Buildings performance indicators to prioritise multi-family housing renovations

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ABSTRACT

Paying attention to the constructed city and renovating buildings are two objectives of current European policies. This article develops a system of physical performance indicators to detect multi-family housing estates that perform worse in energy efficiency, airborne sound insulation against outside noise and accessibility terms. Indicators were developed in close cooperation with the local Administration for residential estates and on a district scale, and allowed the buildings in worse conditions to be detected. The results are graphically represented on urban plans. Indicators are presented by a case study of social housing states in the city of Zaragoza for the 1939-1979 period.

KEYWORDS: Indicators; major renovation; social housing; performance indicators

1. INTRODUCTION

Paying attention to the constructed city is one of the objectives of current European initiatives; e.g., the 2007 Leipzig Charter on Sustainable European Cities, the 2010 Toledo Charter on Urban Development and the European 2020 initiative. They take Integrated Urban Regeneration as a strategic instrument to obtain a smarter, more sustainable and more socially inclusive urban model in already consolidated urban fabrics (UE, 2010), and the district scale has been identified as a suitable consideration (Bourdic, Salat, & Nowacki, 2012). In Europe the Commission urges Partners to mobilise investments in renovating the existing building stock (European Parliament, 2012). Moreover, some Member States, like Spain, urge the Administration to obtain and update maps and censuses of degraded zones or buildings that need to be restored which offer information for their policy making (Jefatura del Estado, 2013). Thus we can say that making information available about diagnosing the existing building park to the European Union and the Public Administrations is important.

Until 2010, in the city of Zaragoza in Spain, non-repayable subsidies for buildings renovation were granted only to families with low income living in previously identified quarters, whereas from 2010 on they are being granted to all kinds of families living in the whole city since the aim is not only supporting vulnerable population but also promoting the move to a low-carbon economy by means of encouraging the renovation of the existing building stock (López-Mesa, Rubio del Val, & J., 2015). The same is happening in the rest of Spain, where Zaragoza is considered one of the pioneer cities in renovation policies implementation. This may explain why in Spain vulnerability indicators have had a considerable development and a strong impact in political decision making, whereas buildings performance indicators are not being widely used yet. The Urban Vulnerability Atlas in Spain (Ministry of Public Works, 2012) constitutes an example of vulnerability indicators. It is included in the Observatory of Urban Vulnerability, a long-term project of the Spanish Ministry of Public Works that contains several studies about Urban Vulnerability. This graphical Atlas allows synthetic indices to be obtained for urban areas of the whole of Spain according to socio-demographic, socio-economic, residential and subjective criteria. They allow to measure the vulnerability of urban areas at the census section scale, as they are obtained from Population Census statistics, the only source of extensive and nationally homogeneous data, with sufficient disaggregation –the Census Section- (Ministry of Public Works, 1996).

The monetary budget of Public Administrations is generally limited and a prioritisation criterion is needed to optimise its allocation in multifamily housing renovations (Ferrante et al., 2017). The vulnerability criterion (which consideres socio-economic aspects) cannot be the only one to be applied now that European cities aim to move to a low-carbon economy. The objective of this article is to develop a system of indicators, complementary to the vulnerability ones, to diagnose how needy residential estates are for renovation according to their degree of performance, which are to be graphically represented on maps. The indicators will allow users to intuitively and visually know and compare the level of renovation need of multi-family housing of cities, supporting administrations in the decision making regarding which buildings require more urgent renovations contributing to reduce the impact of the existing residential sector in the environment.

2. STATE OF THE ART OF ENVIRONMENTAL INDICATORS

An indicator is a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon, with a meaning that goes beyond that associated with the value of the parameter (OECD, 1993). Indicators summarise a situation and are developed for specific aims. They are manageable units of information, and help to describe complex processes as they contain a vast quantity of synthesised data. They also act as a guide for decision making. Indicators can measure and calibrate progress towards a goal, and can provide an early warning to avoid economic, social or environmental setbacks (United Nations, 2007). An index is the quantitative aggregation of several indicators that can provide a simplified, coherent and multidimensional vision of a given system (Mayer, 2008).

The first environmental indicators emerged as a response to growing social awareness about environmental aspects, when in the United Nations Conference on Environment and Development held in 1992 in Rio there was a call for countries to develop indicators for sustainable development (Hass & Palm, 2013) The publication "Indicators of Sustainable Development: Guidelines and Methodologies" (CSD, 2001) developed by the United Nations Commission on Sustainable Development (CSD) is considered the starting point for the national development of environmental indicators.

The challenge for urban authorities is deciding which tool best addresses their needs, which would be easy to implement and which are worth the financial and human effort (European Union, 2015). In some cases, a city may want to join an established global programme of indicators. In other occasions, a city may make a selection of types of indicators to develop according to their priorities, and explore the existing tools to apply them to their own case. In this paper, we work from this second perspective.

There are different models to organise sets of environmental indicators. The most complete scheme is the DPSIR, with five categories of indicators, one for each letter. According to this framework, there is a chain of causal links starting with driving forces (D) (economic sectors, human activities), through pressures (P) (emissions, waste), to states (S) (physical, chemical and biological) and impacts on ecosystems, human health and functions (I), eventually leading to political responses (R) (prioritisation, target setting, indicators).

The DPSIR model is an extension of the PSR model (Pressure-State-Response), both developed by Anthony Friend since the 1970s and adopted in the State of the Environment (SoE) reports of the Organisation for Economic Co-operation and Development (OECD) as a tool for environmental management (OECD, 2003).

3. METHODOLOGY

Sustainability indicators for cities must be selected based on a clear understanding of the requirements in the place where they are to be applied (Shen et al., 2011). The methodology used for this study faithfully follows this principle and is composed of the next steps:

1. Identification of the need for indicators development from the experience of the Local Administration.
2. Definition of the type of indicators to be developed in collaboration with the Local Administration.
3. Indicators development based on the literature, regulations, and the available software.
4. Indicators validation with the local Administration.

Step 1: In 2011, the University of Zaragoza and the Zaragoza Municipal Housing Company (ZMHC) signed a collaboration agreement that led to the creation of the Cátedra Zaragoza Vivienda, whose main goal is to develop co-operation between the University and the ZMHC, with the aim to promote advanced research in the field of housing renovation, allowing an adequate evolution and integration of the academic and the business worlds (Tejedor & Lopez-Mesa, 2015) . This agreement has been running from 2011 until now and is expected to continue. The interaction facilitated by this agreement, mainly during 2012, between the Housing Renovation department of ZMHC and the director of the Cátedra Zaragoza Vivienda, the second author of this paper, allowed to identify the need of developing buildings performance indicators, that used in combination with the then already developed vulnerability indicators could be used to prioritise the most needy buildings. The contact with the responsibility department is a key element in the process of developing sustainability indicators (Zhou, Shen, Song, & Zhang, 2015).

