ARCAS: A MULTICRITERIA METHODOLOGY TO ASSESS THE RENOVATION OF SOCIAL BUILDINGS

Ivan Flores-Abascal [1], Pablo Hernandez-Cruz[1], Moises Odriozola-Maritorena[1], Manuela Almeida[2], Bruna Oliveira[2], Jérôme Nicolle[3], Francis Allard[3], Jérôme Le Dréau[4], Emilio Suárez[5], on behalf of the ARCAS-consortium.

[1]ENEDI Research Group, Department of Energy Engineering, University of the Basque Country (UPV/EHU), Plaza Torres Quevedo 1. Bilbao, Spain.
[2]University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal
[3] Rupeelab - TIPEE, 8 rue Isabelle Autissier 17140 LAGORD, France
[4]LaSIE UMR CNRS 7356, La Rochelle University, France
[5]Fundación FECEA, c/Principado, 11, 33007 Oviedo, Asturias
Correspondence: ivan.flores@ehu.eus

Abstract:

The current Energy Performance Certificates of buildings are mostly based on the expected energy consumption. Recently, some certification schemes are starting to incorporate Indoor Air Quality aspects, but it is still not usual. In this work, a novel multicriteria methodology to assess the renovation of buildings with social interest is presented: the ARCAS methodology. The novelty lies in its transversal approach, which considers three different axes: *Energy Efficiency*, *Energy Poverty*, and *Indoor Environment Quality*. The assessment of the energy poverty is innovative in building certification schemes. Besides, the indicators proposed to assess each axis are based on actual on-site measurements. The methodology has been tested in six demonstrator buildings selected throughout the SUDOE territory. The results show that the ARCAS methodology allows to get a comprehensive assessment of the current situation of the building and helps to propose the renovation measures in a specific direction. Also, advice and guidance for professionals who want to test the methodology are given.

Keywords: building renovation; energy efficiency; energy poverty; indoor environment quality.

Highlights:

- A novel multicriteria methodology to assess the renovation of social housing is presented.
- The methodology is tested in six demonstrator buildings to assess the before and after renovation scenarios.
- The results show the comprehensive overview provided by the methodology to assess the renovation process.

Abbreviations:

A	Acoustic comfort
BEMS	Building Energy Management System
BIM	Building Information Modelling
DHW	Domestic Hot Water
EN	Energy Needs
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ETICS	External Thermal Insulation Composite Systems
EU	European Union

GBC	Green Building Certification
GWP	Global Warming Potential
HLC	Heat Loss Coefficient
HP	Heat Pump
I	Indoor Air Quality
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
IWI	Internal Wall Insulation
L	Visual Comfort
PEC	Primary Energy Consumption
PERC	Primary Energy Renewable Consumption
PERP	Primary Energy Renewable Production
PV	Photovoltaic
Radd	Additional Thermal Resistance
RREE	Renewable Energies
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
T	Thermal comfort
U	Overall thermal coefficient

1. Introduction

Energy certification schemes for buildings began to appear at the end of the last century. Their first intention was to provide a common methodology for quantifying the energy consumption of buildings and to provide building stakeholders with strategies for improving energy efficiency and minimising energy consumption [1]. This was already stated in Article 2 of Directive 93/76/CEE [2], which indicated that this certification "shall consist of a description of their energy characteristics, must provide information for prospective users concerning a building's energy efficiency'' and additionally, ''may also include options for the improvement of these energy characteristics".

In the last 30 years, the use of different building energy certification schemes has been spreading throughout the world. In some countries or regions, such as the European Union (EU), these certificates have become mandatory and are known as Energy Performance Certificates (EPC). Comprehensive analyses of the different types of EPC and the implementation rate in the EU have already been carried out by several researchers and institutions [3]–[7]. Most of the EU countries had schemes running for certain types of buildings, but only seven countries had implemented the EPC scheme for all types of buildings by the beginning of 2009. By 2013, all Member States had implemented the Energy Performance of Buildings Directive (EPBD) [8] requirements into their national legislation.

Recent studies have focused on analysing gaps within the current certification schemes and identifying opportunities for the improvement of the next-generation of EPC [3], [9], [10]. Most of these next generation EPCs are focused mainly on the integration of BIM and the certification of the so-called green buildings. The integration of BIM in the certification scheme is an aid to improve the accuracy of energy simulations and strengthen the reliability of certificates. On the other hand, the Green Building Certifications (GBC) have introduced social and economic aspects in their schemes in order to look forward to more sustainable building projects.

Other aspects are susceptible to be improved in the current certification scheme. One of the most obvious is that the perception of the majority of buildings stakeholders is that EPC is mainly a bureaucratic formality and of no use to the building user [11], [12]. Indoor Air Quality (IAQ) has been identified as one of the main aspects that could reinforce the usefulness of the certificates for building users [13]–[15]. Some certification schemes, such as LEED, BREAM or WELL, already include IAQ in their calculation methodology, but there is still a significant lack of consistency and standardisation towards the implementation of these indicators.

