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Towards an Energy Assessment on an Urban Scale for Retrofitting the Housing Stock in Mediterranean Cities

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Abstract

According to European Directive 2012/27/EU energy retrofitting of the current housing stock is being promoted. However, few studies have been carried out characterizing housing stock energy performance in order to incorporate energy retrofitting in cities in the southern Mediterranean area. The aim of this paper is to propose an energy assessment methodology on urban scale and to apply it to the southern Spanish province of Cadiz. This is followed by the generation of a predictive model for energy assessment in Mediterranean cities which could be further developed and used in the future to estimate overall energy efficiency on an urban scale.

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*Keywords:*Housing stock; Energy modelling; Energy retrofitting; Sustainable retrofitting; Mediterranean city.

1. Introduction

During the second half of the 20th century there was a mass expansion of European cities compared to earlier periods, mostly post-war reconstruction. 68% of European housing predates 1980 [1], and most of this housing stock shows clear energy deficiencies which often bring about obsolescence. European Directive 2012/27/EU [2], whose main aim is to establish a common framework of measures for the improvement of energy efficiency within the strategies of Horizon 2020, promotes the adaptation of European regulations and policies, promoting energy retrofitting of current deficient housing stock.

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In this context of change and transformation there is a need to generate new forms of energy assessment, taking into consideration different methods for classification typologies [3] and new approaches on an urban scale. Numerous studies have been carried out focusing mostly on the climate zones of central and northern Europe and providing an energy characterization of residential stock in original condition and following retrofitting [4,5]. However, the unique socio-cultural and climate conditions of the southern areas of the Mediterranean area require a specific approach through research which to date is limited [6]. We highlight the research by Dall'O' [7] which aims to accelerate energy assessment process for urban buildings, calculating consumption values using a comparative statistical methodology which is currently being researched by other authors [8,9]. Although these new methodologies do not provide detailed results for energy efficiency, the information generated can be used by different administrations to plan retrofitting strategies on an urban scale [10,11]. There are several studies employing the same approach by authors from European Union Mediterranean countries such as Greece and Cyprus [12,13].

The main aim of this research is to propose a methodology for the energy assessment of Mediterranean cities on an urban scale and apply it to Cadiz, a province with a Mediterranean climate in the south of Spain. 40% of the current housing stock built in this province predates 1980 [14], when the first Spanish regulations limiting the energy demand of buildings, NBE-CT-79, were implemented [15]. This methodology is proposed as a prior step to the generation of a predictive model for the energy assessment of Mediterranean cities and can be applied in the future to calculate the overall energy efficiency of the entire housing stock of a city.

A typological and constructive classification of the thermal envelope is carried out in order to achieve these goals. During this process it is also necessary to make onsite measurements, to monitor environmental and energy variables, and to simulate previously calibrated energy models. Results will be gathered on a Geographical Information System (GIS) platform. This study will be a useful tool in providing contributions to enhance the knowledge of energy assessment modelling on an urban scale, and to offer support to technicians and managers in charge of sustainable retrofitting plans.

2. Methodology

The methodology proposed is organized in four phases:

- Phase I: Identification and analysis of the residential neighbourhoods and association to a GIS.
- Phase II: Energy assessment of residential neighbourhoods and association of the results to a GIS.
- Phase III: Generation of an energy assessment model for Mediterranean cities.
- Phase IV: Application of the energy assessment model to draw up a comprehensive plan for the sustainable retrofitting of residential neighbourhoods, associating the results to a GIS.

This methodology is currently being applied to the case study selected: social housing stock built in the province of Cadiz between 1950 and 1980. This paper reflects its application to an example of a single social housing neighbourhood in the city of Cadiz: the Loreto neighbourhood, built between 1970 and 1975.

2.1. Phase I: Identification and analysis of the residential neighbourhoods and association to a GIS.

This phase consists of the following tasks:

Task 1: Case study. A study was carried out in the urban nuclei of the province of Cadiz, analysing multi-family social housing in each of these and defining the corresponding climate zone [16]. This allows us to define the predominant climate area or areas in the province of Cadiz (Fig. 1a), as well as the urban nuclei representative of each of these areas for social multi-family housing, establishing them as case studies for this research.