Step 2: During 2013, the head of the Housing Renovation department of ZMHC and a team from the University of Zaragoza, defined the types of indicators that should be developed, by means of analysing the own experience in the city of Zaragoza, and reviewing the national literature regarding sustainability indicators. The results from this study were published in a conference paper signed by authors from both sides, the Municipal Company and the University (López-Mesa et al., 2013).

Step 3: The second author of the paper got funding from the National Ministry of Economy and Competitiveness for the development of the indicators by means of a research project of four years of duration starting in 2013, within which a doctoral thesis has been developed by the first author of the paper and directed by the second one.

As case study we selected the set of multi-family social housing estates, designed and built between 1939 and 1979 in Zaragoza, which were promoted by public and/or non-profit institutions to produce economic houses, which are now characterised by their high-density buildings, poor-quality constructions, and a public area of low environmental quality that has undergone selective population loss (Ruiz Palomeque & Rubio del Val, 2006). They form part of vulnerable areas, and are one of the typologies that use the most heating energy in Spain (Cuchí & Sweatman, 2011). This particular time period was chosen for this study as the Spanish Civil War ended in 1939 and the first Spanish national law with energy-saving objectives in buildings was approved in 1979. They are composed of 19 residential estates with 228 buildings and 7981 dwellings. Most of the buildings present brick-bearing walls without thermal insulation and sloping two-sided pitched roofs with a horizontal resistant floor and a ventilated air chamber, or four-sided hipped roofs with an inclined slab. Only some of the buildings, built at the end of the studied period, present structures of pillars with the corresponding thinning of the façade and flat roofs. There specific construction characteristics and obsolescence with respect to the current regulations are described in (Kurtz, Monzón, & López-Mesa, 2015a).

The methodology to define and obtain performance indicators consists in: a) revising the international literature regarding buildings performance indicators; and b) Defining and developing the indicators by means of: i) revising available regulations, information and software to study their applicability for the development of indicators; ii) proposing indicators and developing them for the 19 residential estates; iii) defining levels and their graphical representation for the 19 residential estates. Levels are created as self-references as we are interested in comparing them for public decision-making purposes.

Step 4: The proposed indicators were presented to the ZMHC in 2017. However, how they can be put into practice is a matter of current discussion.

Next, we present the results from steps 2 and 3. Step 4 is included in the discussion and conclusions section.

4. DEFINITION OF THE TYPE OF INDICATORS TO DEVELOP

Once the ZMHC and the director of the Cátedra Zaragoza Vivienda had agreed on the interest of developing building performance indicators that could complement the socio-economic or vulnerability indicators in order to consider the importance of moving towards a low-carbon economy, discussions focused on what aspects of building performance should be included.

In order to promote the move to a low-carbon economy, the ZMHC had been supporting the development of a multi-disciplinary study about 21 residential estates (two with single-family houses and 19 with multi-family houses) between 2004 and 2006 (Ruiz Palomeque & Rubio del Val, 2006), and had promoted pilot renovation projects in 5 buildings of the old housing estates of Zaragoza between 2007 and 2010 with excellent results (Sustainable Buildings Challenge. Helsinki 2011, 2011). Improving energy efficiency and accessibility ~~are~~ had been priorities in the major renovation works underway in these pilot studies. As part of energy efficiency, more importance was being attached to cutting energy demands given the vulnerability of users who are to a larger extent than in the rest of the city ~~may be~~ affected by energy poverty (Ruiz Palomeque & Rubio del Val, 2006). The user's behavior has influence on the energy consumption of a building and comfort perception (Gianfrate, Piccardo, Longo, & Giachetta, 2017), and the passive measures in energy retrofitting can obtain high energy demand savings in this type of buildings (Serrano-Jimenez, Barrios-Padura, & Molina-Huelva, 2017). For this reason, energy efficiency indicators (with a focus on cutting energy demands) and accessibility indicators were selected for development for our work. The ZMHC expressed the need of diagnosing the energy efficiency and accessibility levels of the buildings of the 19 residential estates with multi-family housing in a systematic way.

Additionaly, the ZMHC and the authors agreed that even if airborne sound insulation against outside noise was not among the main objectives ~~of~~ in these pilot projects, major renovation is considered an excellent opportunity to improve this aspect because while improving the building's envelope to reduce energy demands, measures can be taken to improve airborne sound insulation against outside noise at no further cost or at low cost. Thus for investments to become more profitable, it was considered that renovation works promoted by Public Administrations should prioritise those housing estates and buildings with worse behaviour regarding energy demand, accessibility and airborne sound insulation against outside noise. Hence we consider useful if they worked with mappable indicators on maps which, according to the budget available at any given time, allow the identification of the housing estates that most urgently require regeneration given their level of physical and socio-economic vulnerability and, among them, the buildings that most need renovation.

Stability indicators were also considered for inclusion but they were discarded for this particular study because among the 21 residential estates no buildings presented stability pathologies.

Fitness for human habitation indicators relating to minimum dimensions in housing were also discarded for this study because the renovation works undertaken in Zaragoza are meant for the common elements of buildings and not for the interior of dwellings.

A state-of-the-art and a critical analysis of the existing works was done to study to what extent building performance indicators considering the selected types of indicators (energy efficiency, airborne sound insulation against outside noise, and accessibility) were being included in the already indicators systems developed in Spain (López-Mesa et al., 2013). Table 1 shows the results obtained with this study, including the starting basis of each of the initiatives, a short description of the included indicators, and the identification of the performance indicators relating to energy efficiency, airborne sound insulation and accessibility.

Indicators system, and Organisation	Starting basis	Short description of indicators	Indicators of building performance relating to energy efficiency, airborne sound insulation and accessibility
Atlas of Urban Vulnerability, by the Ministry of Public works of Spain (Ministry of Public Works, 2012)	A territory vulnerability has to do with two dimensions: a) the conditions of social and structural disadvantage to develop vital projects; and b) the perception that citizens have of the territory where they live and their social conditions, which can lead to processes of discomfort that do not correspond with objective vulnerability indicators	Organised in four main themes: - Demographic vulnerability (5 indicators relating to population ageing, households structure getting complex, foreign immigration from non-developed countries). - Socio-economic vulnerability (6 indicators relating to unemployment, job insecurity, low educational levels). - Residential vulnerability (5 indicators). - Subjective vulnerability (6 indicators). The Atlas allows the use of synthetic indices according to socio-demographic, socio-economic, residential and subjective criteria. Out of the 22 indicators, the following are considered Basic Indicators of Urban Vulnerability (IBVU): percentage of unemployed population, percentage of population without studies, and percentage of population in dwellings with no toilet. The Atlas also offers two large synthetic indices of Inequality, calculated combining the IBVU: IDS (Index of Socio-economic Inequality) and IDU (Index of Urban Inequality).	One of the residential indicators: - Percentage of households located in buildings built before 1951 (P). One of the subjective indicators: - Outside noise (S).
Diagnosis of the need for renovation of the Basque Country building stock (Tecnalia, 2011a). Developed by TECNALIA, in collaboration with the	As recognised in the report, the choice of the initial indicators was conditioned by the availability of statistical data, and for this reason the stability and energy efficiency	The study analyses 65 different indicators (4 regarding stability, 16 fitness for human habitation, 13 accessibility, 29 social vulnerability and 3 energy efficiency), referred to the different parameters of physical and socio-economic vulnerability. The 61 indicators were later on	Among the indicators: - Percentage of households without heating (P). - Percentage of buildings with no hallway accessibility and no lift (P).