In 2020, about 35 million inhabitants of the EU were unable to keep their homes adequately warm [16]. Tackling energy poverty is one of the main objectives of the *Clean energy for all Europeans* package [17]. Therefore, another aspect that could reinforce the usefulness of the EPC is the consideration of the energy poverty indicators. Some studies use EPC data to analyse energy poverty, but the application of energy poverty in certification schemes is still almost non-existent [18], [19].

For the EPCs to be considered both a powerful market tool to create demand for building renovation and to encourage stakeholders to use these certification schemes, rather than being viewed as an administrative obligation, all of the above aspects should be taken into consideration. The ARCAS certification aims to integrate the building's energy efficiency, indoor air quality and energy poverty aspects into a single scheme.

The ARCAS project [20] started in 2019 with a consortium formed by six partners located at the Atlantic Arc of the SUDOE territory, which includes the north region of Portugal, the northern coast of Spain and the southwest coast of France. The climatology of this area appears to be similar, besides there are cultural and organisational synergies.

The ARCAS project aims to develop a methodology to assess the renovation of buildings of social interest, focusing on tackling energy poverty and promoting sustainable rehabilitation, energy efficiency and health in the SUDOE territory. In this sense, the novelty of the ARCAS methodology is that it is a holistic methodology which combines three aspects which are usually assessed separately, namely, energy efficiency, energy poverty and Indoor Environment Quality (IEQ). As explained before, the energy efficiency and IEQ are usually considered in building certification schemes, but the inclusion of the energy poverty assessment is a notorious innovation.

The transversality of the ARCAS methodology helps, when evaluating an existing building, to get a comprehensive overview of the actual conditions of the building. This is not only because of the three-axis focus but also because most of the indicators proposed are based on actual on-site measurements. Basing the methodology not only on software simulations but also on real measurements gives the strength and security of evaluating with a high level of accuracy and confidence the performance of the building, and the energy poverty and indoor conditions of the users.

In this work, the ARCAS methodology is introduced. Later the results obtained after applying it in six demonstrator buildings throughout the SUDOE territory are shown. The process for assessing each axis of the ARCAS methodology and the measurement protocol of the proposed indicators are explained in detail. Besides, the difficulties found when carrying out the measurements and the advantages and disadvantages of the proposed methodology are discussed. Finally, we analyse the possibility of extrapolating the ARCAS methodology to other buildings and the future implications of this novel scheme.

2. Methodology

2.1. Description of the ARCAS methodology

The novelty of the ARCAS methodology lies mainly in its transversal and multicriteria approach, which is divided into three different axes, namely, *Energy Efficiency*, *Energy Poverty,* and *Indoor Environment Quality*. Several different indicators have been chosen in order to assess each axis. Table 1 provides general information about each axis and shows the indicators proposed for each one.

Regarding the *Energy Efficiency* axis, the proposed indicators provide a comprehensive overview of the energy characterisation of the building, considering the quality of the external envelope (EN and HLC), the energy consumption and energy efficiency of the systems (PE_C), the integration of RREE installations (PER_C/PE_C and PER_C/PER_P) and the global warming impact associated with the life-cycle of the renovated building (GWP). The EN indicator considers the heating needed to achieve comfort conditions in the dwelling, and it is suggested to use the value provided by the official EPC. On the other hand, the HLC indicator is measured on-site [21], [22], and it takes into account the total thermal losses of the building through the envelope, including thermal bridges and air leakages. If there is no heating equipment in the dwelling, the HLC may be estimated according to nationally established procedures. The PE_C is obtained by measuring the final energy consumption for heating, cooling, DHW, ventilation and lighting, with energy meters, using the BEMS of the building, or energy bills. Then, the Primary Energy Consumption is obtained considering the conversion factor for each energy vector used, depending on the country. The self-sufficiency ratio (PER_C/PE_C) measures the amount of PE_C which comes from on-site renewable sources, and the self-consumption ratio (PER_C/PER_P) measures the amount of on-site RREE production energy consumed within the building, and thus, not exported to the grid. Both indicators are based on real measurements, using the BEMS data, whenever possible, or estimated according to established national methods. Finally, the Global Warming Potential (GWP) indicator is used to assess the sustainability of the renovation, calculating the amount of CO_2 emissions not emitted due to the, supposedly lower, energy consumption of the renovated building.

In order to measure energy poverty, the scientific community suggests a long list of indicators, such as the *inability to keep home adequately warm*, the 2M, the M/2, among others. [23]. For the ARCAS methodology, the 10% Indicator has been chosen to evaluate how the building's performance can support energy poverty alleviation. This indicator measures the ratio between the total energy expenditure of the dwelling and the household's net income. This indicator has been chosen due to several reasons. Firstly, it is a consistent, flexible, and relatively easy-to-measure indicator. Secondly, this indicator is related to the PE_C indicator of the *Energy Efficiency* axis through the final energy consumption parameter, uniting the methodology. At last, the choice of an expenditure-based indicator has been considered appropriate since the project focuses on buildings with social interest, which means that economic availability to pay for energy services is valued in the chosen approach. The incorporation of the *Energy Poverty* axis is one of the most differentiating aspects of the ARCAS methodology.

