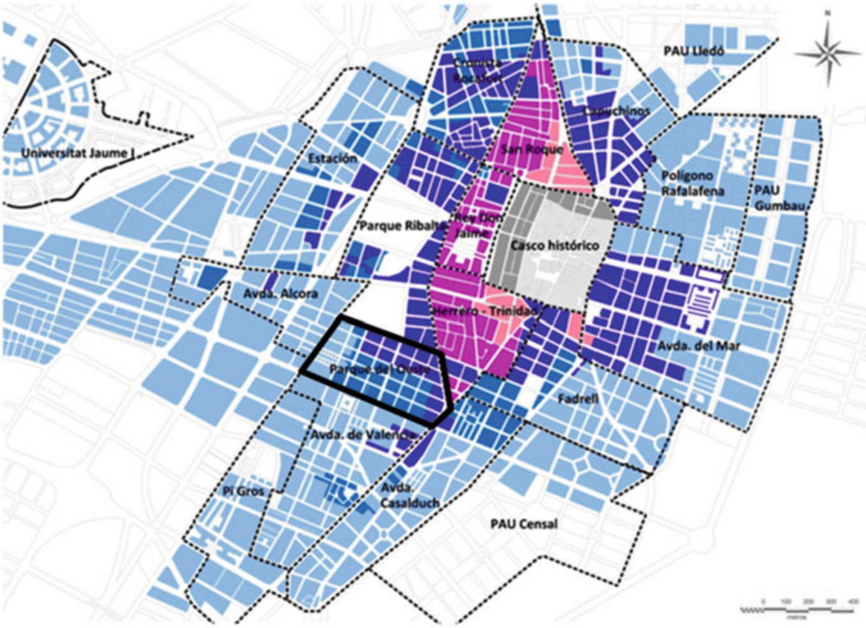

Fig. 1 Analysed neighbourhood (*Parque del Oeste*) in the context of Castellón de la Plana

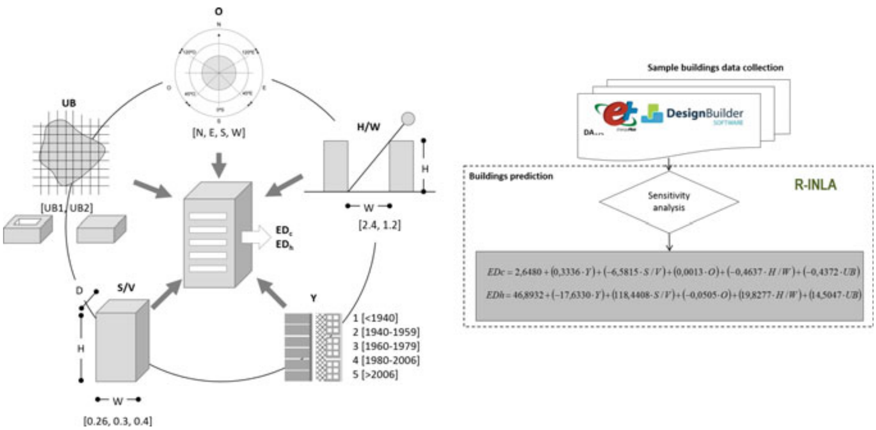

Fig. 2 Description of covariates (*left*) and prediction equations for ED_c and ED_h, adapted from Braulio-Gonzalo et al. (2016) (*right*)

The statistical data modelling through the Integrated Nested Laplace Approximation (INLA) (Blangiardo and Camaletti 2015) allowed one equation to be developed for each response variable (ED_c and ED_h) to predict the energy performance of every single building that make up the neighbourhood. Figure 2 graphically describes the covariates and the four prediction equations. INLA allowed a sensitivity analysis to be done and the level of the significance of the covariates to be identified in order to propose a set of passive design strategies, which implied energy savings in new urban developments.

Based on the conclusions drawn in the statistical analysis, a new urban layout is proposed, which is energy-assessed. The comparison made between the current scenario and the new one allowed the energy savings that can be achieved to be estimated by only integrating the use of passive energy strategies into urban planning. This study is presented in response to the growing need to develop comprehensive energy diagnosis tools to assist local authorities and other involved stakeholders in decision making during urban planning and regeneration processes.