Task 2: Identification of neighbourhoods and residential neighbourhoods in each of the urban nuclei studied. The aim of this task is to identify the neighbourhoods in each urban nucleus selected as well as the developments from each neighbourhood built in 1950-1980. In order to complete this task the following sub-tasks were carried out in each of the urban nuclei:

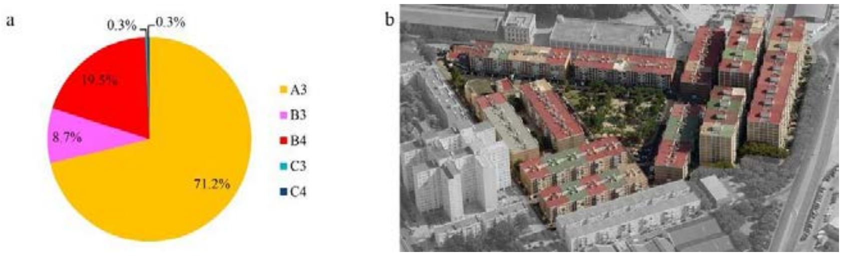

Fig. 1. (a) Percentage of multi-family social housing built between 1950 and 1980 in each climate zone in the province of Cadiz; (b) Identification of the Loreto neighbourhood in Cadiz.

- T2.1: Definition of the historic and urban framework of the urban nucleus. Based on different bibliographical sources and the analysis of the different urban plans developed over the 20th century, a brief historical survey of the evolution is presented to facilitate the identification of residential neighbourhoods which constitute urban nuclei.
- T2.2: Analysis of the evolution of national, regional and local energy regulations during the period under study, identifying the conditioning factors found during the design of the residential complexes under study.
- T2.3: Description of the current regulations as regards energy efficiency and sustainable retrofitting, specifying demands and objectives.
- T2.4: Identification of neighbourhoods and developments of multi-family housing built in the period under study (Fig. 1b). An initial minimum of 100 housing units per development phase is established. Only housing stock with a composition relevant to the urban nucleus are considered, ignoring small housing stock which do not take the form of a neighbourhood.
- T2.5: Creation of an initial database of the residential housing stock (Table 1). The database includes data relating to the housing stock and to each of the housing blocks.

Table 1. Database identifying the Loreto neighbourhood in Cadiz.

Development data		Block data	
Code	CA_30_02	Code	CA_30_02_001
Name of development	Loreto	Cadastral Reference	4636309QA4443F
Developer	Inmobiliaria Loreto S.A.	Address	C/ Plus Ultra 1. C.P: 11011
X, Y Coordinates	744307.56, 4043323.79	X, Y Coordinates	744552.55, 4043523.80
Decade of construction	‘70	Decade of construction	‘70
Year of construction	1970 - 1975	Year of construction	1975
Number of blocks	58	Number of housing units	40
Number of housing units	1490	Building type	‘H’-shaped block
Building types	‘H’-shaped block	Number of stories	10
Number of stories	5 -10	Occupied surface	288.72 m^2
Occupied surface	15863.10 m^2	Built surface	3015.00 m^2
Built surface	108836.00 m^2	Number of housing units on Ground Floor	4
		Number of housing units on Typical Floor	4

Task 3: Analysis of the neighbourhoods and larger housing stock for each of the urban nuclei used as case studies. After the second identification task, the more representative neighbourhoods and housing stock for each case study are analysed. This task is made up of the following sub-tasks:

- T3.1: Selection of larger neighbourhoods and developments, applying the following selection criteria: representativeness of the housing stock in the urban environment of the city, number of housing units in the housing stock and access to the sources of information from the original plans of the residential housing stock.
- T3.2: Compilation of documents on the design for each housing stock chosen as case studies. For the purposes of our case study the original designs for the social housing stock were consulted in the Provincial Historical Archive of Cadiz and in the Municipal Historical Archive for each urban nucleus. In addition, a diverse

bibliography on the social housing stock analysed was consulted and visual inspections were carried out through visits to the different neighbourhoods.

- T3.3: Creation of a second database expanding the first with information on the construction systems of individual blocks (Table 2).

Table 2. Database on analysis of the Loreto neighbourhood in Cadiz.