Finally, in the scientific community, there is not a clear consensus regarding which method should be used to rate the overall level of IEQ in dwellings. In this sense, within the framework of the EU ALDREN project [24], a new classification rating scheme, the TAIL Index, was developed to assess IEQ in offices and hotels undergoing deep energy renovation, and it has been adapted to the reality of dwellings by some of their authors [25]. This methodology combines the Thermal Environment, the Acoustic Environment, the Indoor Air Quality, and the Visual Environment. Thus, the TAIL Index indicator has been chosen as a comprehensive methodology to assess the *Indoor Environment Quality* axis, and is also based on real on-site measurements.

Concerning the advantages of the proposed methodology, the second main strength of the ARCAS methodology is that it is mostly based on direct measurements, whereas most of the certification schemes are only based on simulations, i.e., to derive the majority of the indicators for each axis, direct measurements or monitoring processes within the building need to be carried out. Also, the calculations needed to develop each indicator are not excessively difficult and may be performed using a spreadsheet or similar. Nevertheless, as will be explained later, there are some exceptions in which it is not possible to carry out the on-site measurements. In these situations, it is suggested to calculate the indicators using energy bills, consistent energy simulations according to national regulations, or estimations based on energy audits.

The ultimate aim of the ARCAS Methodology here introduced is to assess a specific building with a multicriteria and transversal scope, by measuring and calculating the selected indicators previously described. With this, for each indicator, four different categories have been established depending on their results. The ranks for each of them have been obtained using reference standards of each participant country of the ARCAS project. The number of ranks chosen is 4, which is not a high number that could make the ranking confusing but is enough to appreciate different aspects when assessing a renovation proposal. Table 1 also summarises the ranks for each category, shown in green colour for the best category (I) and red colour for the worst (IV). The ranking categories for the Renewable Energy Self-Consumption Ratio (PER_C/PER_P) is clarified here. This indicator, as explained before, measures the amount of produced RREE energy that is consumed within the building, and thus, not exported to the grid. In the ARCAS methodology, positive energy buildings are willed, meaning that the lower the value of the PER_C/PER_P indicator, the more RREE is being exported to the grid. Thus, the best category for this indicator is when its value is less than 40%.

Table 1: Description of each axis and indicator, comments about the measurement process and categories of the ARCAS methodology

Axis	Acronym	Indicator	Unit	Comments about the measurement process	Categories of the ARCAS methodology			
					I	II	III	IV
Energy Efficiency	PE_C	Primary energy consumption	$kWh/m^2 \cdot y$	Direct measurement, through monitoring or energy bills, or estimation of the primary energy consumption of the building used for heating, cooling, DHW, ventilation and lighting	< 85	[85, 125)	[125,165)	[165,205)
	EN	Energy Needs	$kWh/m^2 \cdot y$	Heat to be delivered to or extracted from a thermally conditioned space to maintain the intended space temperature conditions during a given period, obtained using the EPC of the building	< 18	[18, 50)	[50, 85)	[85, 115)
	PER_C/PE_C	Renewable energy self-sufficiency ratio	%	Measures the ratio between renewable energy consumption and total primary energy consumption	≥ 60	[40, 60)	[20, 40)	[0, 20)
	PER_C/PER_P	Renewable energy self-consumption ratio	%	Measures the ratio between the renewable energy consumption and renewable energy production	< 40	[40, 60)	[60, 80)	[80, 100)
	HLC	Heat Loss Coefficient	$W/m^2 \cdot K$	Measures, through a monitoring process, or estimate the total thermal losses of the building through the envelope, including thermal bridges and total air change	< 1.4	[1.4, 2.4)	[2.4, 3.4)	≥ 3.4
	GWP	Reduction of the Global Warming Potential	%	Measures the potential of reduction of the carbon footprint of the building after the renovation process	≥ 30	[20, 30)	[10, 20)	[0, 10)
Energy Poverty	10% Indicator	10% Indicator	%	Measures the relation between the energy expenditure, when reaching comfort conditions, and the net income of the dwelling	≤ 10	(10, 15]	(15, 20]	> 20
Indoor Environment Quality	Thermal comfort, T	Temperature	ºC	During warm season	[21, 23]	≥20 & ≤24	≥19 & ≤25	Others
				During cold season (mech. cooling)	[23.5, 25.5]	≥23 & ≤26	≥22 & ≤27	Others
	Acoustic comfort, A	Acoustic Comfort	dB(A)	-	≤25 (night-time) ≤ 30 dB(A) (daytime, living room)	≤30 ≤ 35 dB(A)	≤35 ≤ 40 dB(A)	Others
	Indoor Air Quality, I	CO_2 (above outdoors)	ppm	-	≤ 550 ppm (living room) ≤ 380 ppm (bedroom)	≤ 800 ppm (living-room) ≤ 550 ppm (bedroom)	≤ 1350 ppm (living-room) ≤ 950 ppm (bedroom)	Others
		Relative Humidity	%	-	[30, 50]	≥25 & ≤60	≥20 & ≤60	Others
		Ventilation Flow Rate	h^{-1}	-	ACH ≥ 0.7	ACH ≥ 0.6	ACH ≥ 0.5	Others
		Mold	cm^2	-	0	<400	<2,500	Others
		Particulate matter PM2.5	$\mu g/m^3$	-	<10	≥10	no criteria	≥25
		VOC Formaldehyde	$\mu g/m^3$	-	<30	≥30 & <100	-	≥100
		VOC benzene	$\mu g/m^3$	-	<2	≥2 & <5	-	≥5
		Radon	Bq/m^3	-	<100	≥100 & <300	-	≥300
	Visual Comfort, L	Illuminance	%	% of the day with 300-500 lux	[100, 60]	(60, 40]	(40, 10]	<10
				% of the night with 100 lux	0% with ≥100 lux	≤50% & >0% with ≥100 lux	≤90% & >50% with ≥100 lux	>90% with ≥100 lux
		Daylight factor	%	Daylight factor during daytime	≥5.0%	≥3.3%	≥2.0%	Others