2 Methodology

Drawing on the previous work described above, this study analyses the influence of the covariates (S/V, Y, UB, H/W and O) on the response variables (ED_c and ED_h). After conducting statistical modelling by INLA, every single covariate proved significant. So they all significantly influenced the energy demand of the residential stock. The order of covariates, according to level of significance, was: S/V, Y, H/W, UB and O, where Y and H/W were at the same level.

This analysis allowed a set of strategies for each covariate to be established in order to reduce the energy demand in a particular urban area. These passive energy strategies were used to propose a new urban layout as an alternative scenario to the current neighbourhood. The energy diagnosis of the new scenario allowed a comparison to be made with the existing neighbourhood and to then make an estimate of the energy savings that can be achieved when integrating energy efficiency criteria into urban planning design. Figure 3 presents the methodology followed in this study.

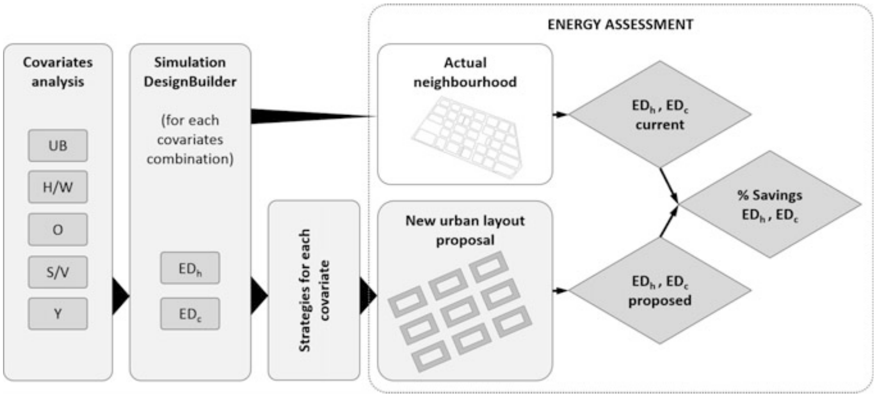

Fig. 3 Methodology

3 Analysis of Covariates

This section presents the covariates analysis results. Figure 4 offers the variation of energy demand for heating and cooling depending on each covariate. From the conclusions obtained, an array of urban design strategies is set to be applied to urban planning designs. The covariates analysis is detailed in the following sections by level of significance of the covariates.

3.1 Shape Factor (S/V)

The shape factor is the most significant covariate. The values adopted in the case study were 0.26, 0.30 and 0.40, which corresponded to the three building typologies found in the neighbourhood. It is observed that compact buildings, which mean lower S/V, have better energy performance for heating, but perform worse for cooling. However, the winter energy demand greatly exceeds the summer one; thus, lower S/V values are more convenient from the energy performance point of view.

3.2 Year of Construction (Y)

Secondly we found Y. In this case, year of construction is linked to the thermal transmittance (U-values) of the building thermal envelope since thermal characteristics, and whether thermal insulation is included or not, affect energy demands. In turn, envelope assemblies depend on year of construction. So five temporal periods were established and a set of envelope assemblies were assigned to each one for façade, dividing walls, roof, ground floor, windows and thermal bridges. These temporal periods included the buildings constructed in: before 1940, 1940–1959, 1960–1979, 1980–2006, and after 2006.

The results for Y showed that a general trend exists in reducing ED_h in recent buildings. Only a change in trend was observed in the buildings constructed during period 3 (1960–1979) when poorer quality construction techniques were employed. A general trend in increasing ED_c was seen in more recent buildings, which responded to loss of thermal inertia in building envelope elements.