Technical University of Madrid and the Polythecnic University of Valencia, for the Government of the Autonomous Community of the Basque Country	parameters had a smaller number of indicators compared to fitness for human habitation, accessibility and social vulnerability. This work was only applied to one Autonomous Community of Spain, the Basque Country.	reduced to 41 through a refinement process. From the 41 refined indicators, 10 factors were obtained using the method of main components factor analysis. These 10 factors explain 69% of the variance to identify and visualise the areas with greater or lesser physical and social vulnerability in 250 municipalities and 1.698 census tracts of the Autonomous Community of the Basque Country. These factors are, according to the factor analysis method, hypothetical variables that highlight several observable variables [15], i.e., indices that combine several simple indicators. The factors include: 1. Density. 2. Socio-economic vulnerability. 3. Vulnerability due to building state of conservation. 4. Vulnerability due to ageing. 5. Vulnerability due to poor communications and services. 6. Vulnerability due to distance to work. 7. Low occupation of dwellings. 8. Vulnerability due to immigration. 9. Vulnerability due to inefficient heating. 10. Vulnerability due to deteriorated urban environment. For the analysis of urban districts vulnerability, we can use these 10 factors or the indicators that appeared to be more relevant through the factor analysis method, which were up to 23 indicators.	- Percentage of buildings built before 1980 (P). - Percentage of buildings without natural gas services (P). - Percentage of households with individual heating (P). Among the 10 factors: - Vulnerability due to inefficient heating (S).
Indicators of Urban Quality by the Agency of Urban Ecology of Barcelona (Agency of Urban Ecology of Barcelona, 2010)	System of indicators, which aims to fit the Mediterranean city model, characterized by being compact and complex. The indicators can apply both to the to the consolidated tissues and to the new developments.	A set of 53 indicators to manage urban sustainability: - Land occupation (compactness, density) - Public space occupancy (11 indicators regarding air quality, acoustics, thermal comfort, accessibility, etc.) - Sustainable mobility (7 indicators regarding proximity to public transport networks, public road sharing, etc.) - Urban complexity (4 indicators regarding functions diversity, proximity to commercial units, or balance between activity and residence) - Urban metabolism (14 indicators regarding the use of energy resources, waste, pollution and others) - Urban biodiversity (6 on green surfaces, tree shading, land occupation, etc.) - Social cohesion (6 on ageing, social segregation, public housing or subsidised, public	No one

		facilities and accessibility to them, etc.)	

Table 1. Indicators systems to diagnose urban areas in Spain (in parentheses: P for pressure indicator, S for state indicator, and R for response indicator)

The identified energy efficiency, airborne sound insulation and accessibility indicators were also classified according to the PSR scheme. Since this scheme had been created for sustainability indicators, and we wanted to apply it to building performance indicators, we transformed the causality logic of the PSR scheme as follows:

- (Pressure) Residential buildings and their urban surroundings press both the environment and the human beings.
- (State) By doing so, they change the ecosystem (emissions, waste…) and quality of life (degree of comfort, expenses and health problems).
- (Responses) In the same way, the society responds to these changes through environmental, economic and sectorial policies.

With this framework, we classified the building performance indicators in table 1, in the three types. As can be observed, 6 out of the 8 indicators are pressure ones, and only 2 are state indicators. On the top of this, the state indicators relating to energy performance and acoustics are insufficiently precise because they are based on available statistical data. With the current availability of energy and acoustic simulation tools, we considered that these indicators could significantly be improved, and therefore we proposed the development of new and more precise state indicators as follows next.

5. PERFORMANCE INDICATORS DEVELOPMENT

When analysing the performance indicators in the international literature (US GBC, 2009b) (US GBC, 2009a) (BRE Global, 2011) (Gaffron et al., 2005)(Gaffron et al., 2008)(Charlot-Valdieu & Outrequin, 2005) (Chrysoulakis, N., Lopes, M., San José, R., Grimmond, C.S.B., Jones, M.B., Magliulo et al., 2013) (Daly & González, 2013) (Fariña Tojo & Manuel Naredo, 2010)(SMIS, 2010)(CGYM, 2010)(Seville, 2010)(BCN, 2009)(BIL, 2008), we observe that of all the sustainability indicators of the building stock, energy efficiency is the third most important indicator and pollution is present in all indices, where noise pollution is the most represented (Braulio-Gonzalo et al., 2015). Noise indicators cover the subjective perception of home dwellers, or are expressed in façade exposure terms, but they do not provide objective data about noise levels inside buildings, which depends on the level of outside noise and the airborne sound insulation of buildings. One of the novelties of this paper is the development of noise indicators considering both aspects. Energy indicators (Economidou et al., 2011) (Loga et al., 2016)(WWF España, 2010)(Dascalaki et al., 2016) are obtained from statistical data about energy use and they are all consumption-based indicators (Monzón & López-Mesa, 2017). These energy consumption-based studies have the disadvantage that, as calculations are based on proportionally sharing the official energy consumptions according to the building, envelope or installation typologies, specific residential block factors such as orientation or social factors affecting energy consumption are ignored (Monzón & López-Mesa, 2017), and therefore they do not allow the performance of residential blocks to be distinguished from others in the same urban area. One of the novelties of this paper is the development of energy demand-based indicators at the residential block scale for the diagnosis of the residential building stock.

No international literature was found regarding accessibility indicators. However, according to the 2011 Population and Housing Census, only 23% of the buildings in Spain are accessible, as almost 50% of buildings with five storeys and 65% with four have no lift (INE, 2011).

Accessibility is the best valued improvement by users of major renovation works and is, therefore, a compulsory improvement in renovating buildings towards urban regeneration. The development of this type of indicator is another novelty of the paper.