2.2. Description of the sample

To test the ARCAS methodology, six demonstrator buildings have been selected in the SUDOE territory, spread around the countries of the project. Table 2 includes general information on the demonstrator buildings, such as the year of construction or the size of the dwellings. Regarding the size of the buildings, the demonstrator buildings comprise a wide range of configurations: from small buildings of 16 dwellings to high developments of 171 dwellings. Also, the quality of the external envelope and the type of energy system is shown in

Table 2. Although the overall coefficient of transmission of the opaque envelope is not significantly bad, there is room for improvement considering the quality of the windows. Regarding the energy systems, there is a high variety, with buildings using district heating for heating and DHW, buildings using collective gas boilers or even buildings with individual gas heaters for DHW and portable electric heaters.

As depicted in Table 2, most of the buildings are quite old, with more than 40 years of construction, except for the building S-1, located in Spain, which was constructed in 2010. However, the buildings located in France have undergone a renovation process during the years 2019 – 2020, both affecting the external envelope and the energy systems. Thus, the ARCAS methodology has been tested in different scenarios, with buildings which have not been renovated yet and with buildings which have already been renovated. Also, for the non-renovated buildings, a proposal of renovation measures is assessed using the ARCAS methodology. The buildings that have been tested in each scenario are also shown in

Table 2.

In this sense,

Table 2 also shows the main characteristics of the renovation packages applied in each of the demonstrator buildings, both for the *After Renovation* scenario and for the *Design Stage* scenario. It can be seen that all of the renovation packages imply deep renovations, affecting the external envelope, the improvement of the energy systems and the installation of RREE systems.

Table 2: general characteristics of the demonstrator buildings for the ARCAS Methodology

Building	**F-1**	**F-2**	**P-1**	**P-2**	**P-3**	**S-1**
General information						
Renovation status	Renovated during 2019-2020.	Renovated during 2019-2020.	No renovation	No renovation	No renovation	No renovation
Location	La Rochelle, France	La Rochelle, France	Braga, Portugal	Braga, Portugal	Braga, Portugal	Vitoria-Gasteiz, Spain
Year of construction	1954	1974	1983	1976	1976	2010
Number of dwellings	16	64	246	171	171	126
Monitored dwellings	2	2	1	1	1	4
U walls [W/m²·K]	1.75	0.73	0.60	0.71 – 1.46	0.71 – 1.46	0.31
U windows [W/m²·K]	1.6 – 4.5	2.9 – 4.95	4.1 – 5.05	1.98	3.4 – 5.1	3.3
Heating and DHW	Gas-fired condensing boiler	District Heating	Individual Electric Heater and Gas water heater for DHW	Individual Electric Heater and Gas water heater for DHW	Individual Electric Heater and Gas water heater for DHW	Collective gas fired boiler
Ventilation	Natural	Natural	Natural	Natural	Natural	Natural
Stages in which each building has been assessed with the ARCAS methodology						
Before Renovation	X	X	X	X	X	X
Design Phase			X	X	X	X
After Renovation	X	X				
	Buildings After Renovation		**Buildings in the Design Stage**			
Renovation details	External walls - IWI (Radd > 4-5 m²·K/W). Insulation floor (Radd > 4 m²·K/W) and roof (Radd > 7.1 m²·K/W) Double-glazing (4-16/4 with Argon filling). Mechanical ventilation with humidity control. Collective DHW production system.	External walls 20+9.5cm (U = 0.12 W/m²·K). Insulation floor (14 cm) and roof (20 cm). Double-glazing (U = 1.3 W/m²·K) Assisted natural ventilation. Change of emission systems. Solar collectors (34 vacuum tube solar collectors). PV panels (36 kWp).	70 mm EPS insulation wall apartment - stairwell. 80 mm EPS insulation slab basement-dwelling. ETICS 100 mm EPS. Replacement of the exterior door with a wooden door without glazing. Replacement of all windows with standard double-glazed PVC windows U= 1.95 W/m²·K. HP for AC, SCOP= 4.0 and SEER= 6.1. Solar collectors for DHW.	70 mm EPS insulation wall apartment - stairwell. ETICS 60 mm EPS. 100 mm EPS above the horizontal slab of the unoccupied pitched roof. HP for AC, with SCOP= 4.0 and SEER= 6.1. Solar collectors for DHW.	70 mm EPS insulation wall apartment - stairwell. ETICS 60 mm EPS Replacement of all windows with standard double-glazed PVC windows U= 1.97 W/m²·K. HP for AC, with SCOP= 4.0 and SEER= 6.1. Solar collectors for DHW.	ETICS 100 mm EPS. 16 cm of XPS in the roof. 8 cm of MW to the lower floor of dwellings. Renovation of all the windows transmission of U = 1.45 W/m²·K. HP for heating and DHW of SCOP= 2.5 or higher. PV panels with 4.1 kWp.