3.3 Street Height-Width Ratio (H/W)

Street height-width ratio (H/W) defines the street proportion and is responsible for solar accessibility on the building's façade. According to the City Urban Plan of the neighbourhood under study, eight floors above the ground level are allowed and

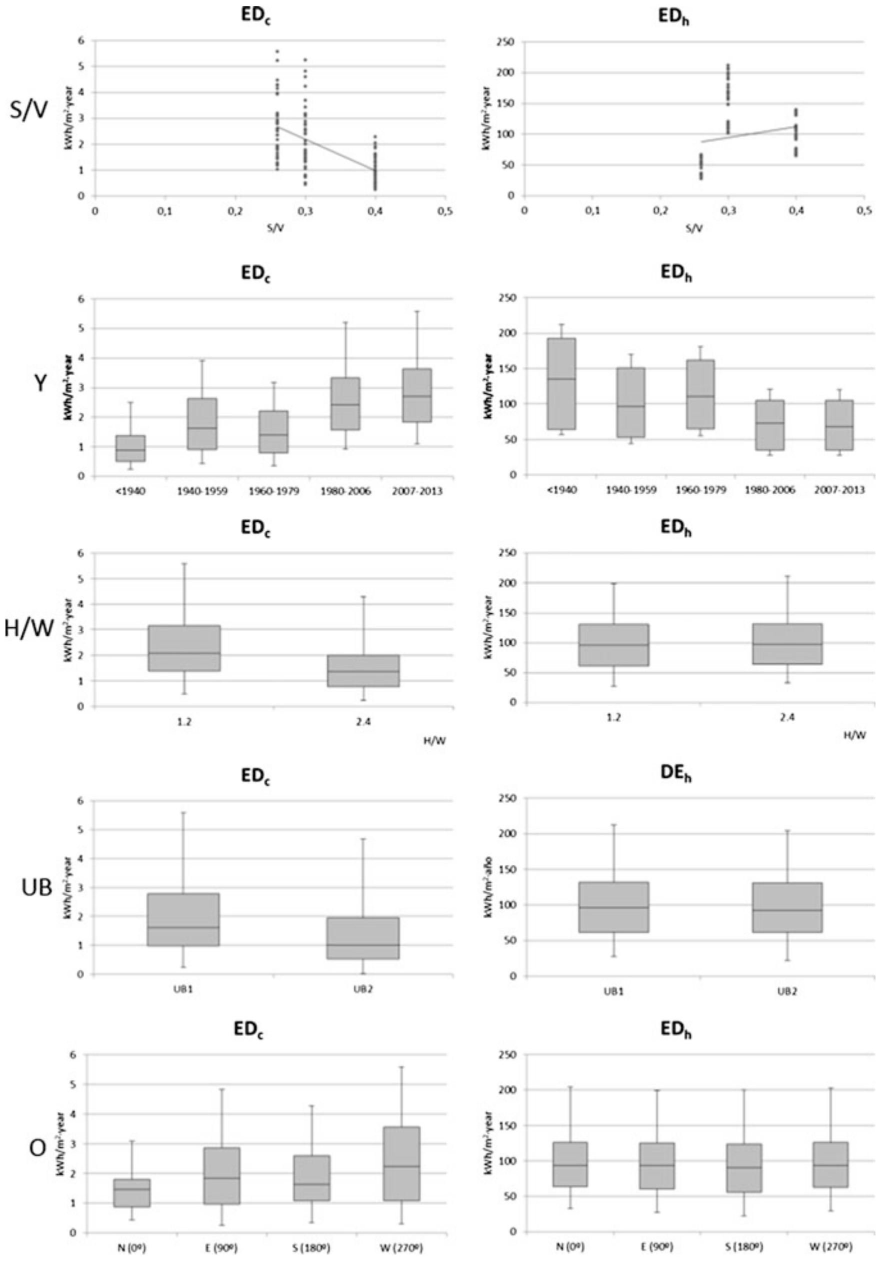

Fig. 4 Response variables results according to each covariate

two street widths were identified; 10 and 20 m. This results in two values for H/W, 2.4 in narrower streets and 1.2 in wider streets. The energy simulation results show that higher H/W ratios implied higher ED_h since narrow streets with high buildings limit solar accessibility. However, higher H/W ratios help decreasing ED_c.

In order to determine optimum H/W ratios, it was considered that an element had solar accessibility if it received at least 2 h of beam radiation during the winter solstice (Higueras 2006). Therefore for the latitude of Castellón de la Plana (39.98°) during the winter solstice (solar elevation 26.61°, at 12:00 p.m.), the H/W ratio should be 0.50 (Braulio-Gonzalo 2016), which implies that street width (W) must be more than twice the building height (H).