5.1. Performance indicators for lack of energy efficiency development of indicators

a) Revising regulations, literature and software:

Energy certificates, controlled in Spain by Royal Decree 235/2013 (Spanish Ministry of the Presidency, 2013), are expressed by energy labels, by means of which buildings are classified into seven levels/grades, expressed with letters that go from A (the most efficient) to G (the least efficient). Until 14 January 2016, the energy certification process allowed information to be obtained from two indicators, CO_2 emissions and primary energy use (IDAE, 2009), but only the former awarded grades (Ruá & López-Mesa, 2012). On the above date, the energy efficiency certification process for buildings changed in Spain, where information is provided by two main energy indicators (Ministry of Industry, Energy and Tourism. IDAE, 2016):

- Annual CO_2 emissions expressed as kg per m^2 of the building's usable area
- Annual primary non-renewable energy, in kWh per m^2 of the building's usable area

These two indicators are calculated from the estimated energy consumed by buildings to meet the comfort needs associated to normal climate conditions, general operation and occupancy. The current limits between energy classes for CO_2 emission and primary energy use depend on the climate zone and building typology, single-family or blocks. The official Spanish software to obtain energy demand and consumption estimates is the Unified LIDER-CALENER computer software tool (HULC). Although building's energy demand can be calculated using simulation software, an indicator must use information that is easy to obtain. The work of (Monzón & López-Mesa, 2017) presents a simplified methodology by which the heating/cooling energy demand value can be obtained if certain data about the building are known, such as its main construction characteristics, geometry and the sunlight it receives. A coefficient of performance can be applied to obtain the final energy from the heating energy demand and cooling energy demand.

Total final energy is the sum of heating energy use, cooling energy use and domestic hot water (DHW) systems energy use. To obtain the reference CO_2 emissions of residential buildings for heating, final energy has to be multiplied by a step coefficient, which depends on the energy type used. To obtain the step coefficients of final electric energy, certain factors need to be taken into account, such as production losses, distribution losses, outputs of each power station's electric production and the CO_2 emissions produced by used fuel. Likewise, some conversion factors go from final energy to primary energy, which can be renewable, non-renewable, or total. The conversion factors that go from final energy to primary energy for conventional electricity and those that go from final energy to CO_2 emissions, which were passed in January 2016 (Ministry of Industry, Energy and Tourism IDAE, 2016), are provided in Table 2 below.

Conversion factors to go from final to primary energy			Conversion factors to go from final energy to CO_2 emissions
KWh Primary renewable energy /kWh Final energy	KWh Primary non-renewable energy /kWh Final energy	KWh Total Primary energy /kWh Final energy	Kg CO_2/kWh Final energy
0.414	1.954	2.368	0.331

Table 2. Conversion factors to go from final to primary energy, and conversion factors to go from final energy to CO_2 emissions.

b) Proposal of indicators:

The performance indicators for lack of energy efficiency include:

- Heating energy demand indicator (HED)
- Heating+cooling energy demand indicator (TED)
- CO_2 emissions indicator (CO_2/year·m²) (CO_2)
- Non-renewable primary energy use indicator (NRE)

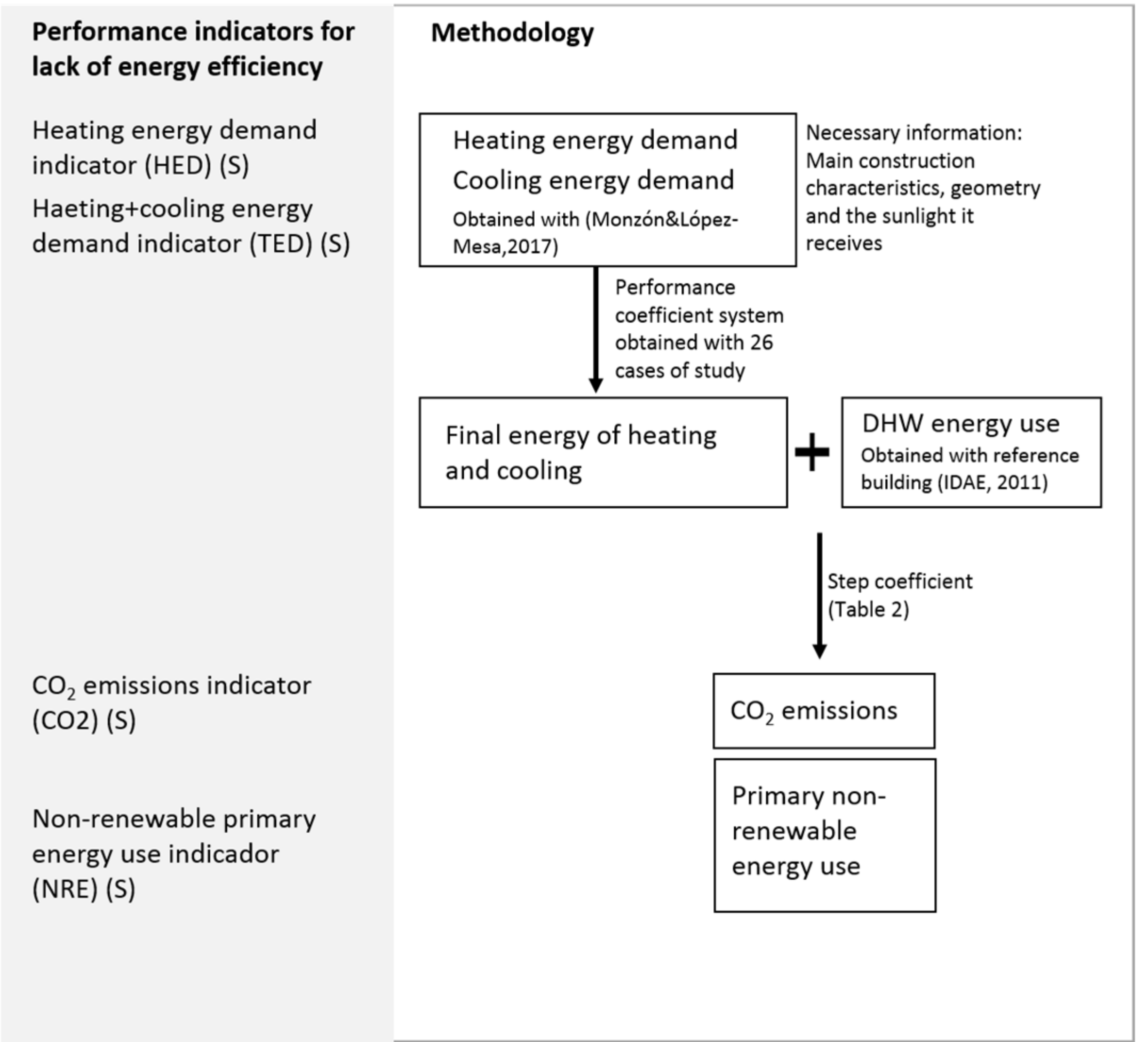

Figure 1. Performance indicators for lack of energy, methodology and necessary information. (S) State indicators.