3. Results and discussion

3.1. Results of the ARCAS methodology

The results obtained when using the ARCAS methodology to assess the different scenarios of the demonstrator buildings are shown in Table 3. The result for each indicator is highlighted with the corresponding colour for its category, as indicated in Table 1. Thus, not only the numerical results for each indicator may be analysed, but also the ARCAS category may be compared at a glance when analysing Table 3.

Regarding the *Before Renovation* scenario, it is clearly depicted that the overall results for the housing stock analysed are poor in the three axes of the ARCAS methodology. The indicators of the energy efficiency axis show that both the energy demand and the primary energy consumption of the buildings are considerably high, implying a poor energy efficiency category. Regarding the RREE indicators, as there are no RREE installations in most of the buildings, both the self-consumption and self-sufficient indicators are really bad. The HLC indicator is in line with the EN of the building. In some cases, the result for the HLC indicator is slightly better than the result for the EN indicator. This is because the HLC indicator is derived from real measurements carried out in real operation conditions, with the occupied dwellings during a specific period, whereas the EN indicator is based on the standardised conditions of the EPC of the building.

All of these poor results derived from the energy efficiency indicators are reflected in the indicators of the Energy Poverty and IEQ axes. Together with the user profile of these dwellings, the results for the Energy Poverty axis are significantly bad. Of the six demonstrator buildings, five have a category III and one has category IV in terms of energy poverty. As far as IEQ is concerned, the results of the TAIL Index also show bad conditions at the dwellings, with a generalised result for the IV category. There are a few exceptions in some buildings where Temperature, Acoustic and Luminance are not category IV.

Thus, considering the results of the ARCAS methodology for the analysed buildings in the *Before Renovation* scenario, it is clear that there is room for improvement in the demonstrator buildings. This will be assessed using the ARCAS methodology for the *Design Stage* scenario and for the *After Renovation* scenario. Comparing at a glance the results shown in Table 3, it is possible to identify a significant improvement in the ARCAS indicators for the renovation scenarios. Regarding the energy efficiency indicators, it can be seen that the PE_C, EN and HLC indicators achieve really high categories, meaning that the renovation proposals are useful for decreasing the energy consumption of the buildings. With the installation of RREE facilities, the self-sufficiency indicator (PER_C/PE_C) shows different results. In some cases (P-1, P-2, and P-3), the improvement of the (PER_C/PE_C) is clear. In the rest of the demonstrator buildings, the proposed installation of the RREE is not enough to achieve a high category for this indicator. Regarding the self-consumption ratio (PER_C/PER_P), none of the buildings, even those with important RREE installations, achieve a good category. This is because the RREE production is mostly self-consumed in the building and is not exported to the grid.

In addition, since the energy expenditure is expected to decrease with increasing energy efficiency due to the renovation of the buildings, the previous results presented for the energy efficiency indicators directly reflect in the energy poverty indicator, where improvements of two categories (from category III to category I, and from category IV to II) are achieved. With this, the importance of analysing social aspects is proved. When facing the renovation of a building, not only the reduction of the energy consumption should be expected, but also the improvement of the living conditions of the households.