3.4 Urban Block (UB)

Two urban blocks are identified in the neighbourhood under study. UB1 has a big internal courtyard that allows solar gains on the south, east and west façades of buildings, with an inward orientation towards the courtyard. UB1 proves more favourable in the energy performance of buildings as it helps reduce ED_h, which is notably higher than ED_c. In contrast, UB2 does not have a big courtyard, but smaller light wells that act as internal building elements. It is observed that ED_c is lower in UB2 and that ED_h is almost the same in both blocks. The fact that UB1 has a big courtyard allows two opposite orientations on the building's façade, that confer passive solar gains benefits.

3.5 Orientation (O)

This covariate is the least significant of the model. It is motivated by the influence of the urban layout in the energy demand of buildings, which modifies the natural behaviour pattern of orientation. In the case study, UB1 provides two orientations to the building (street main façade and light wells façade). Therefore, little variation between data pairs S-N and E-O is observed. In UB2, the buildings have only one main façade (to the street), so the variability in ED_c among the four solar orientations is notable.

The streets with an N-S axis generate east- and west-oriented façades, which receive solar gains in the morning and the evening, respectively. But this option impedes façades having solar gains during central day hours, when a better benefit can be obtained. The streets with an E-W axis generate north- and south-oriented façades. An S façade is optimum in winter and is also quite favourable in summer as it does not yield high ED_c values and is easier to protect from extra sunlight than E and W façades. Therefore, an N-S orientation is the most favourable for façades. Nevertheless, Higueras (2006) and Olgyay (1963) suggest slightly rotating the façade towards an E orientation, which is considered ideal for temperate zones because solar gains are more beneficial in the morning, with lower temperatures than in the afternoon in W.

3.6 Design Strategies for Reducing Energy Demand

The above-conducted analysis for each covariate allows a set of suggestions for the urban planning design to be established for latitudes near 40° in the northern hemisphere. These are detailed below.

- **S/V**: Lower S/V values (more compact buildings).
- **Y**: Envelope assemblies with lower thermal transmittance values (U-values).
- **H/W**: The optimum value is 0.50.
- **UB**: The urban block shape should be rectangular [with length >1.5 width (Olgyay 1963)] and its longitudinal axis should be developed in an E-W orientation. Accordingly, most of the façade surface would be south-oriented. UB1 is the most appropriate because it allows two opposite façades to be oriented N-S.
- **O**: It has been suggested to orient the street axis in an E-O direction so that the streets shape is a rectangular grid with most building façades oriented to N and S. Buildings should be designed so they have two opposite façades, S-N or E-W. The orientation of the main façade of buildings to SE (with an azimuth angle of 18°) is, a priori, better than perfect S (azimuth 0°), but it should be verified experimentally. This influences covariate H/W because orienting the grid towards SE helps lower the W value, which leads to more compact urban structures. Thus in grids oriented to 18°E, H/W can be 0.53.

4 New Urban Layout Proposal

Following these criteria, we explored the optimum urban block by analysing the effect of dimensions and proportions. Each strategy should be applied in a logical order of the urban planning design from the urban scale to the building. The procedure to be followed is shown in Fig. 5.

Having identified UB1 as the most suitable, the parameter that conditions its dimensions is the maximum height of buildings provided by the City Urban Plan. In order to shape an urban block with an inner courtyard, which ensures sunlight on the S façades of buildings, the H/W ratio should c. However, considering the eight floors above ground level, set out in the City Urban Plan, would imply excessively big blocks. For this reason, it is proposed herein to reduce the maximum number of floors to six. This results in a street width of 28.30 m, which is more coherent with the actual urban layout in the city. The new urban layout is presented graphically in