A heating energy demand indicator was first developed to identify the housing estates that performed worse during the coldest/underheated period by the method with a confidence level of 95% described in (Monzón & López-Mesa, 2017). Later after having also obtained the cooling energy demand, a second overall climatisation demand (heating+cooling) indicator was obtained.

Then another energy grading indicator for housing estates was developed, which was obtained according to CO_2 emissions and primary non-renewable energy use according to the country's energy grading regulations. To obtain the coefficient of performance of the heating and cooling systems, 26 cases of study are simulated with HULC. Initially UEI buildings had neither climatisation nor DHW systems. No data were available about housing that had fitted heating, cooling and DHW systems over time on an individual basis. For the present study, no cooling system was included and, therefore, simulation was done with a substitution system. Given the UEI characteristics, a single-zone heating system was assigned to each space (i.e.: to each home) with electric heating equipment of nominal capacity and nominal use of 100 watts per m^2. To homogenise all the estates, a surface area of 60 m^2 was assumed for each home, and the nominal capacity and nominal use of each piece of equipment was 6 kW/home. The correction curve of use per partial load used was that provided by the programme for an electric heater of partial load use. Based on the simulations done with the 26 residential blocks in the case study, the mean performance of the heating and cooling systems was calculated to be able to apply this value to all the blocks. This allowed a relation to be established between demands and uses and obtain the mean performance with heating and cooling systems, which was applied to the other blocks was 0.98% for heating performance and 1.96% for cooling performance.

While the building's construction and geometric conditions intervene in the heating+cooling energy demand/use, this is not the case for DHW. Use of DHW only depends on demand in quantity terms (in litres) and on the system that produces DHW in each home. Thus to be able to estimate the energy grading of blocks, each block must take the DHW energy demand of the reference building (IDAE, 2011).

When these performance values were applied to the calculated demands, the heating and cooling energy uses were obtained. Total energy use was obtained by summing this quantity and the DHW energy use, which was obtained from dividing the reference demand of 12.9 kWh/m^2 between the performance of an assumed individual equipment that produced electricity, estimated at 90%. To this obtained final energy use, the step coefficients shown in Table 2 were applied, and the CO_2 emissions and primary non-renewable energy use values were obtained, by means of which we obtained the energy grading for blocks according to the official grading system.

c) Defining levels and graphical representation

The values obtained in the HED and TED indicators were divided into three self-reference groups by considering the obtained higher and lower energy demand values, which provided three self-reference levels (Figure 2). Each level was represented by a colour: red indicated higher physical obsolescence and, therefore, its priority to be regenerated was higher; yellow denoted lower physical obsolescence.

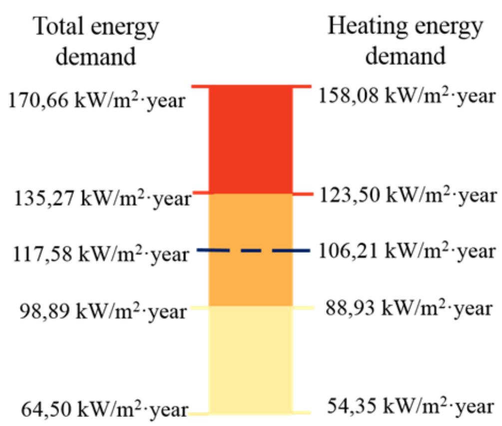

Figure 2. Classification scale and limits

Indicators CO_2 and NRE were classified into levels according to the limits set by regulations, and are represented in Figure 3. Colours were determined by those that State organisations select to represent them.

Figure 3. Limits of energy grading classes for primary non-renewable energy use (right) and CO_2 emissions (left).

The obtained levels represented by colours were graphically represented on an urban map showing the UEIs (Figure 4). This allowed the physical obsolescence state of the residential blocks to be visually and intuitively known. We can see how energy performance can vary from one block to the next in all the blocks with the same age and building characteristics.

5.2. Performance indicators for lack of airborne sound insulation against outside noise

a) Revising regulations, literature and software:

Spanish regulations on noise conditions in buildings, this being the Basic Document on protection against noise in the Technical Building code (CTE, in Spanish) (DB HR CTE), is currently applicable only to the construction of new buildings. However, it can act as a guide for the levels considered suitable to undertake daily living tasks without being bothered by outside noise. This regulation guides demands according to the global insulation provided by the rooms as a whole in relation to outside noise, where the façade plays an important role, but sound being indirectly transmitted through flanking elements is also influential. The employed index was $D_{2m,nt,Atr}$ – standard levels difference, weighted A, for traffic noise–, which depends mainly on the interior dimensions of the room, and on the building solutions on the façade and the opening. In order to learn the sound performance of a building in relation to outside noise, it is necessary to calculate the $D_{2m,nt,Atr}$ of all its rooms, which implies much time-consuming work that is considered inappropriate for the development of indicators. On the top of this, we already know that no building within the studied residential states would comply with current regulations due to the poor acoustic behaviour of their openings. For this reason, what results interesting is checking the potential behaviour of the building as if the openings were renovated.

Figure 4. Graphical representation of the performance indicators for lack of energy efficiency for the residential states Andrea Casamayor, Casta Álvarez and Balsas de Ebro Viejo.

Sound insulation of a room in relation to another room, or of a room in relation to outside noise, is determined as frequency bands (one-third octave or one-octave bands), which are used to obtain an overall index. Outside noise also has a low-frequency component caused by traffic, which must be considered in the sound insulation of façades. Therefore, standard UNE EN ISO 717-1 proposes spectral adaptation terms -C, C_{tr}- that are applied to the global R_w and D_w when the predominant sound is pink or traffic, respectively (AENOR, 2013). Spectral adaptation term C_{tr} is the value in decibels, which must be added to the overall magnitude value to consider the characteristics of a spectrum of a particular noise, which is traffic noise in this case (AENOR, 1999) (AENOR, 2013). The magnitudes employed in the Spanish Basic Document on protection against noise (DB HR), sound reduction index, weighted A, for outside noise predominantly caused by vehicles (R_{Atr}), and the standardised level difference, weighted A, on façades, roofs and floors in contact with the outside air for vehicle noise ($D_{2m,nT,Atr}$), include the adaptation to the spectrum standardised to traffic noise.

For the calculations of airborne sound insulation against outside noise with DB HR the reference curves of traffic noise are used because the dominant outside noise is traffic noise. Therefore, the magnitude $D_{2m,nT,Atr}$, is used:

$$D_{2m,nT,Atr} = -10 \log \sum_{i=1}^{n} 10^{(LAtr,i-D2m,nT,i)/10}$$

where $D_{2m,nT,i}$ is the difference in the standard levels in frequency band i (dB), $L_{Atr,i}$ is the standardised spectrum level of traffic noise, weighted A, in frequency band i (dBA), and i, which covers all the one-third octave frequency bands from 100 Hz to 5 kHz (Spanish Ministry of Public Works, 2009).

b) Proposal of indicators:

We assume that performance indicators for airborne sound insulation must provide objective information about the sound disturbances in homes caused by outside noise. Two kinds of indicators are proposed: explanatory and synthetic.