Finally, regarding the IEQ, it is not possible to calculate the TAIL Index in the Design Stage scenario. In the *After Renovation* scenarios, it has only been possible to measure the TAIL Index in the demonstrator building F-2. Comparing the TAIL Index for this demonstrator building before and after renovation, it can be depicted that the renovation has not significantly affected the indoor environment of the dwellings. There is an improvement in the Acoustic sub-parameter, but the rest remain the same. In this sense, the utility of the ARCAS methodology is to notice that further renovation measures need to be applied if a significant improvement in the IEQ conditions wants to be achieved.

Table 3: results of the ARCAS methodology for the demonstrator buildings, in the *Before Renovation*, *Design Stage* and *After Renovation* scenarios

			Energy Efficiency						Energy Poverty	Indoor Environment Quality				
Country	**Location**	**Building**	**PE_C [kWh/m²·y]**	**EN [kWh/m²·y]**	**PER_C/PE_C [%]**	**PER_C/PER_P [%]**	**HLC [W/m²·K]**	**GWP [%]**	**10% Ind. [%]**	**T [-]**	**A [-]**	**I [-]**	**L [-]**	**TAIL [-]**
Before Renovation														
France	La Rochelle	F-1	187.0	130.0	0.0	-	3.88	-	16.9	II	IV	IV	IV	IV
	La Rochelle	F-2	198.0	137.0	6.7	100.0	3.01	-	17.2	II	IV	IV	IV	IV
Portugal	Braga	P-1	387.7	141.1	0	-	4.91	-	17.9	IV	IV	IV	IV	IV
	Braga	P-2	449.3	164.6	0	-	5.29	-	16.8	IV	IV	IV	II	IV
	Braga	P-3	220.5	75.9	0	-	2.96	-	15.3	IV	IV	IV	I	IV
Spain	Vitoria-Gast.	S-1	140.6	55.1	0	-	2.10	-	21.0	IV	II	IV	IV	IV
Design Stage														
Portugal	Braga	P-1	42.5	20.0	73.0	100.0	1.22	88.0	1.02	-				
	Braga	P-2	49.7	26.0	65.8	100.0	1.31	88.1	0.97					
	Braga	P-3	38.8	20.2	67.5	100.0	1.15	80.3	1.35					
Spain	Vitoria-Gast.	S-1	70.9	16.5	27.0	100.0	0.6	54.0	14.0					
After Renovation														
France	La Rochelle	F-1	64.0	25.0	0.0	-	1.37	45.0	8.3	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
	La Rochelle	F-2	72.0	25.0	44.0	100.0	0.92	62.0	8.1	II	I	IV	IV	IV

[1] NA: Not Available

3.2. General aspects, difficulties, and future implications of the ARCAS methodology

The results shown in section 3.1 are useful to introduce the ARCAS methodology and explain how it works both as a certification tool and as a design aid tool when assessing the renovation process of a building. As a certification methodology, the multicriteria and transversal focus provides an overall and comprehensive picture of the current state of the building, not only focusing on energy efficiency, as most of the certification schemes do, but also considering possible energy poverty situation within the users and the indoor environment quality of the dwellings.

This multicriteria scope allows us to identify the current weaknesses of the building and propose specific renovations to tackle them. Then, using the ARCAS methodology for the *Design Stage* or for the *After Renovation* stage, the effectiveness of those renovation proposals may be assessed.

However, several difficulties have also been found during the ARCAS monitoring processes needed to measure and calculate the different indicators. For instance, some of the analysed dwellings did not have heating systems, hence the monitoring process for the HLC indicator could not be carried out. Also, it may happen that households do not allow the access to the dwelling or the installation of the monitoring equipment. Another possible eventuality is that the certification needs to be performed, for instance, during the summer, so several parameters are not able to be assessed. In all of these scenarios, indicators may be estimated according to the official EPC or using data from previous energy audits, but the on-site measurements should be always prioritised. All of these aspects and drawbacks have to be considered by anyone who wants to apply the ARCAS methodology to any building. A properly arranged and scheduled monitoring campaign, considering dates, period, possible assistance from external agents, etcetera, is needed to achieve success with the ARCAS methodology.

Finally, one important step for the future of the ARCAS methodology would be to involve local agencies and governments to use the ARCAS methodology to assess the renovation wage. In this work, it has been shown that the ARCAS methodology is a multicriteria tool, thus allowing local agencies to assess the renovation of buildings not only in the energy consumption aspect but also in social and indoor environment quality aspects.

4. Conclusions

In this work, a novel multicriteria methodology to assess the renovation of buildings of social interest is presented. This transversal methodology evaluates the building in three axes, namely, Energy Efficiency, Energy Poverty, and Indoor Environment Quality. In order to test the methodology, six demonstrator buildings have been selected in the SUDOE territory, and the ARCAS methodology has been used to assess the current situation, the renovation proposal, and the rehabilitated scenario for those buildings.

The results for the *Before Renovation* scenario show that there is a huge room for improvement in the three axes of the ARCAS methodology. The poor quality of the external envelope, together with the low-efficiency energy installations, implies a high energy consumption. Considering the user profile of these buildings, and the high energy consumption, the results for the Energy Poverty indicator show a worrying situation. Finally, the TAIL Index for the IEQ axis also depicts existing poor conditions of the indoor environment.