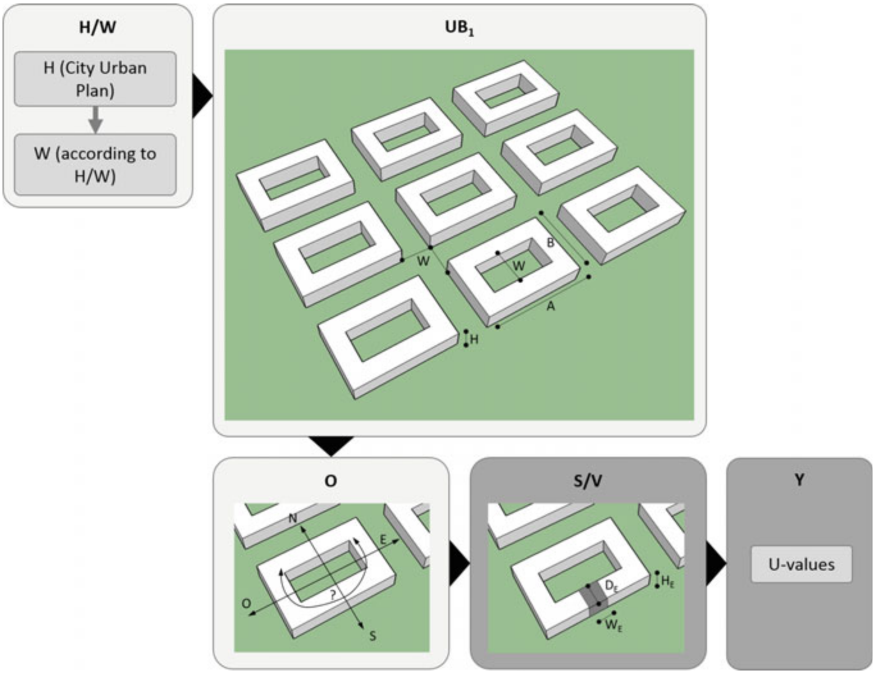

Fig. 5 Procedure for defining the new urban layout

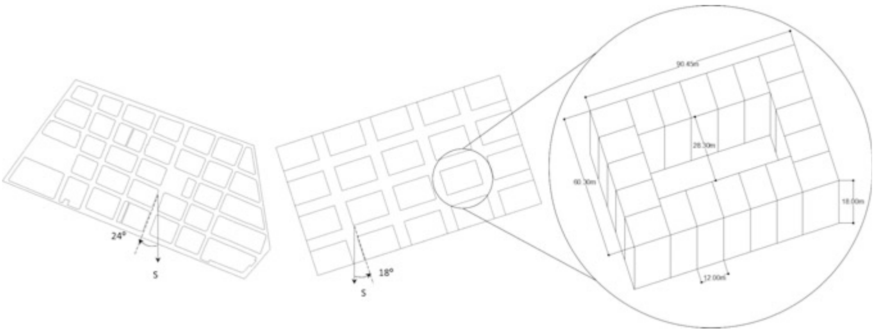

Fig. 6 Current neighbourhood planning (*left*) and new planning proposal (*right*)

Fig. 6. This can be considered when designing urban layouts in new urban developments.

At this point, new energy simulations were conducted to assess the energy performance of the buildings that would make up the new urban proposal. A multi-family building with low $S/V_{0.26}$ in UB1, $H/W_{0.53}$ and with building envelope assemblies from temporal period 5 (Year), in 24 possible solar