- Explanatory indicators: indicator of the medium noise level with an impact on façades (MN) and an indicator of the maximum noise with an impact on façades (MxN).
- Synthetic indicators: percentage of the rooms of a building that would achieve the levels of airborne sound insulation against outside noise demanded by the CTE by simply amending the façade opening (WN).

Kind of indicator	Indicator	Necessary information
Explanatory indicators	indicator of the medium noise level with an impact on façades (MN) (S)	Noise map Length and heights of blocks
	indicator of the maximum noise with an impact on façades (MxN) (S)	Noise map Length and heights of blocks
Synthetic indicators	percentage of the rooms of a building that would achieve the levels of airborne sound insulation against outside noise demanded by the CTE by simply amending the façade opening (WN) (S).	Noise map The noise reduction indices RA and RA,tr of the direct/indirect transmission elements Geometry and use of the dwelling rooms

Table 3. Proposal of performance indicators for lack of airborne sound insulation against outside noise, and its necessary information. (S) State indicators.

Explanatory indicators provide information about the noise level to which a building's façades are exposed. Two indicators within this type are proposed: one that provides information about the maximum noise level with an impact on façades and another on the medium noise level with an impact on façades. The intention of synthetic indicators is to objectively provide information about noise disturbances inside homes. Increasing the airborne sound insulation of façades will reduce the levels of sound inside homes, but will not stop the high noise levels on façades. For this reason, both indicators are considered necessary and complementary.

An indicator of the mean noise level with an impact on façades is obtained by firstly calculating the percentage of façade on a block scale, exposed to each noise level, using the noise map of the city of Zaragoza (Mapa Estratégico de Ruido y Plan de Acción contra el ruido 2009-2015, 2009). After obtaining the fraction of the façade exposed to each noise level, it is multiplied by the number of building storeys and floor-to-floor height on the ground level of the built storeys. If the same block has different heights on distinct storeys, the mean value is applied. The relation between the area exposed to each noise level between the total façade surface area will indicate the percentage of façade exposed to each noise level. Information about lengths and heights was obtained from original projects and from the Cadastre. Finally, the average outside noise value was obtained by weighting the surface exposed to each noise level.

Several blocks are placed in such a way that one of their façades is exposed to a high noise level, but the opposite one is quieter. The mean resulting value is similar to a block with all its façades exposed to a medium noise level, but in the first case, some homes or parts support very high noise levels, a situation that the indicator of the maximum noise with an impact on façades reflect.

One of the façades of some blocks of UEIs face a quieter outside area, which can be considered a positive aspect (El Parlamento Europeo y el Consejo de la Unión Europea, 2002). However, the home's interior configuration is a somewhat determinant factor for the noise disturbances that occur inside. Many of these homes are dwellings that allow cross ventilation, for which one of the façades contains protected rooms, like living rooms and bedrooms, while another façade contains the kitchen and bathroom. In this case the position of the quiet outside area is a determinant factor because, if it coincides with the façade with the two rooms with water supply, its practicality would be null.

Calculating airborne sound insulation against outside noise of all the protected rooms of all the blocks of UEIs is an arduous and unnecessary task. An indicator needs data that can be acquired quite easily and their input should be significant. Therefore, one room type in each block was assumed and the fulfilment of the airborne sound insulation levels of this room was evaluated. The chosen rooms were the secondary bedrooms in the homes because the smaller size of the receiving room, the lower the achieved insulation levels.

In most sound-proofing renovations done because of noise that comes from outside, the problem is solved by substituting the opening or by fitting a double window because the opening is generally the weakest element in airborne sound insulation terms, unless the opaque part is extremely light and the building is located in an area with high levels of outside noise (Instituto de Ciencias de la Construcción Eduardo Torroja, 2014). Accordingly, developing an indicator was proposed to provide information about the percentage of rooms that met the airborne sound insulation levels expected by the CTE by simply renovating the façade opening. airborne sound insulation was calculated by index $D_{2m,nt,Atr}$, with the General Option of the CTE regulation, using the selected rooms in each block, and by assuming that a double sliding window was fitted in front of the original/existing one. The General Option Tool is based on the simplified method set out in Section 4.4 of Standard UNE-EN 12354-1 (Sobreira Seoane, Rodríguez Molares, Romero Fernández, Carrascal García, & Tenorio Ríos, 2008). In order to introduce construction elements and solutions, those indicated in a previous study were used (Kurtz, Monzón, & López-Mesa, 2015b).

The insulation levels expected in DB HR are more restrictive for bedrooms than for living rooms. To stay on the side of security and to simplify, and as these old homes may have transformed living rooms in bedrooms, we set an airborne sound insulation requirement for all the rooms equivalent to that for bedrooms. In this way the airborne sound insulation levels inside the homes' protected rooms depended on the L_d outside daytime noise index (see Table ~~3~~4).

L_d (dBA)	$D_{2m,nT,Atr}$ expected between a bedroom of residential use and the outside
$L_d \leq 60$	30
$60 < L_d \leq 65$	32
$65 < L_d \leq 70$	37
$70 < L_d \leq 75$	42
$L_d > 75$	47

Table 4 Values of $D_{2m,nT,Atr}$, in dBA, between a bedroom and the outside according to the Ld daytime noise index, obtained from DB HR

The noise reduction indices R_A and $R_{A,tr}$ of the direct/indirect transmission elements used in calculations are summarised in Table 3. The drawings and composition of façades F1-F15 and roofs C1-C9 (Table 5) can be found in (Kurtz et al., 2015b).