Block data		U (W/m^{2}K)	m (kg/m^2)
Code	CA_30_02_001		
Free height of stories	2.5 m		
Number of bedrooms in type housing unit	3		
Usable surface in type housing units	56.7 m^2		
Type of foundations	Piles		
Type of structure	Reinforced concrete pillars. Unidirectional framework with ceramic pieces.		
Type of roof	Accessible unventilated flat roof. Sloping porous concrete with lime, clay and rubble aggregates, asphalt underlay, lime mortar, ceramic tiles. S = 226.6 m^2.	2.06	617.60
Type of flooring in contact with the ground	Mass concrete flooring. S = 214.5 m^2; Perimeter = 65 m		
Type of flooring in contact with the exterior	Does not exist		
Type of vertical indoor partitions	Rendering, half-foot solid brick and rendering. S = 100.5 m^2.	3.01	
Type of roof with non-habitable space above	Does not exist		
Type of floor with non-habitable space below	Does not exist		
Façade data			
Code	CA_30_02_001_F01		
Type of façade	11.5 cm solid exposed brick, 5 cm air chamber, single hollow brick partition wall, rendered and coated. S = 321.8 m^2	1.69	328.55
Orientation	East		
Type of openings	3 mm single glazing. Metal joinery.	5.7	
Size of openings	0.82 x 1.25 m. 0.10 m overhang		

- T3.4: Characterization of the housing from the period analysed through a statistical study of the architectural composition. An analysis is carried out of aspects relating to building types used, number of stories in housing blocks, compactness of the blocks, number of bedrooms, usable surface of housing units and free height of stories.
- T3.5: Identification and characterization of the construction systems used incorporating statistical values. Statistical analysis provides knowledge of the constructive materials used in each period. Aspects relating to construction solutions used on the façade and roof, the type of joinery and glazing used, and solar protection used on openings, are studied. This analysis determines the case studies to be analysed in Phase III.

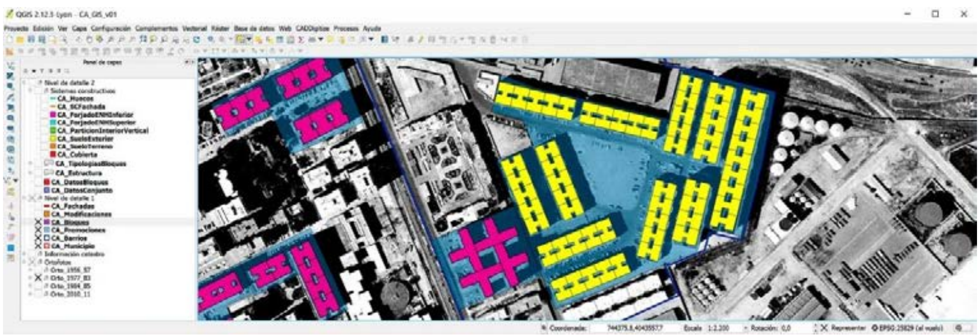

Fig. 2. GIS Platform (identification layer of blocks with information on the Loreto neighbourhood in Cadiz is highlighted).

Task 4: Incorporation of documentation compiled on the housing neighbourhoods into a GIS (Fig. 2). During this task all the information obtained and generated by the databases from tasks 2 and 3 are uploaded to a GIS using the free software QGIS2.12.3 for a better understanding of the information and easier access.

2.2. Phase II: Energy assessment of residential neighbourhoods and association of the results to a GIS.

This phase is carried out through the two tasks below:

Task 5: Energy assessment of the larger residential neighbourhoods for each of the urban nuclei under study. This task consists in the energy assessment of housing stock on a neighbourhood scale. Analysis is carried out to ascertain the energy status of the housing in neighbourhoods selected for study. The following sub-tasks are dealt with in this task:

- T5.1: Construction of the energy models for each of the housing stock selected, using CE^3X [17, 18], a program recognized by the Spanish Government which follows a simplified energy rating process for existing residential buildings. The construction of these energy models requires the prior definition of location, climate data, and use and operation conditions, as well as the energy characterization of the envelope for each model, specifying the transmittances and masses of the enclosures of the envelopes of the housing developments analysed, in addition to the characteristics of openings, joinery and solar protection. All these data are obtained based on the regulations of the country of the case study, in this case CTE-DB HE1 2013 [19].
- T5.2: Energy assessment of the housing developments in their current condition using the CE^3X program to calculate the energy efficiency rating, heating and cooling demand, and global demand (Table 3).