When using the ARCAS methodology for the *Design Stage* and the *After Renovation* scenarios, the effects of the renovation proposals towards the three axes may be assessed. The influence of the renovation proposals on the energy efficiency of the buildings is clear since most of the indicators improve considerably. The quality of the external envelope and the efficiency of the installations improve, and so does the energy consumption. The bad results for the self-consumption ratio (PER_C/PER_P) indicate that more RREE exported to the grid is suggested. In addition, the renovation proposals are also effective to alleviate energy poverty in social housing, where improvements of two categories (from category III to category I, and from category IV to II) are achieved for the energy poverty indicator. The incorporation of the Energy Poverty axis provides a social assessment of the renovation which is not considered by other certification schemes. Finally, the results for the TAIL Index in the renovated building, indicate that other types of renovation packages are needed to improve the indoor environment of the dwellings.

With this, the ARCAS methodology has been presented as well as its utility to assess the renovation of social buildings with a multicriteria focus. Further steps are needed to reinforce this methodology, considering the difficulties of measuring some of the proposed indicators. Also, further actions to involve local agencies in the use of this methodology are being developed.

Author contributions

Ivan Flores-Abascal, Pablo Hernandez-Cruz, Moises Odriozola-Maritorena: Term, Conceptualisation, Methodology, Data Curation, Writing - Original Draft.

Manuela Almeida, Bruna Oliveira, Jérôme Nicolle, Francis Allard, Jérôme Le Dréau, Emilio Suárez: Conceptualisation, Methodology, Data Curation, Writing - Review.

All authors have read and agreed to the published version of the manuscript.

Acknowledgements

The Project ARCAS (SOE3/P3/E0922) has received funding from the Interreg Sudoe Programme and the European Regional Development Fund (ERDF).

The members of the ARCAS Consortium are: Arturo Gutiérrez de Terán, Emilio Suárez, Pablo García Martínez, Manuel García (FECEA, Spain), Manuela Almeida, Ricardo Mateus, Luís Bragança, Sandra Silva, Bruna Oliveira Onety (University of Minho, Portugal), Iván Flores, Moisés Odriozola, Pablo Hernandez-Cruz (University of the Basque Country, Spain), Marc Abadie, Francis Allard, Patrice Joubert, Jérôme Le Dréau (La Rochelle Université, France), Jérôme Nicolle (Plateforme technologique du bâtiment durable–TIPEE, France), Enrique Alonso, Soledad Rodríguez, Ángela Nogués (Government of Cantabria, Spain).

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] L. Pérez-Lombard, J. Ortiz, R. González, and I. R. Maestre, "A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes," *Energy Build.*, vol. 41, no. 3, pp. 272–278, Mar. 2009, doi: 10.1016/J.ENBUILD.2008.10.004.

[2] "Council Directive 93/76/CEE of 13 September 1993 to limit carbon dioxide emissions by improving energy efficiency (SAVE)".

[3] Y. Li, S. Kubicki, A. Guerriero, and Y. Rezgui, "Review of building energy performance certification schemes towards future improvement," *Renew. Sustain. Energy Rev.*, vol. 113, Oct. 2019, doi: 10.1016/J.RSER.2019.109244.

[4] E. Iribar, I. Sellens, L. Angulo, J. M. Hidalgo, and J. M. Sala, "Nonconformities, Deviation and Improvements in the Quality Control of Energy Performance Certificates in the Basque Country," *Sustain. Cities Soc.*, vol. 75, Dec. 2021, doi: 10.1016/J.SCS.2021.103286.

[5] P. Vaquero, "Buildings Energy Certification System in Portugal: Ten years later," *Energy Reports*, vol. 6, pp. 541–547, Feb. 2020, doi: 10.1016/J.EGYR.2019.09.023.

[6] J. Volt, S. Schmatzberger, and & Zsolt, "EPC The Romanian Association of Energy Auditors for Buildings, e-think and Centre for Renewable Energy Sources and Saving (CRES)," 2020, Accessed: Jan. 27, 2023. [Online]. Available: https://x-tendo.eu/.

[7] A. Arcipowska *et al.*, "A MAPPING OF NATIONAL APPROACHES ENERGY PERFORMANCE CERTIFICATES ACROSS THE EU BPIE review and editing team," 2014, Accessed: Jan. 27, 2023. [Online]. Available: www.bpie.eu.

[8] "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)." .

[9] O. I. Olanrewaju, W. I. Enegbuma, M. Donn, and N. Chileshe, "Building information modelling and green building certification systems: A systematic literature review and gap spotting," *Sustain. Cities Soc.*, vol. 81, Jun. 2022, doi: 10.1016/J.SCS.2022.103865.