Façade	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
$R_{A,tr}$ (dBA)	64	60	48	61	61	57	57	56	56	44	59	46	45	46	39
Roof	C1	C2	C3	C4	C5	C6	C7	C8	C9	Roof	C1	C2	C3	C4	C5
$R_{A,tr}$ (dBA)	31-59	60	59	50-64	65	50-64	54	52-68	50-63	$R_{A,tr}$ (dBA)	31-59	60	59	50-64	65

Flanking element			
Slabs	Code	R_A (dBA)	M (kg/m^2)
25-cm thick one-way spanning slab with ceramic beam filling*	Fc	54	305
15-cm thick one-way spanning slab with ceramic beam filling, plus a 4-cm compressing layer, a 4-cm levelling layer and a 2-cm terrazzo layer**	Fbc	51.9	300
25-cm thick one-way spanning slab with precast concrete beam-filling*	Fh	55	332
15-cm thick one-way spanning slab with precast concrete beam-filling, plus a 4-cm compressing layer, a 4-cm levelling layer and a 2-cm terrazzo layer**	Fbh	53.9	340
25-cm thick one-way spanning slab without beam filling*	Fs	51	289

Partition walls			
7-cm hollow brick partition wall plastered on both sides*	T7	36	89
4-cm hollow brick partition wall plastered on both sides**	T4	33.7	77

Table 5. The sound-reducing indices R_A and $R_{A,tr}$ of the direct/indirect transmission elements used in the calculations. *(CSIC, 2010) **(Moreno & Peña, 2002)

The heterogeneity of the windows of UEIs has been studied in (Kurtz et al., 2015b). In order to simplify, all the windows were taken as the original wooden ones with 4-mm thick glass. A new window with these characteristics offers an R_{Atr} of 26 dBA (Instituto de Ciencias de la Construcción Eduardo Torroja, 2010), but we were interested in estimating the insulation of the old windows. Two processes were followed to determine the R_{Atr} level of the old windows: on the one hand, the procedure described in (Moreno & Peña, 2002), which presents a method to quantify the R_{Atr} of old windows; on the other hand, by taking airborne sound insulation in situ measures in two blocks of the studied UEIs. As they are currently private homes, it was not possible to gain access to a larger number of homes. The $R_{A,tr}$ of the opening was taken as 20dBA.

Firstly, forecasting calculations were done to obtain the difference in the standard weighted A levels on the façade that came into contact with the outside air for traffic noise, $D_{2m,nT,Atr}$. The protected areas per block were selected and original wooden windows were assumed. Then the same calculation was done by fitting a double window on the outside of the original one, which would be a sliding model. Two glass composition cases were assumed: a double-glazed window with the 4-6-4 composition, which is the option chosen from renovation works done in UEIs, for which data are available; a window with asymmetric 4-6-6 double-glazed glass. Calculations of the double window's insulation were done using both options with Insul 7.0.6 (Marshall Day Acoustics, 2016). For the first option, an R_{Atr} of 30 dBA was obtained for UEIs, and an R_{Atr} of 33 dBA was obtained for UEIs with the second option.

The rooms for which calculations were done were selected as follows: for each UEI, the original building plans were studied. If these plans were not available, the dimensions of the interior rooms were estimated according to the bibliography (Ruiz Palomeque & Rubio del Val, 2006) (Sánchez Ventura, 1948) and to their similarity to other UEIs. Of the rooms with smaller dimensions in each UEI, one was or several were selected depending on whether the building had different façade solutions, and if there were any areas with openings with a variety of dimensions, which could give different $D_{2m,nT,Atr}$ values. In those cases where a variety of dimensions could exist for openings or façade types, which could change the airborne sound insulation, all the possible options were calculated to obtain the most accurate results. To count the rooms that met the DB HR demands, the room that obtained the lowest $D_{2m,nT,Atr}$ value was chosen for each façade solution. A building whose homes would all meet the noise levels expected by regulations if their windows had been changed was considered to be a lower renovation priority than another block which, despite windows being changed, did not meet the expected levels. Those buildings that required sound insulation on the blind façade part as well as new windows had to be considered priority major renovation cases because changing windows privately is somewhat more affordable for owners.

c) Defining levels and graphical representation

For indicator MN, three self-reference groups were obtained according to the medium noise level with an impact on each block's façade. Levels are represented by colours (see Figure 5).

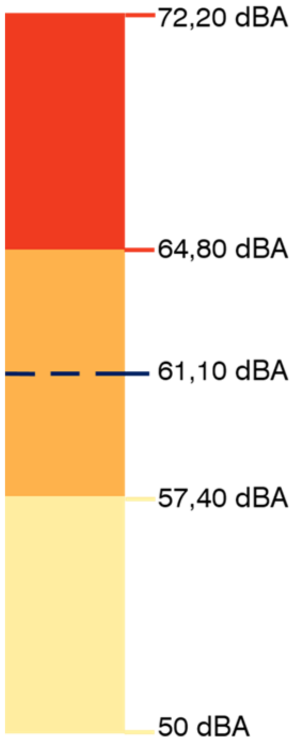

Figure 5 Grading scale of outside noise to obtain the outside noise indicators.

Indicator MN was obtained by dividing the sum of the façade surface exposed to noise levels of 70 dBA and 75 dBA between the total façade surface area. In this way, the percentage of the façade exposed to very high outside noise levels was obtained. The blocks with 0.33 or a smaller fraction of exposed façade were assigned to group 1 (yellow). Those with an exposure fraction of up to 0.66 (inclusive) were assigned to group 2 (orange). Group 3 (red) represents the blocks that had the biggest façade surface exposed to high noise levels and, therefore, had a higher regeneration priority, and their corresponding fraction went from 0.66 to 1. The blocks whose façades were not exposed to such high levels obtained a value of 0 (green).

To determine the levels in the WN indicators, the fraction of the rooms that met the expectations of regulations was calculated per block. According to this calculation, the indicator was assigned to each fraction. Group 1 (whose renovation was less urgent) included the blocks which achieved 100% success by changing windows, group 2 included those which went from 50% to 100% –excluded-, while group 3 (red), which represented higher priority, included those that obtained up to 50% of fulfilling areas.

Figure 6 represents the indicators on urban maps. Visually, by means of a colour code, it is possible to detect the blocks with a higher renovation priority from the airborne sound insulation viewpoint in the same UEI.