Table 3. Energy assessment of the Loreto neighbourhood in Cadiz.

Block data	
Energy efficiency rating	E (23.1 – 31.8 $kgCO_2/m^2$)
Heating demand	32.2 – 56.7 kWh/m^2
Cooling demand	13.5 – 25.5 kWh/m^2
Global demand	48.1 – 81.1 kWh/m^2

Task 6: Creation of an energy assessment GIS for the residential neighbourhoods. This task records all the information generated in task 5, providing an overview of the current energy status of the urban nucleus under study.

2.3. Phase III: Generation of an energy assessment model for Mediterranean cities.

This phase consists in the development of an energy assessment of representative housing units from the developments analysed, making it possible to establish sustainable retrofitting strategies for the thermal envelope. All this is geared towards the ultimate aim of generating an energy assessment model on an urban scale for Mediterranean cities.

This phase is made up of three tasks:

Task 7: Energy analysis of representative housing from the neighbourhoods under study.

This task is carried out at the level of the housing unit, selecting representative housing units from developments as objects of study. The behaviour of housing units, indoor conditions, and energy flows through the thermal envelope are analysed and assessed using energy simulation tools (DesignBuilder). In order to complete this task the following sub-tasks are carried out for each housing unit selected for study:

- T7.1. Selection of representative housing units for the neighbourhoods under study, based on the statistical analysis of the architectural composition and construction systems developed in Phase I.
- T7.2: Onsite measurements. Monitoring is carried out in two housing units over a nine-month period, collecting date every hour, in order to establish hygrothermal behaviour and energy consumption, using several data loggers and a meteorological station. Temperature, relative humidity and indoor CO_2 level are monitored in two rooms of different uses; total electric energy consumption in the housing unit and individual energy consumption for the seven most consuming electrical devices; in those cases where gas is the source of energy, the registered consumption values will be used; outdoor temperature and relative humidity, wind direction and speed, rainfall and atmospheric pressure levels (Fig. 3). The level of airtightness of the housing unit envelope is

established through pressurization and depressurization tests using BlowerDoor equipment, and an infrared thermographic study of the enclosures is carried out to detect weak energy points in the envelope.

- T7.3: User surveys on behaviour habits in order to define templates for use, activity, occupation and lighting, as well as energy consumption.
- T7.4: Elaboration of energy models using energy simulation programs (DesignBuilder). Values that create a higher level of uncertainty, mainly solar protection and natural ventilation, are introduced taken into account the instability of the action of the user [20].
- T7.5: Validation of energy models based on the data obtained from onsite measurements.
- T7.6: Assessment of the energy behaviour of individual housing units using energy simulation and assessment programs (DesignBuilder). Discussion of results.

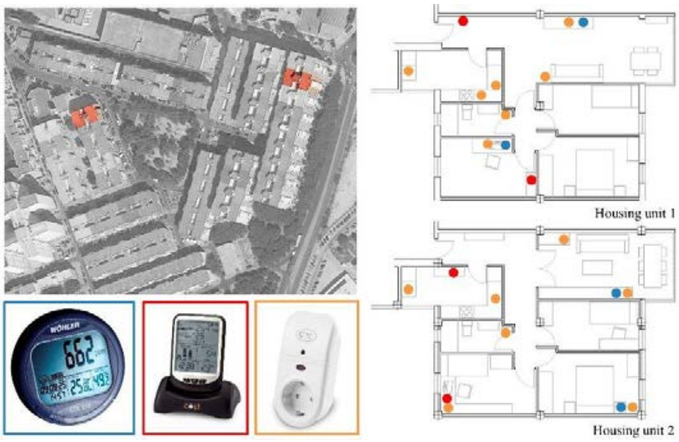

Fig. 3. Monitoring of housing units of the Loreto neighbourhood in Cadiz.

Task 8: Establishment of integrated strategies for sustainable retrofitting of the thermal envelope. After ascertaining the energy conditions of the urban nucleus used as case study, retrofitting solutions are sought to improve the energy efficiency of housing neighbourhoods.