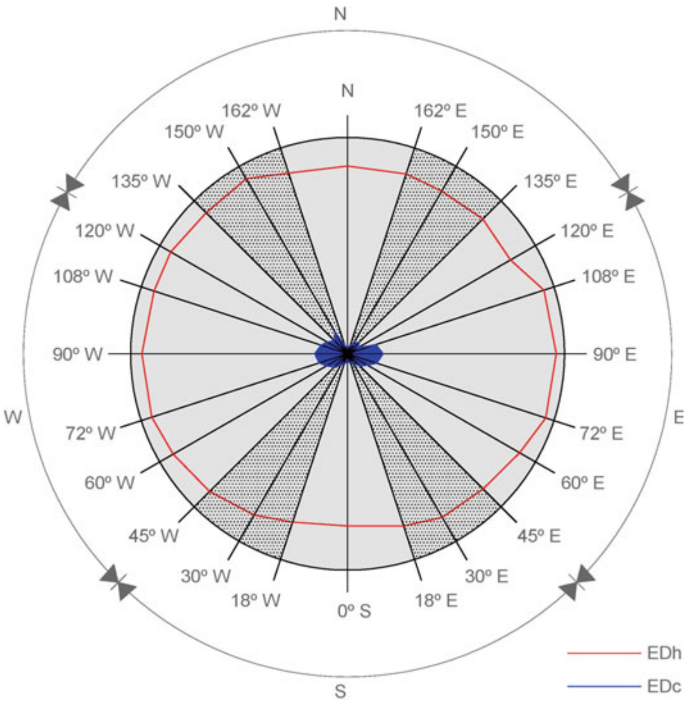

Fig. 7 Relationship between ED and orientation: optimum orientation

Table 1 Comparison between the existing layout and the new proposal (Braulio-Gonzalo 2016)

	Existing	New proposal	Variation %
Built area (m^2)	313,301.00	275,849.40	−11.95
ED_c (MWh/Year)	523.53	1073.88	205.13
ED_h (MWh/Year)	29,354.89	11,739.32	−60.01
ED_G^a (MWh/Year)	29,878.42	12,813.20	−57.12

[a] ED_G Global energy demand

orientations (O), was energy modelled. The results for ED_c and ED_h are shown in Fig. 7, which allow the optimum solar orientation to be identified. This optimum fell within a range of orientations between 18°E and 45°E, which yielded opposite façades between 135°W and 162°W. With these angles, lower ED_h, values are recorded and ED_c values are acceptable. The symmetric range (between 18°O and 45°O) could also be favourable, but the solar radiation in the morning is more beneficial than in the afternoon because of higher temperatures.

Table 1 presents the comparative results for ED_h, and ED_c between the existing neighbourhood and the new urban layout proposal.

The energy assessment of both scenarios allowed the energy demand for heating to be reduced by 60.01% to be estimated. The energy demand for cooling, however, significantly increased by 205.13%. In the existing neighbourhood, narrow streets in summer impede sunlight to reach building façades, which results in low energy demand for cooling. Yet narrow streets imply a notable increase in energy demand for heating. For this reason, the increase in ED_c compensates the more marked reduction in ED_h (60.01%), which is responsible for most of the global energy demand in the neighbourhood. The results of assessing both scenarios reveal that a reduction of 57.12% in the global energy demand for both heating and cooling can be achieved by implementing the new urban planning design, which implies considering only geometrical aspects. Therefore, the importance of urban morphology in the energy performance of building stocks has been demonstrated.

5 Conclusions

This work analyses the influence of urban and building parameters on the energy performance of residential stocks by taking into account energy demand. Based on a previous work done that analysed the energy demand in a neighbourhood in Castellón de la Plana with a statistical prediction model, this work identifies a set of passive design strategies which aim to reduce energy demand. These allow a new urban layout to be proposed, whose energy assessment outlines that important energy savings can be achieved (57.12%) by considering only passive urban and building design aspects.

The results of the analysis stressed that building-related aspects [shape factor (S/V) and year of construction (Y)] are the most influential for reducing energy demand. However, urban environment-related aspects should not be overlooked since they also notably affect the energy performance of the residential stock. In particular, H/W has the same level of significance as Y as it conditions solar gain possibilities in buildings, which greatly influence energy demand for heating and cooling. The urban block shape (UB), depending on it having a courtyard or not, also affects energy performance. Finally, O is the least significant covariate as its behaviour is strongly related to the other urban covariates (H/W and UB).

This study, which forms part of a wider methodology to assess the passive energy performance of residential building stocks, is a decision-making tool for local administrations when taking part in urban development interventions and regeneration projects. As acting on existing urban layouts is a complex process, it is crucial to provide tools that enable energy diagnoses to be made for exploring energy saving measures in existing stocks and their savings potential. Thus local administrations play a key role in integrating energy efficiency criteria into the City Urban Plan and also in prioritising retrofit actions, which have already been covered by Law 3R: urban rehabilitation, regeneration and renovation (Gobierno de España 2013). The integration of passive design criteria into urban planning in order to improve the energy efficiency of residential stocks is a key issue to achieve the energy savings targets set internationally to be met in the near future.

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