[10] C. Jiménez-Pulido, A. Jiménez-Rivero, and J. García-Navarro, "Improved sustainability certification systems to respond to building renovation challenges based on a literature review," *J. Build. Eng.*, vol. 45, p. 103575, Jan. 2022, doi: 10.1016/J.JOBE.2021.103575.

[11] M. M. Sesana and G. Salvalai, "A review on Building Renovation Passport: Potentialities and barriers on current initiatives," *Energy Build.*, vol. 173, pp. 195–205, Aug. 2018, doi: 10.1016/J.ENBUILD.2018.05.027.

[12] A. Chegut, P. Eichholtz, and N. Kok, "Supply, Demand and the Value of Green Buildings," *Urban Stud.*, vol. 51, no. 1, pp. 22–43, 2014, doi: 10.1177/0042098013484526.

[13] A. M. Y. Ho, J. H. K. Lai, and B. W. Y. Chiu, "Key performance indicators for holistic evaluation of building retrofits: Systematic literature review and focus group study," *J. Build. Eng.*, vol. 43, Nov. 2021, doi: 10.1016/J.JOBE.2021.102926.

[14] W. S. E. Ismaeel and A. G. Mohamed, "Indoor air quality for sustainable building renovation: A decision-support assessment system using structural equation modelling," *Build. Environ.*, vol. 214, Apr. 2022, doi: 10.1016/J.BUILDENV.2022.108933.

[15] W. Wei, O. Ramalho, and C. Mandin, "Indoor air quality requirements in green building certifications," *Build. Environ.*, vol. 92, pp. 10–19, Oct. 2015, doi: 10.1016/J.BUILDENV.2015.03.035.

[16] "8% of EU population unable to keep home adequately warm - Products Eurostat News - Eurostat." https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20211105-1 (accessed Jan. 27, 2023).

[17] "Clean energy for all Europeans package." https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en (accessed Jan. 27, 2023).

[18] M. H. Abbasi, B. Abdullah, R. Castaño-Rosa, M. W. Ahmad, A. Rostami, and J. Cullen, "Planning energy interventions in buildings and tackling fuel poverty: Can two birds be fed with one scone?," *Energy Res. Soc. Sci.*, vol. 93, Nov. 2022, doi: 10.1016/J.ERSS.2022.102841.

[19] K. Fabbri and J. Gaspari, "Mapping the energy poverty: A case study based on the energy performance certificates in the city of Bologna," *Energy Build.*, vol. 234, p. 110718, Mar. 2021, doi: 10.1016/J.ENBUILD.2021.110718.

[20] F. E. C. E. A. (FECEA), Universidad del País Vasco/Euskal Herriko Unibertsitatea, La Rochelle Université, Technological & Innovative Platform for Environmental Efficiency -Tipee, Universidade do Minho, and O. del T. y U. Gobierno de Cantabria. Consejería de Obras Públicas, "ARCAS - Interreg Sudoe." http://www.arcassudoe.eu/about/?lang=en (accessed Mar. 30, 2023).

[21] I. Uriarte, A. Erkoreka, A. Legorburu, K. Martin-Escudero, C. Giraldo-Soto, and M. Odriozola-Maritorena, "Decoupling the heat loss coefficient of an in-use office building into its transmission and infiltration heat loss coefficients," *J. Build. Eng.*, vol. 43, Nov. 2021, doi: 10.1016/J.JOBE.2021.102591.

[22] I. Uriarte, A. Erkoreka, C. Giraldo-Soto, K. Martin, A. Uriarte, and P. Eguia, "Mathematical development of an average method for estimating the reduction of the Heat Loss Coefficient of an energetically retrofitted occupied office building," *Energy Build.*, vol. 192, pp. 101–122, 2019, doi: 10.1016/j.enbuild.2019.03.006.

[23] European Commission, "Energy Poverty Advisory Hub," 2023. https://energy-poverty.ec.europa.eu/index_en.

[24] P. WARGOCKI, C. MANDIN, and W. WEI, "ALDREN Project," 2019. https://aldren.eu/aldren-

tail/ (accessed Mar. 24, 2023).

[25] W. Wei, C. Mandin, and P. Wargocki, “TAIL : categories for dwellings,” 2021.

Track your submission

This is a new submission-tracking service.

Is this helpful? Yes No

Peer review status

ARCAS: A MULTICRITERIA METHODOLOGY TO ASSESS THE RENOVATION OF SOCIAL BUILDINGS

- Reviews completed: 0
- Review invitations accepted: 0
- Review invitations sent: 2+

Under Review

Last review activity: 5th April 2023

Watch to learn what we're doing behind the scenes ↗

Journal:
Journal of Building Engineering

Corresponding author:
Ivan Flores-Abascal

Manuscript number:

JBE-D-23-02607

First author:

Ivan Flores-Abascal

Date of submission:

31st March 2023

Need more help?

Please visit our Journal Article Publishing Support Center