The following sub-tasks are carried out to complete this task:

- T8.1: Creation of intervention scenarios, hypotheses and cataloguing of proposals for the improvement of the thermal envelope depending on the construction systems found in housing neighbourhoods. The aim is to improve energy efficiency and compliance with current national regulations of the country in which the urban nucleus is located. In this case, the sub-task is generated based on the information collected thanks to R&D&I project CELDA: “Energy and environmental retrofitting of social housing in Andalusia: Assessment using test cells”, funded by the Andalusian Regional Government and developed by the research group of the authors of this study.
- T8.2: Elaboration of energy models for the housing units studied with the proposals for the retrofitting of their envelopes through energy simulation and assessment programs.
- T8.3: Energy assessment of the housing units studied by applying the retrofitting proposals for their envelopes, using energy simulation and assessment programs to calculate the energy efficiency rating, heating and cooling demand, and global demand, aiming to improve energy efficiency.

Task 9: Generation of an energy assessment model on an urban scale. A model for the assessment of demand and energy rating is created based on the results of previous tasks.

- T9.1: Transversal analysis of the results obtained in the analysis of residential neighbourhoods and developments (Task 3) and their energy assessment (Task 5), in the energy analysis of the housing units (Task 7) and in the establishment of energy retrofitting strategies (Task 8). All these results are analysed statistically seeking correlations between energy demand obtained and the information available for all the housing units identified in each of the urban nuclei (geometrical characteristics, construction period, construction type, state of conservation, etc).

- T9.2: Generation of an energy assessment model based on the correlations found in the previous sub-task.
- T9.3: Validation of the energy assessment model based on the results obtained in the energy assessment of the housing developments under study.

2.4. Phase IV: Towards a plan for the sustainable retrofitting of residential neighbourhoods.

Finally, this phase consists of the application of the energy assessment model generated in a previous phase to the neighbourhoods of the urban nucleus under study, in order to generate a comprehensive plan for sustainable retrofitting, associating the results obtained to a GIS.

This phase is made up of the following tasks:

Task 10: Application of the energy assessment model on an urban scale to the residential neighbourhoods of the urban nucleus. The energy assessment model generated in Phase III is applied to all the residential neighbourhoods of the urban nucleus, calculating the energy demand and rating for each housing development identified. Thus, general information is collected on the energy efficiency of the housing units of urban nuclei, information which is extremely useful to retrofitting specialists and managers.

- T10.1: Comparative analysis of the energy assessment results for the residential neighbourhoods before and after the application of sustainable retrofitting strategies, calculating the improvement potential for these housing neighbourhoods.
- T10.2: Implementation of the model in a sustainable retrofitting plan on an urban scale.

Task 11: Association of the results from the application of the energy assessment model in the housing neighbourhoods to a GIS. The results of the energy assessment of residential neighbourhood are uploaded to a GIS following the application of the assessment model, offering an overview of the energy status of these neighbourhoods and potential for improving the implementation of a comprehensive sustainable retrofitting plan.

3. Conclusions

Most of the housing units in Mediterranean cities, especially social housing, are obsolete in energy terms. Hence the current European policies calling for the improvement of energy behaviour of this housing stock and promoting retrofitting. The current processes for the energy transformation of housing stock through retrofitting are lengthy and complex, with somewhat uncertain results. This process can be optimized and accelerated using a suitable methodology affecting energy behaviour on an urban scale.

Therefore, the application of the methodology proposed in this paper could provide general knowledge on an urban scale of the housing stock in Mediterranean cities from different perspectives: typological, morphological, constructive, and in terms of energy. This characterization of the housing stock is a necessary initial step for obtaining a predictive energy model on an urban scale to gather further information on the improvement potential of the housing stock of Mediterranean cities before and after the application of major retrofitting strategies.

The proposed methodology, organized into the four phases described with their corresponding tasks and sub-tasks, is based on the knowledge and analysis of the energy behaviour of representative buildings from the housing stock, using onsite measurements, monitoring environmental and energy consumption variables, generating energy models and establishing conditions for use and operation, validation and simulation of energy models and finally, statistical analysis of the results obtained. This is complemented with the potential offered by tools such as GIS.

The methodology offers a global assessment of current energy conditions and the potential for a hypothetical retrofitting plan for the housing stock, which could be of great use to the managers and specialists from different public administrations in charge of planning sustainable retrofitting strategies at the urban scale.

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