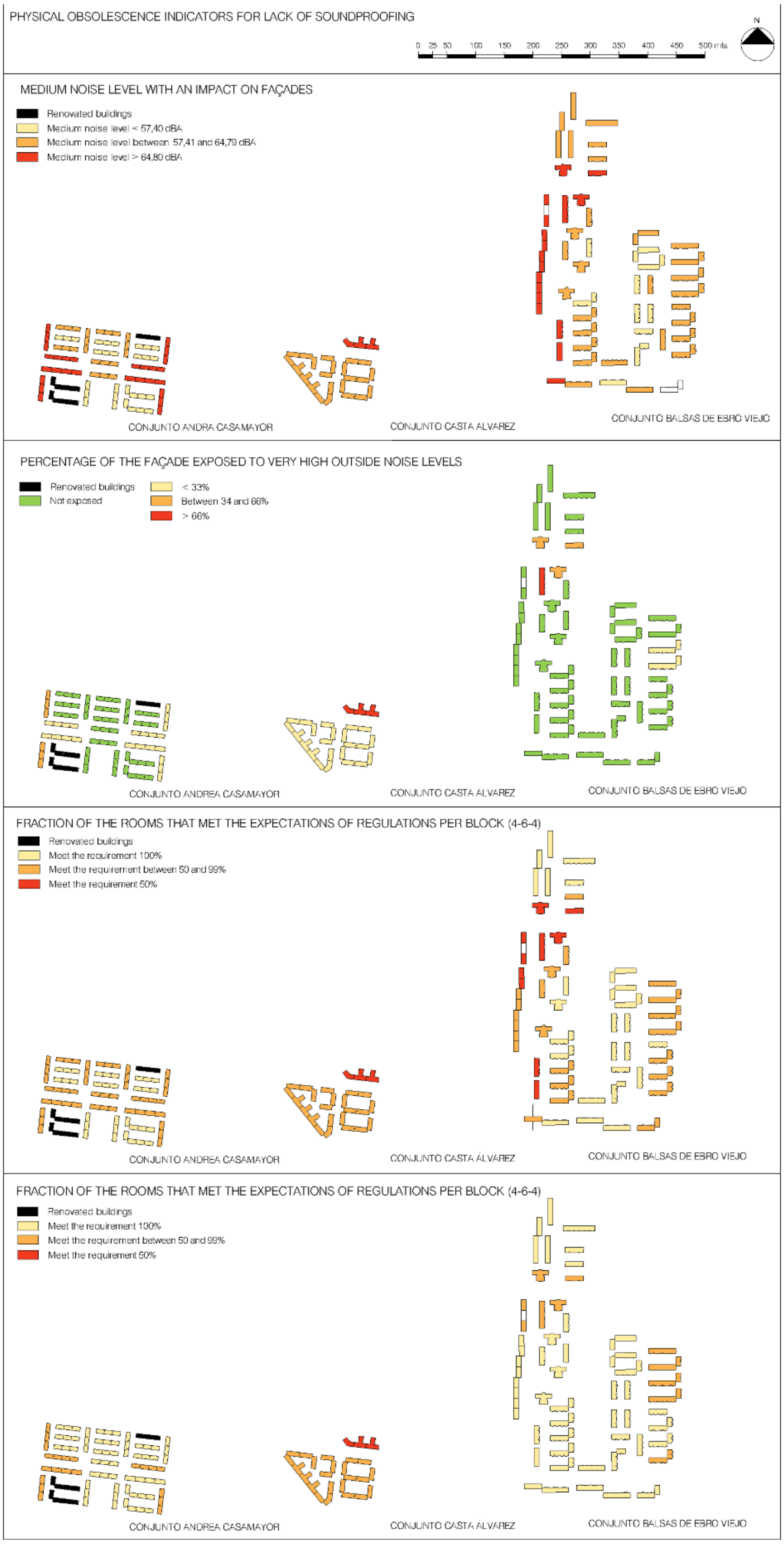

Figure 6. Graphical representation of the performance indicators for lack of airborne sound insulation against outside noise for the residential states Andrea Casamayor, Casta Álvarez and Balsas de Ebro Viejo.

5.3. Performance indicators for lack of accessibility

a) Revising regulations, literature and software:

The Basic Document of Secure Use and Accessibility –DB SUA- establishes that private residential buildings to be newly built have to fit an accessible lift when it is necessary to go up more than two storeys from any accessible main entrance to reach a home, or if it consists in more than 12 homes with no accessible main entrance to the building. This is not required for existing buildings, unless major renovations works are undertaken (Ministry of Public Works, 2007).

b) Proposal of indicators:

We proposed developing an indicator that reports if a block has a lift or not, quantified according to the number of affected homes and storeys in the building, as set out in DB SUA, which applies to newly constructed buildings and major renovation work.

Therefore, there are two conditions considered to make fitting a lift a priority:

- It is necessary to go up more than two storeys to reach a home
- There are more than 12 homes on existing storeys

Indicator	Necessary information
Lak of accessibility (S)	Number of storeys Number of dwellings on each storey

Table 6. Proposal of performance indicators for lack of accessibility. (S) State indicators.

c) Defining levels and graphical representation

The indicator was determined by giving a score for each above condition met. Thus a block in which it was necessary to go up more than two storeys to reach a home scored 0.50, and a block with more than 12 homes on existing storeys scored 0.50. Each block obtained an indicator of between 0 and 1, where 1 represents higher renovation priority. The blocks in the representations on urban maps that reached level 1 were represented in red, those that reached 0.5 were denoted in orange, and those below 0.5 in yellow.

Figure 7. Graphical representation of the performance indicators for lack of accessibility for the residential states Andrea Casamayor, Casta Álvarez and Balsas de Ebro Viejo.

5. DISCUSSION AND CONCLUSIONS

The set of proposed performance indicators allow the easy and visual detection of those buildings that more urgently require renovation work from the energy efficiency, airborne sound insulation against outside noise, and accessibility points of view, as well as the residential states that have more buildings with poor energy, airborne sound insulation, and accessibility performance. The development of these indicators shows that within the same state with buildings with similar construction characteristics and year of construction, the performance of some blocks compared with others can vary and have a higher renovation priority due to different orientations and exposure to outside noise.

The performance indicators for lack of energy efficiency provide different kinds of information: heating energy demand; overall energy demand; primary non-renewable energy use; CO_2 emissions. They can be used according to each country's environmental policies and strategies.

Two types of performance indicators for lack of airborne sound insulation against outside noise were developed; explanatory and synthetic. Explanatory ones provide information about outside noise levels and buildings exposure to it. Synthetic indicators also take into account the construction characteristics and the interior distribution of homes, providing objective data about the specific solution behavior in its actual context.

Finally, performance indicator for lack of accessibility informs about the urgency of fitting a lift in each main entrance.

The main limitation of this set of indicators is that for the moment they are applied to a reduced type of residential housing (social housing built during 1939-1979), and they should be extended to the whole city. For this, some simplifications should be made, and this represents a matter of future research. In any case, it should be mentioned that this type of residential housing had been previously identified as of special interest by the local Administration, and is considered one of the important building typologies in the Spanish long term strategy for the energy renovation in the buildings sector.

The set of performance indicators of multi-family buildings developed for the case of residential estates built during the period 1939-1979 in Zaragoza has been well received by the local Administration, but how it is going to be used to favor both the energy retrofit of residential buildings and the support to the vulnerable population remains under discussion. The three aspects that are mostly being discussed at the moment are: a) how to deal with the fact that the information provided by the vulnerability indicators at the census or neighborhood scale, offer diffuse information when it comes to prioritizing the intervention of some blocks versus others, given that the information is diluted throughout the section; b) how much relative weight should be given to vulnerability aspects versus building performance ones, and even between the different indicators within the vulnerability ones and the building performance ones, is a complex task; and c) the need of further indicators that do not only measure the state of obsolescence but also the opportunities for improvement of multi-family housing states that include both the urban and building dimensions, and serves both to evaluate the progress achieved over time with the major renovation of buildings and integrated urban regeneration, and to evaluate different proposals of intervention on the residential states and/or their buildings. Future research will include how to deal with these three issues.

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